

Unintended Weather Modification



Caution!
Unintended Consequences Ahead

Examples of Unintended Changes

- Weather changes due to cloud seeding.
- Weather changes due to other activities.



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.

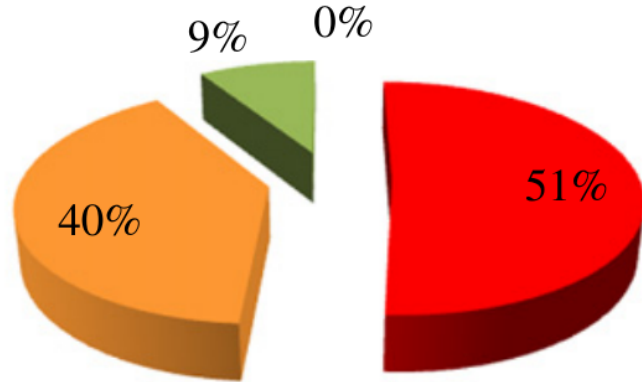


Extended-area Effects

- 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

Non-Seeded (Natural) Cloud System



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

Seeded (Natural) Cloud System

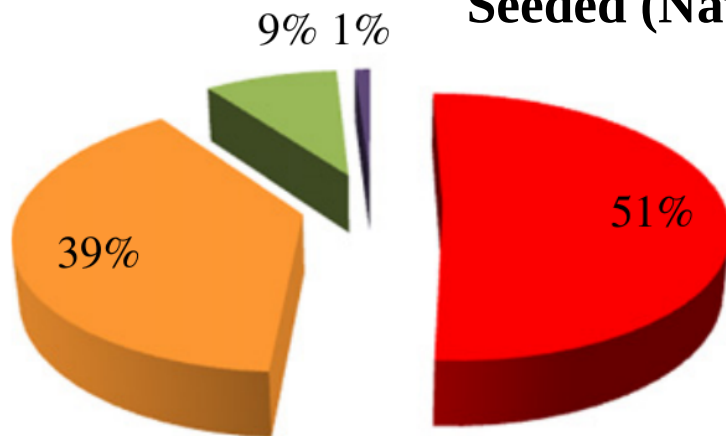


Figure 1 of DeFelice, T. P., J. Golden, D. Griffith, W. Woodley, D. Rosenfeld, D. Breed, M. Solak, and B. Boe, 2014: Extra area effects of cloud seeding — An updated assessment. *Atmospheric Research*, 135–136, 193–203, <https://doi.org/10.1016/j.atmosres.2013.08.014>.

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

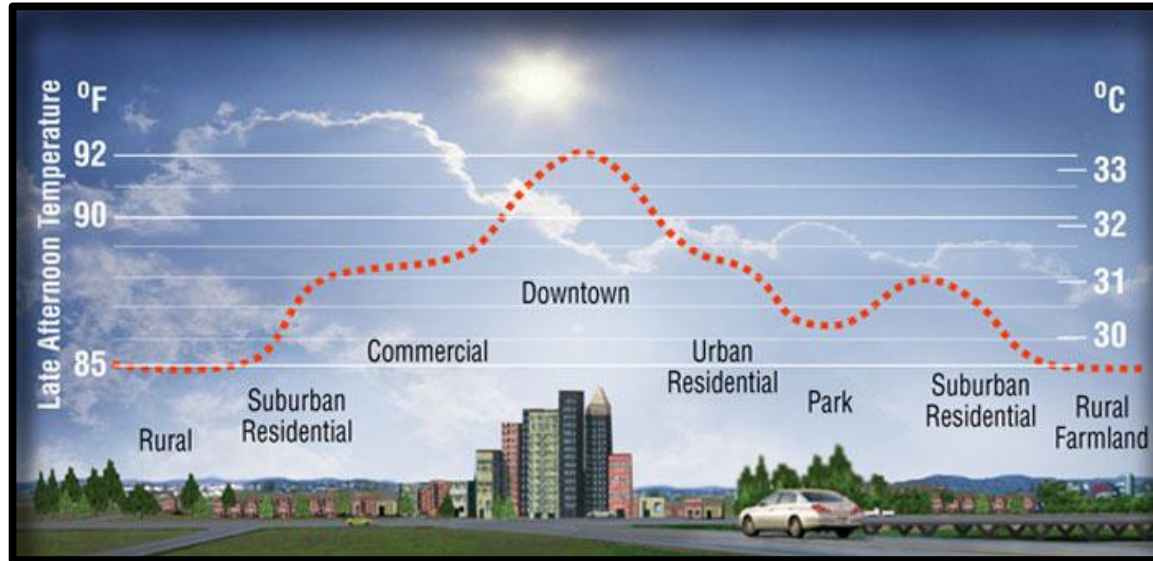
Table 4-2. Weather changes (percent) resulting from major urbanization in the Northern Hemisphere.^a

