Unintended Weather Modification

Examples of Unintended Changes

- Weather changes due to cloud seeding.
- Weather changes due to other activities.
- **Inadvertent Weather Modification is used to describe changes by human not done to alter weather.**

Possible Mechanisms - Dynamic

- Cloud-Environment Interaction
  - Compensating Subsidence
  - Pressure Field Changes
  - Downdraft/low-level Outflow
  - Dynamic Intensification
- Dynamic Intensification
  - Larger Storm
  - Longer-lived Storm
  - Change of Storm Motion

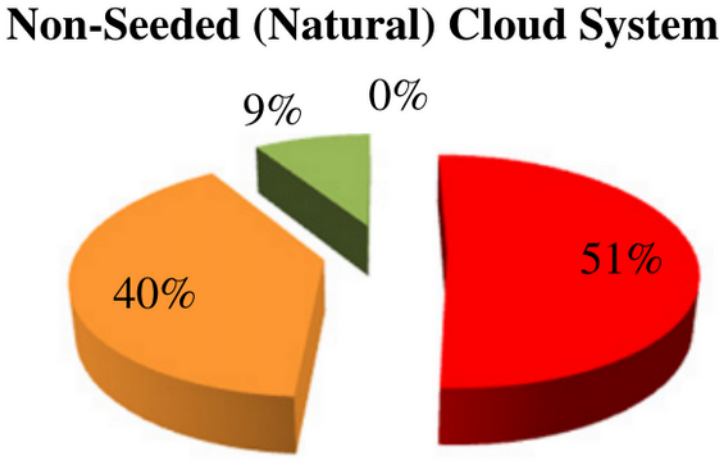
Possible Mechanisms - Microphysical

- Downwind Transport of Cloud Seeding Material
  - AgI Deactivation Rates
  - AgI Transport/diffusion
    - Does not enter cloud.
    - Carried into anvil by ice crystals.
    - Detrained from sides of cloud.
    - Removed by evaporating precipitation.
- Downwind Transport of Ice Crystals
  - Ice crystal seeding by anvils.
  - Thermal effects of cirrus shield.

Extended-area Effects

- North Dakota seeing small rainfall increases downwind of target areas.
  - Extra area effects of cloud seeding — An updated assessment
  - Reported a 5-15 percent increase in precipitation.
- We are having enough trouble finding direct effects of seeding, so indirect effects not likely to be very large.

Conceptual Water Budget



- **Remains as Vapor in the Atmosphere**
- **Remains in Condensed Phase as Water or Ice**
- **Condensed Phase as Natural Precipitation**
- **Condensed Phase as Seeded Precipitation**

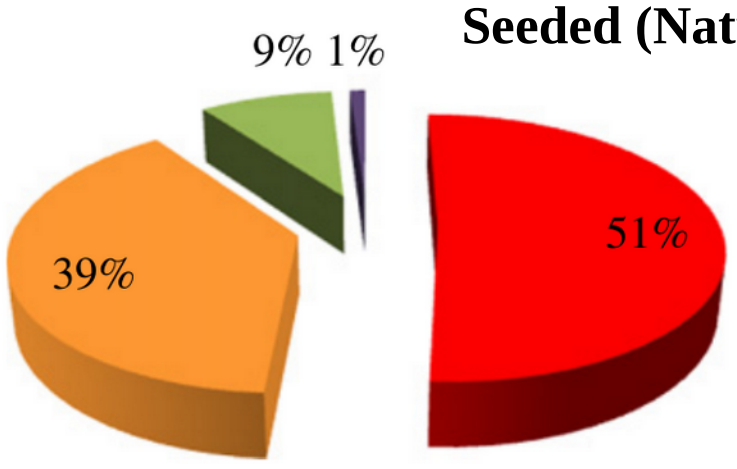


Figure 1 of DeFelice, T. P., J. Golden, D. Griffith, W. Woodley, D. Rosenfeld, D. Breed, M. Solak, and B. Boe, 2014: Extra area effects of cloud seeding — An updated assessment. Atmospheric Research, 135–136, 193–203, https://doi.org/10.1016/j.atmosres.2013.08.014.

Inadvertent Weather Modification

- Weather changes due to human activities not done to alter the weather.
- Why address in the class?
  - Effects are greater than all planned activities.
  - Effects may need to be considered in planning a cloud seeding project.
  - Much can be learned from these effects.

Falcon 9 Rocket Contrail
David Delene, July 2019

Scales of Inadvertent Weather Modification

- Range in space from miles to thousands of miles, and in time from minutes to days
  - Local
    - Obvious and Certain
      - Precipitation Amount
  - Regional
    - Becoming Apparent
      - Precipitation Type
  - Global
    - Apparent
      - Warming

Possible Parameters Affected

- Visibility
- Sunshine
- Cloudiness
- Precipitation
- Thunderstorms
- Temperature
- Wind
- Fog
- Humidity

General Types of Activity

- **Urban**
- Non-urban Non-agricultural Land Use
- Agriculture Land Use
- Transportation

Urban Changes

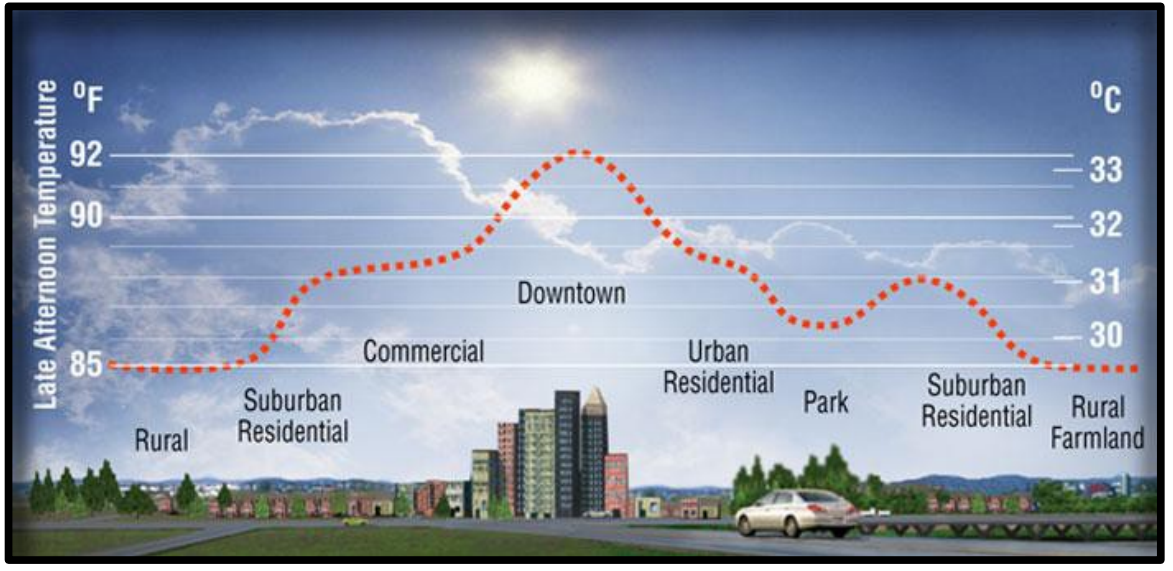
Table 4-2. Weather changes (percent) resulting from major urbanization in the Northern Hemisphere.[a]

Weather Phenomenon	Annual	Cold Season	Warm Season
Contaminant Volume	+1,000	+2,000	+500
Solar Radiation	-22	-34	-20
Temperature (°C)	+2	+3	+1
Relative Humidity	-6	-2	-8
Visibility Frequency	-26	-34	-17
Fog Frequency	+60	+100	+30
Wind Speed	-25	-20	-30
Cloudiness Frequency	+8	+5	+10
Rainfall	+14	+13	+15
Snowfall	+10	+10	
Thunderstorm Frequency	+15	+5	+30