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

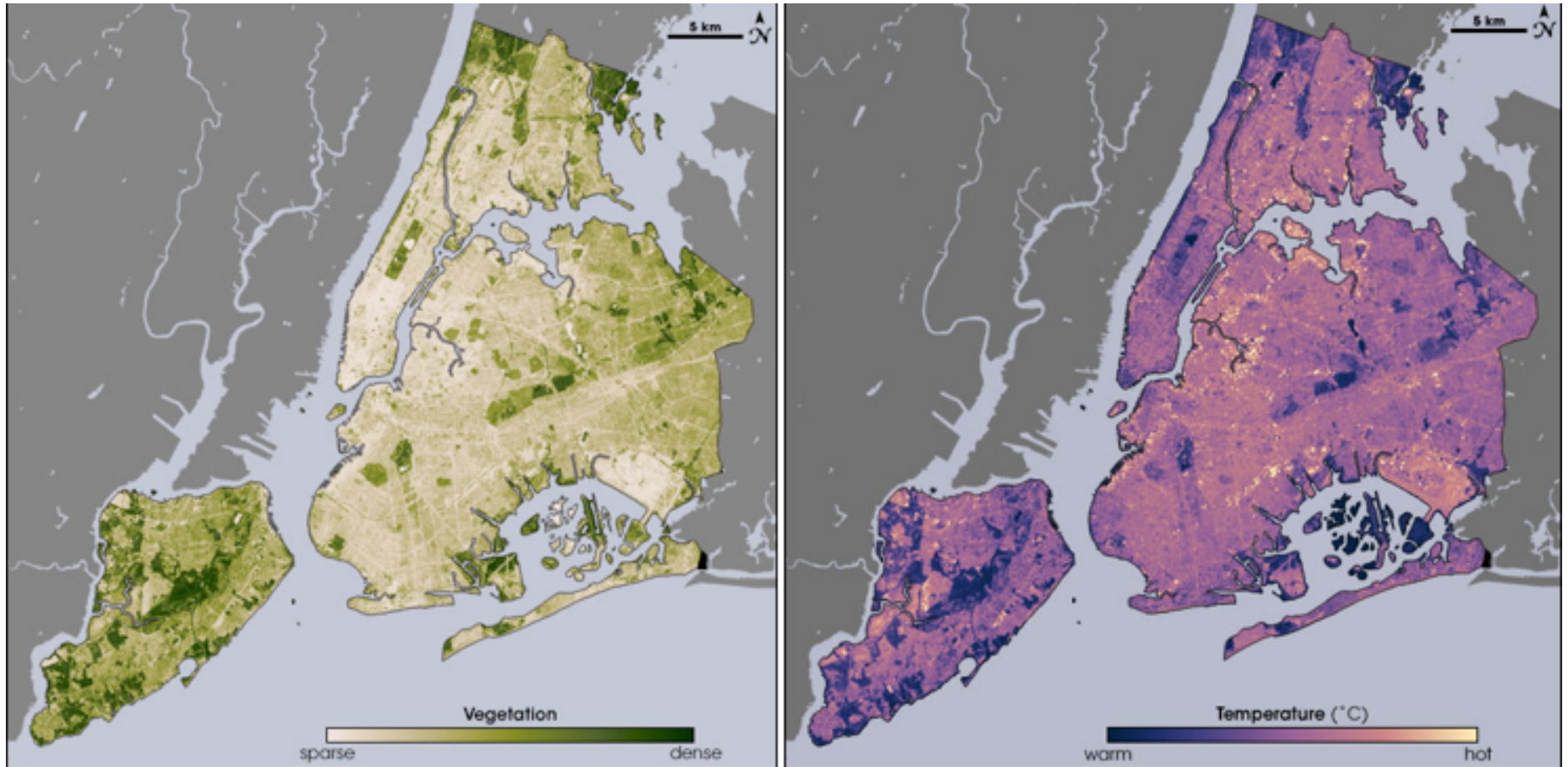
^aFrom Changnon (1976)