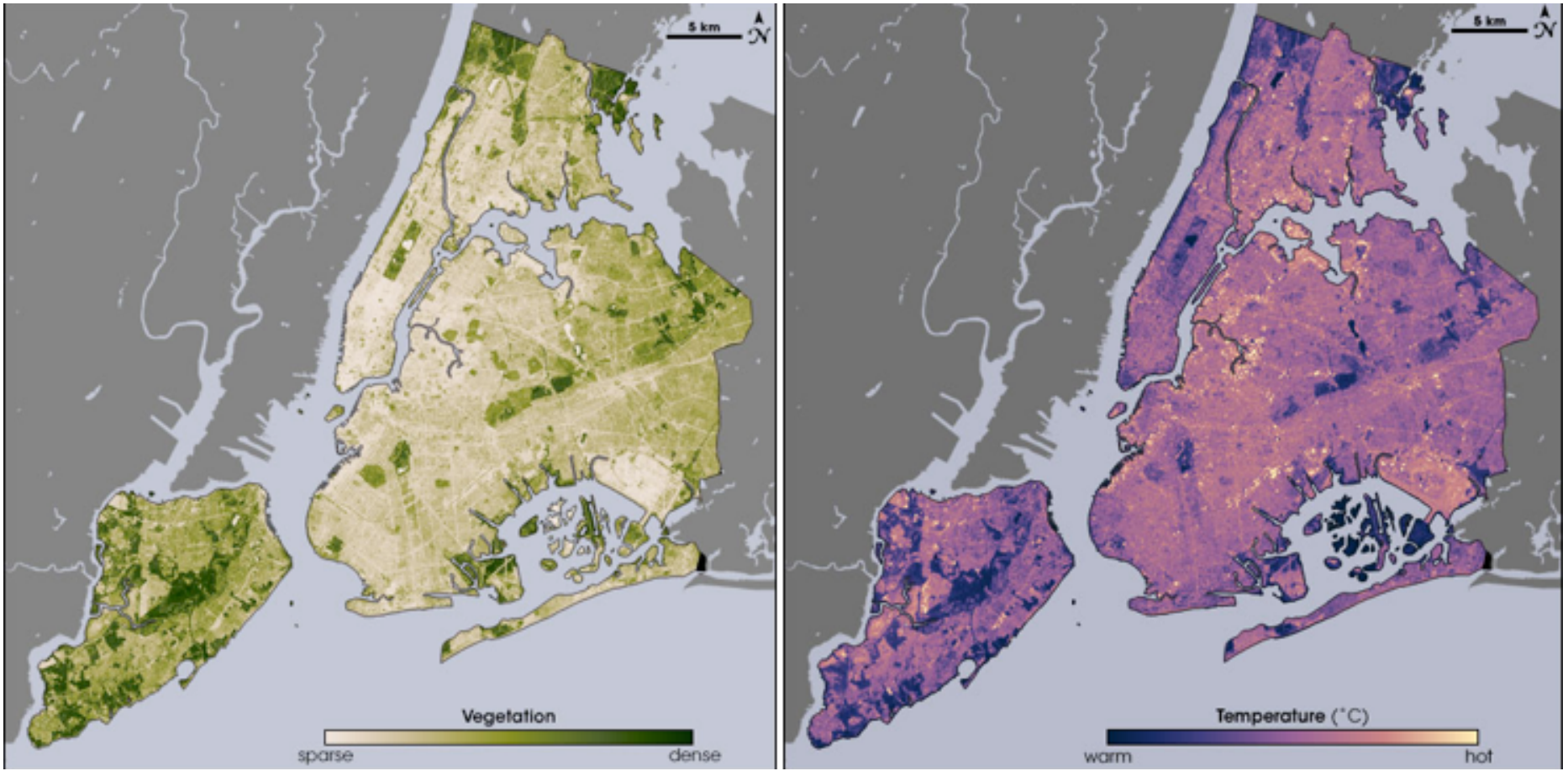
[a]From Changnon (1976)

Urban Activity

- Contrasting Thermal Properties
- Less Water for Evaporation
- Aerodynamic Roughness
- Gases and Particulates

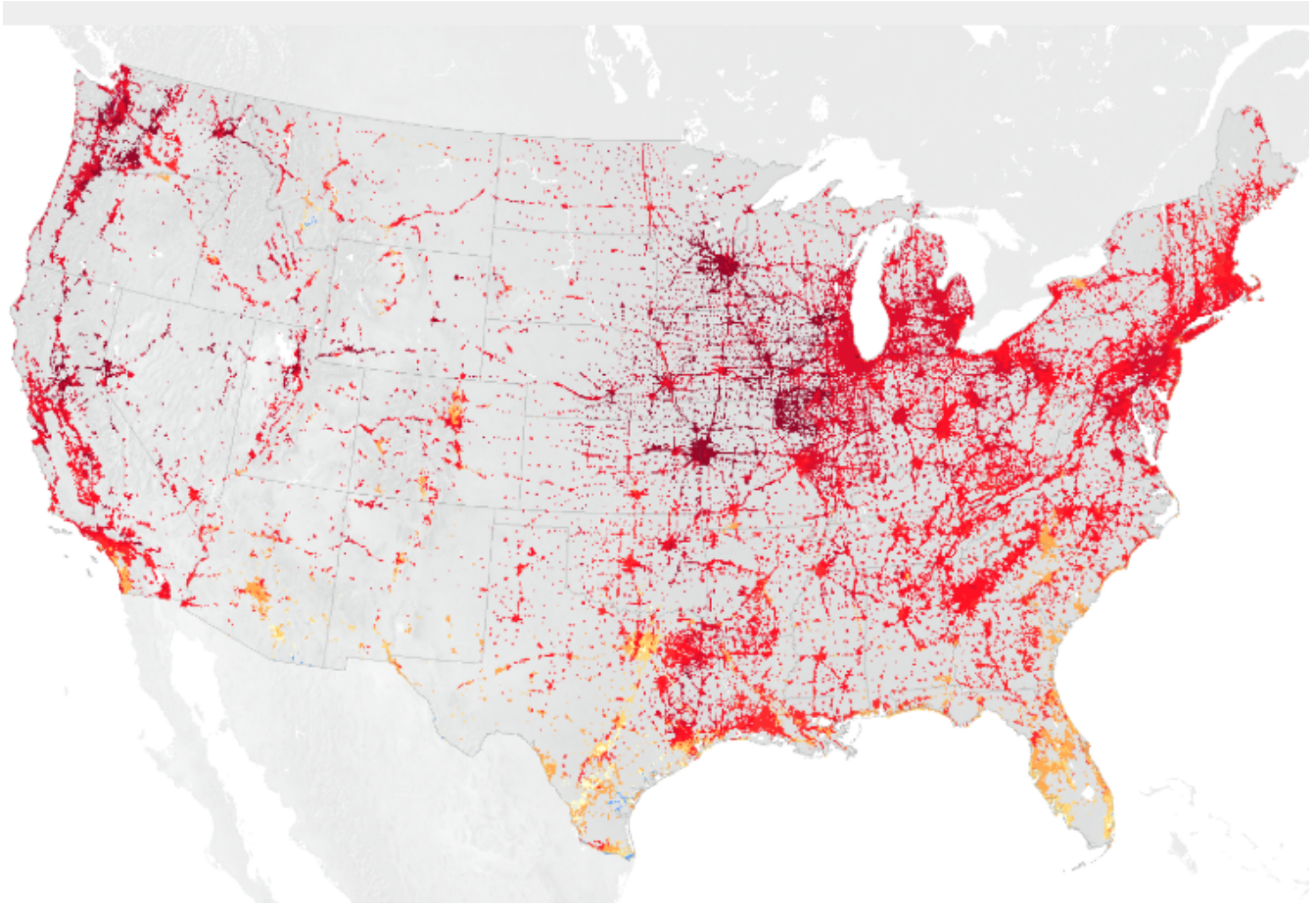


Contrasting Thermal Properties



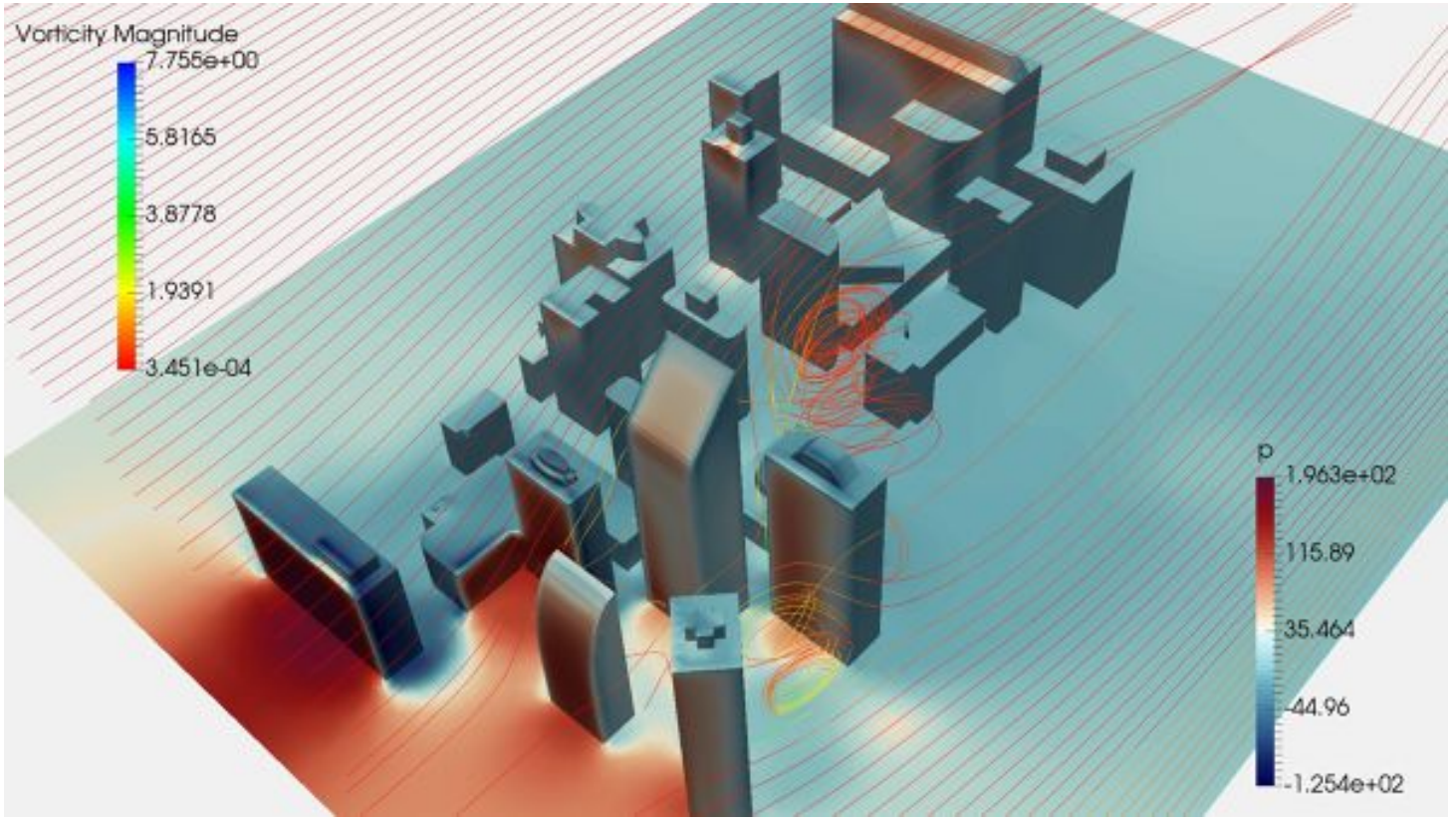
Images from the NASA/USGS satellite Landsat showing plants (left) and temperature (right) on New York City's heat. Image credit: Maps by Robert Simmon, using data from the Landsat Program.