Urban Activity

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

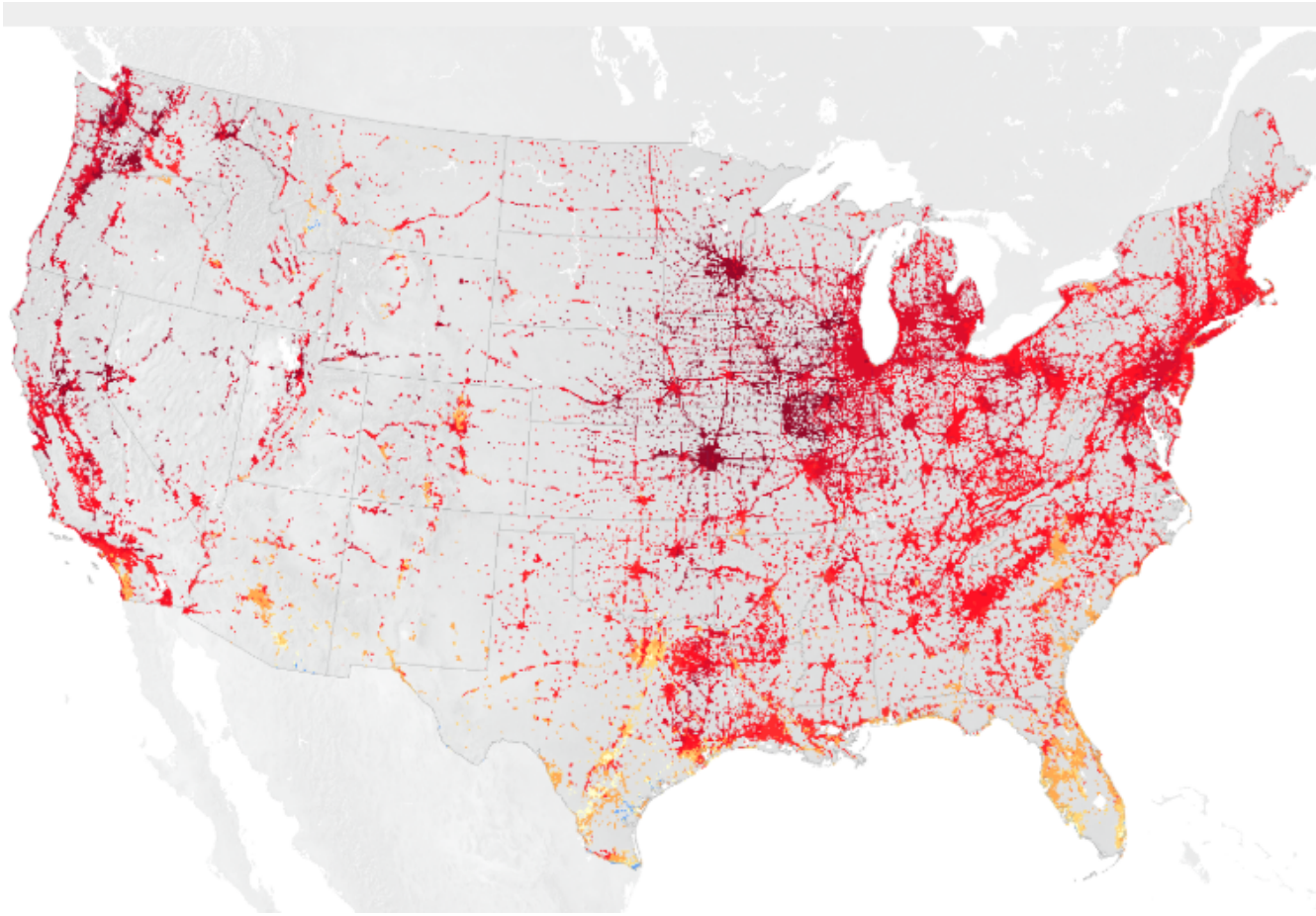


Contrasting Thermal Properties



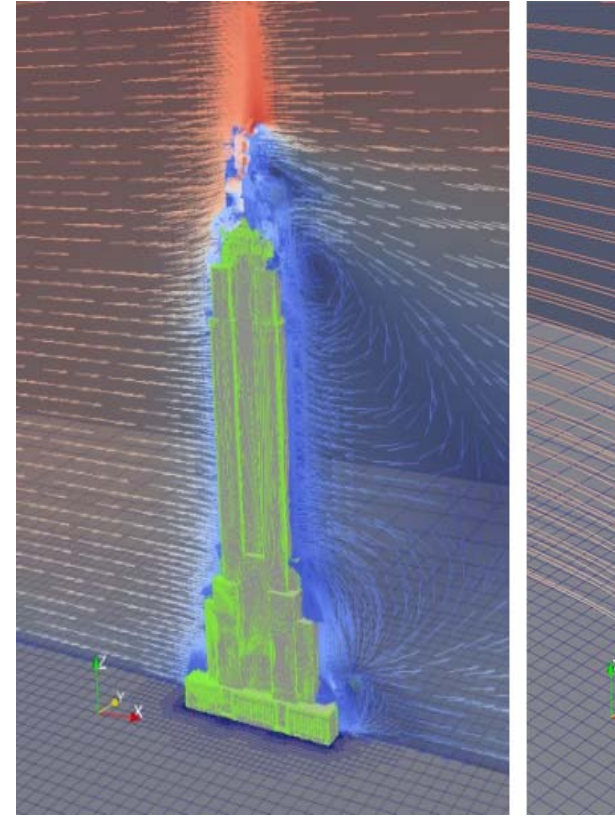
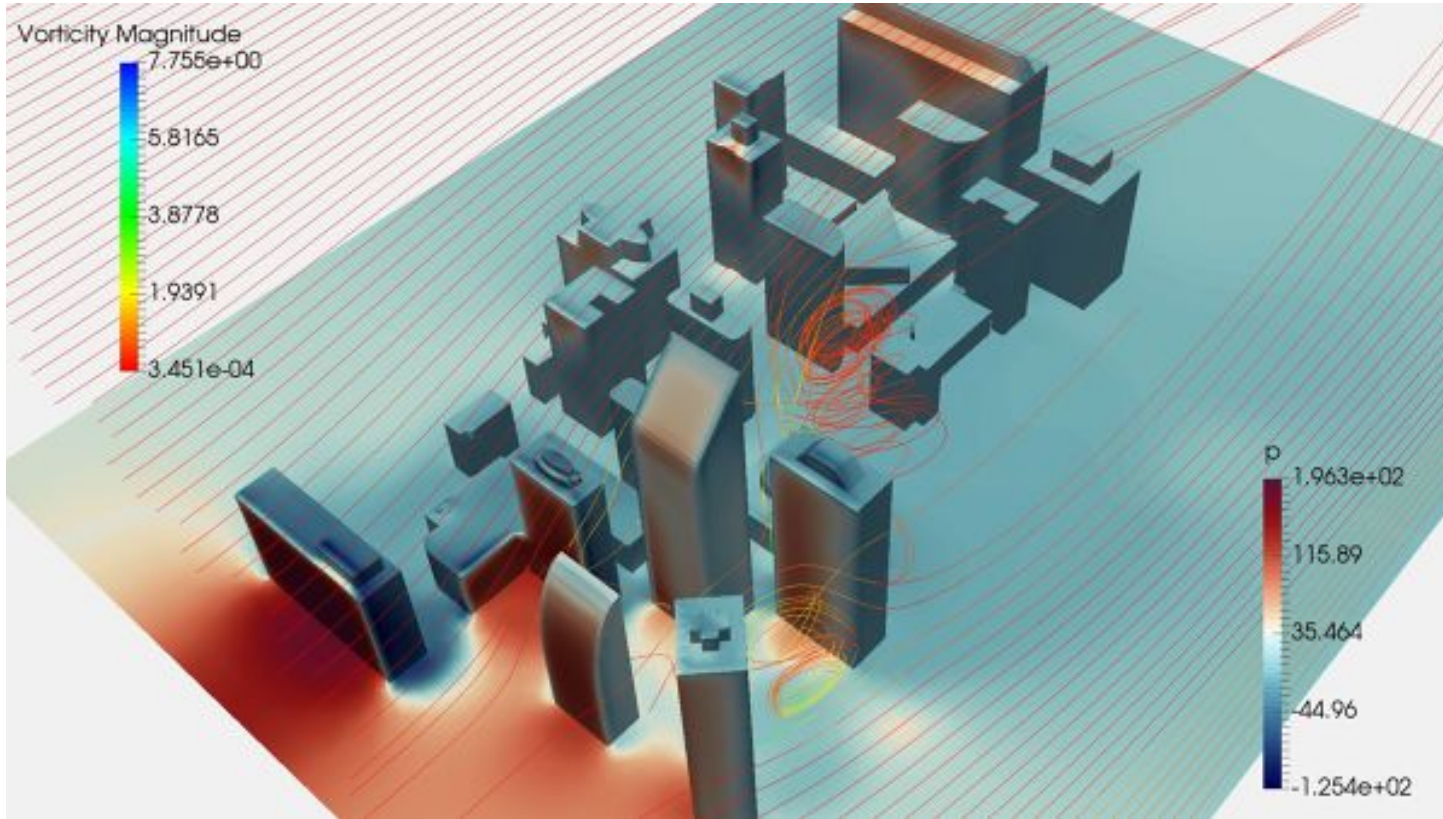
Images from the NASA/USGS satellite Landsat showing plants (left) and temperature (right) on New York City's heat. Image credit: Maps by Robert Simmon, using data from the Landsat Program.