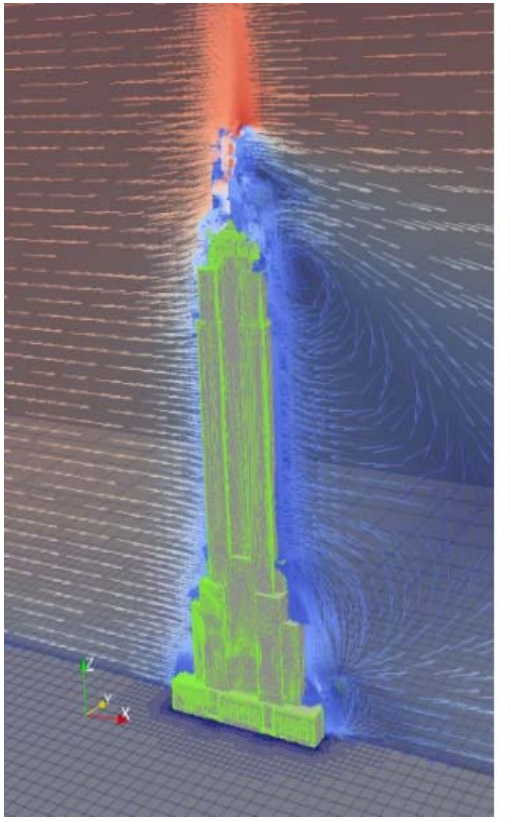
Less Water for Evaporation



Temperature Difference Between Urban and Vegetated Land Due to Impervious Surface Area
Credit: NASA Earth Observatory image by Joshua Stevens, using data from Bounoa, et al. (2015).

Aerodynamic Roughness





Particulates and Gases

Images of Seoul, South Korea. Credit: David Delene – 2019/10/30.

Urban Research Studies

- METROMEX
  - St. Louis, late 1960s
  - Looked at effects in and around urban area
  - Found significant changes both in city and downwind in rural areas
    - 30 % increase in rainfall.
    - 40 % increase in heavy rains and storms.
    - 100 % increase in strong surface winds.
    - 100 % increase in hail-fall intensities.

Non-agricultural Land Use Changes

- Deforestation
  - Increased Ground-level Solar Radiation
  - Greater Surface Temperature Extremes
  - Possible Droughts
    - Over-grazing
    - More Dust and Less Moisture
  - Strip Mining
    - Albedo Change

Agricultural Land Use Changes

- Burning
  - Increase Nulei (CCN, IN)
  - Affect Cloud Processes
- Irrigation
  - Higher Humidities
  - Lower Albedo
  - Lower Temperatures
  - Rain Increases over large areas

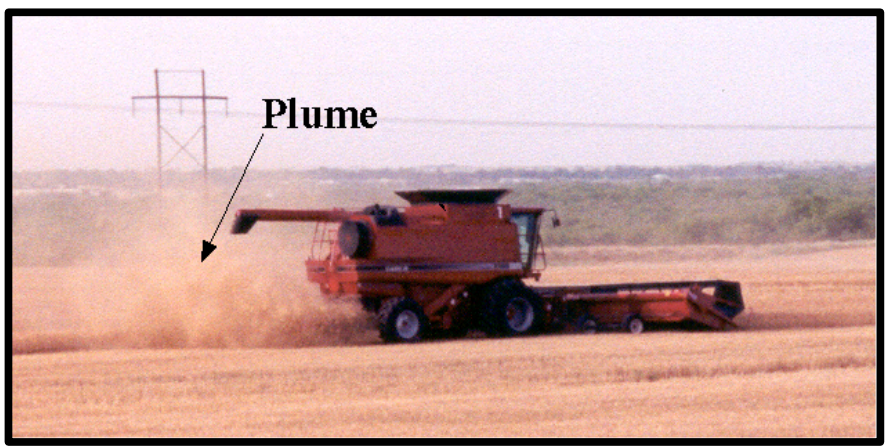
Transportation Changes

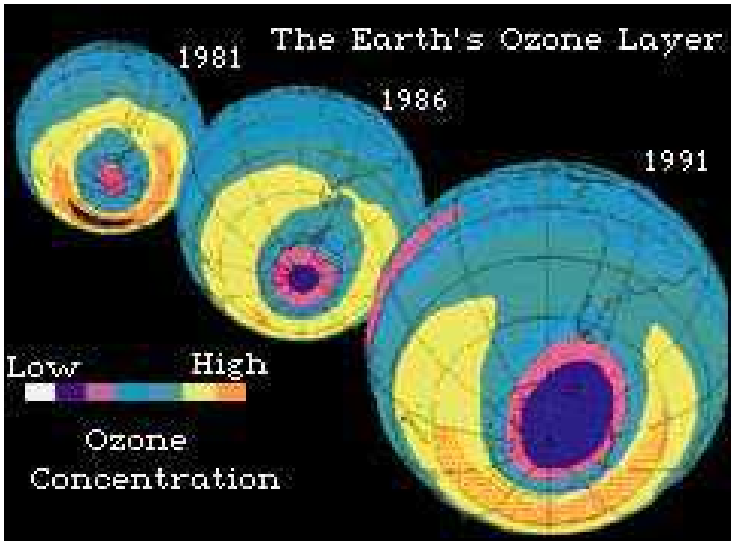
- Aircraft
  - Exhaust
  - Ozone Effects and Particulates
  - Contrails
    - Reduced solar radiation
    - Falling ice crystals

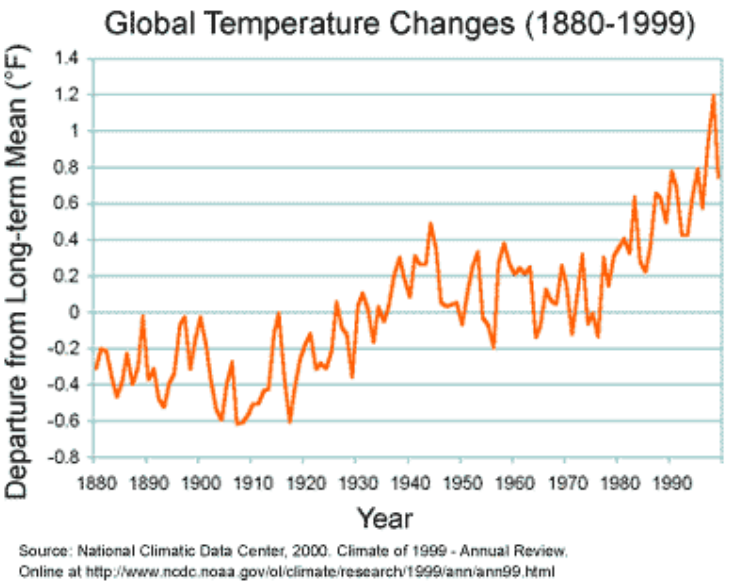
Near NASA Wallops on December 3, 2021. Credit: David Delene.

Climate Modification

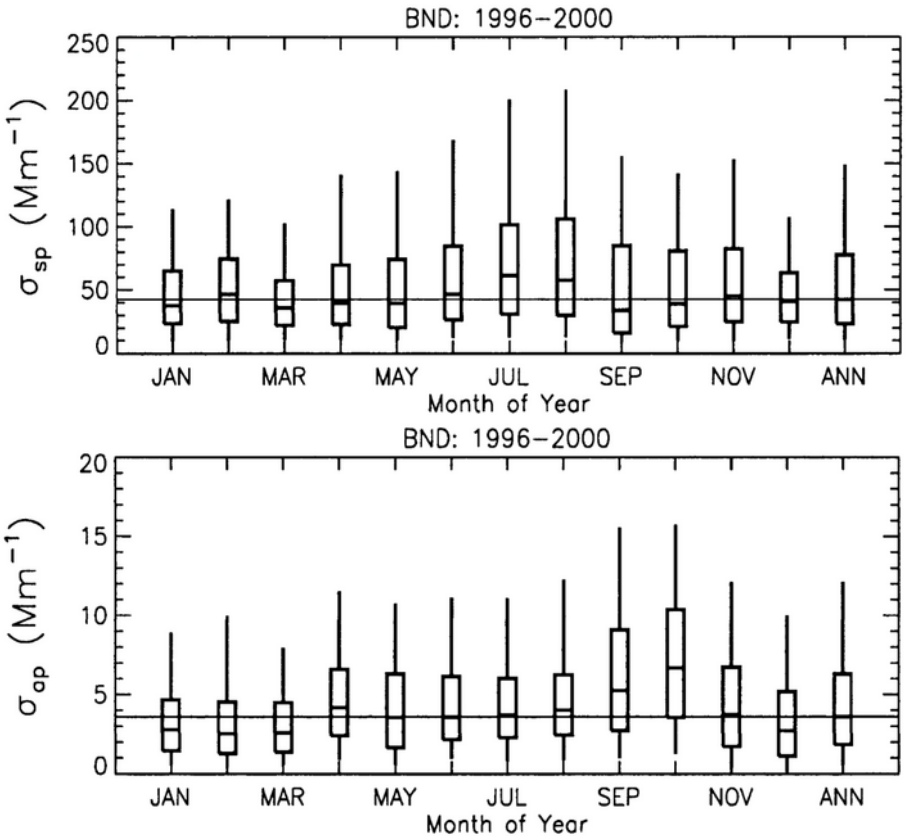
- Fluorocarbons
  - Ozone hole
- Carbon Dioxide
  - Global Warming
- Dust, Clouds
  - Global Warming/cooling