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



Transportation Changes

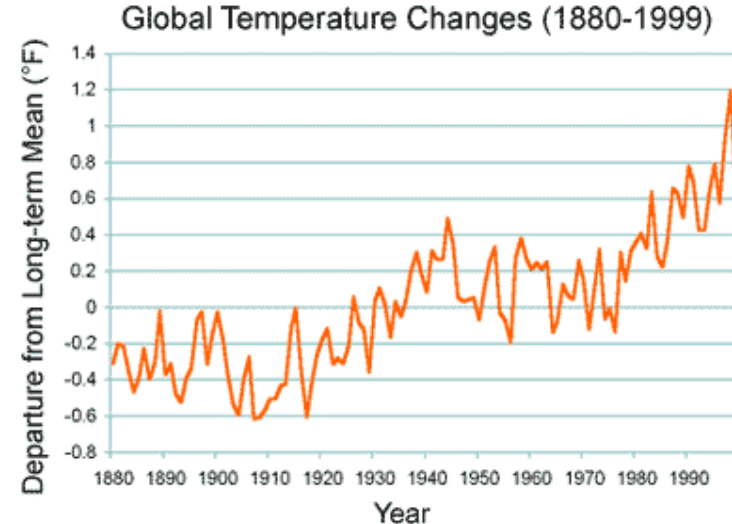
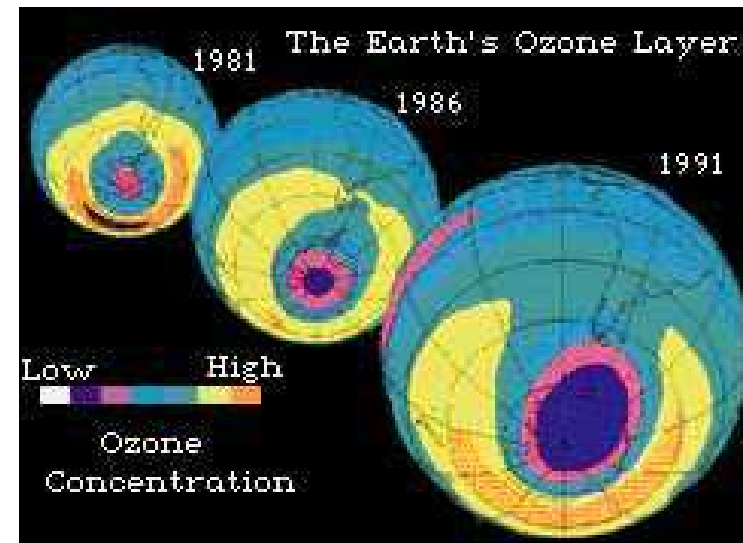
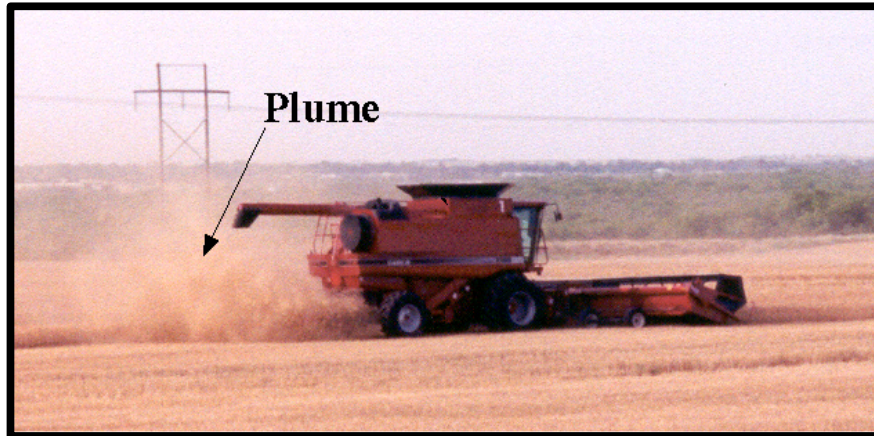
- Aircraft
 - Exhaust
 - Ozone Effects and Particulates
- Contrails
 - Reduced solar radiation
 - Falling ice crystals