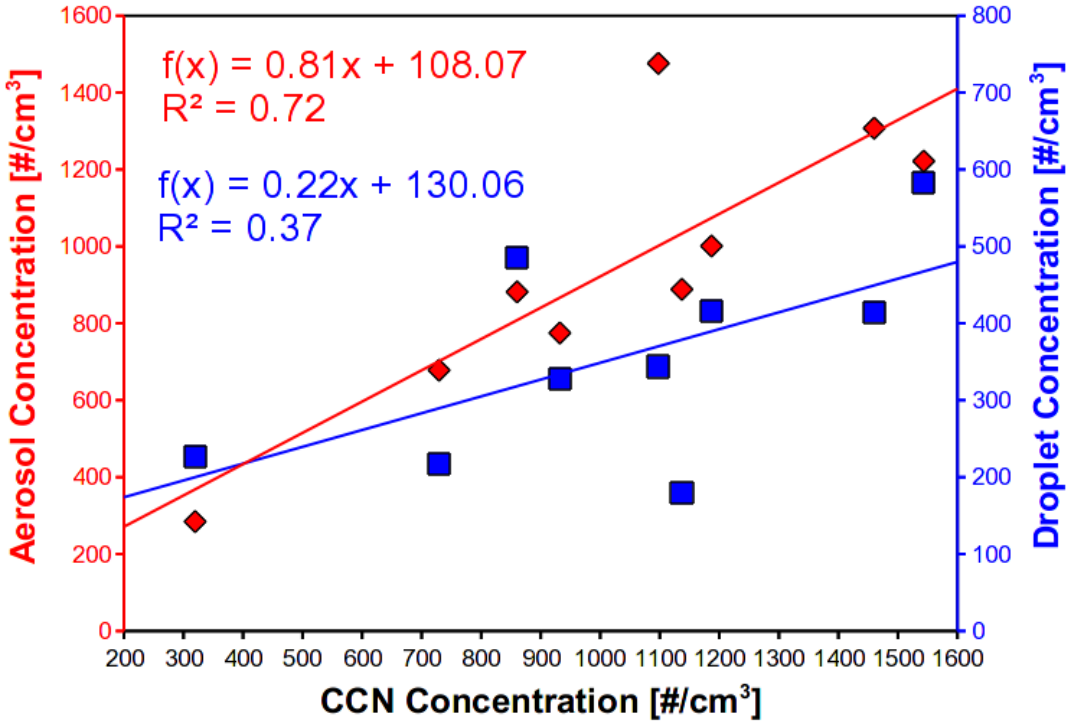




Direct/Indirect Impact of Particles



Delene, D. J., and J. A. Ogren, Variability of aerosol optical properties at four North American surface monitoring sites, Journal of Atmospheric Sciences, 59, 1135-1150, 2002.



Delene, D. J., C. Grainger, P. Kucera, D. Langerud, M. Ham, R. Mitchell, and C. Kruse, The Second Polarimetric Cloud Analysis and Seeding Test, Journal of Weather Modification, 43, 14-28, 2011, URL: http://www.weathermodification.org/publications/index.php/JWM/article/viewArticle/147.