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



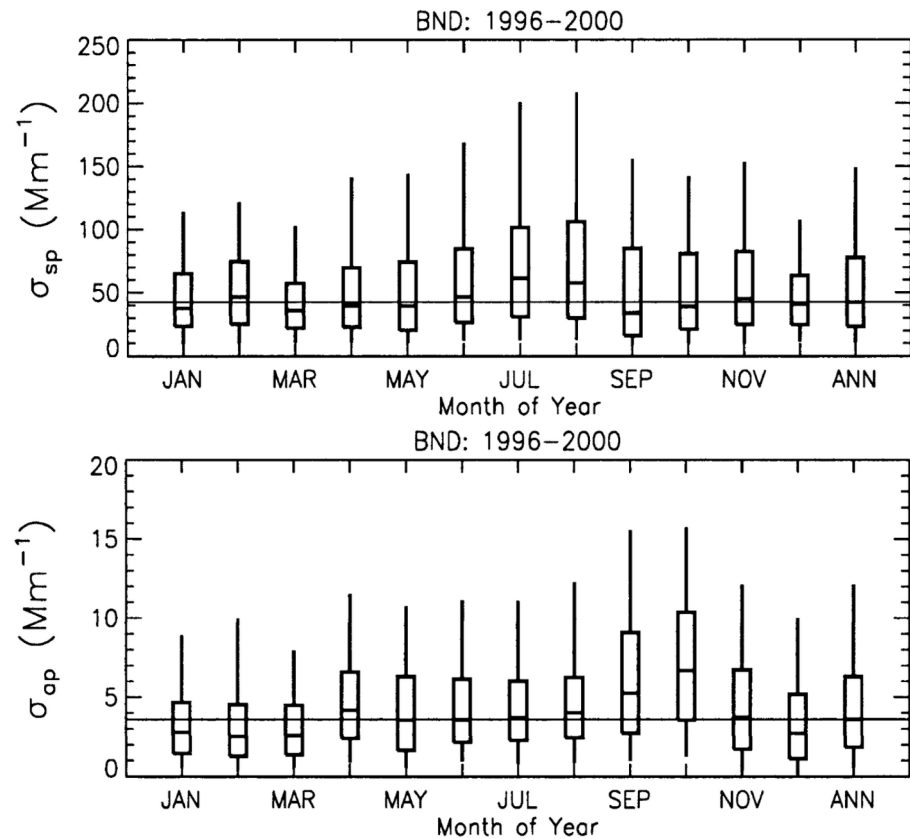
Climate Modification

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

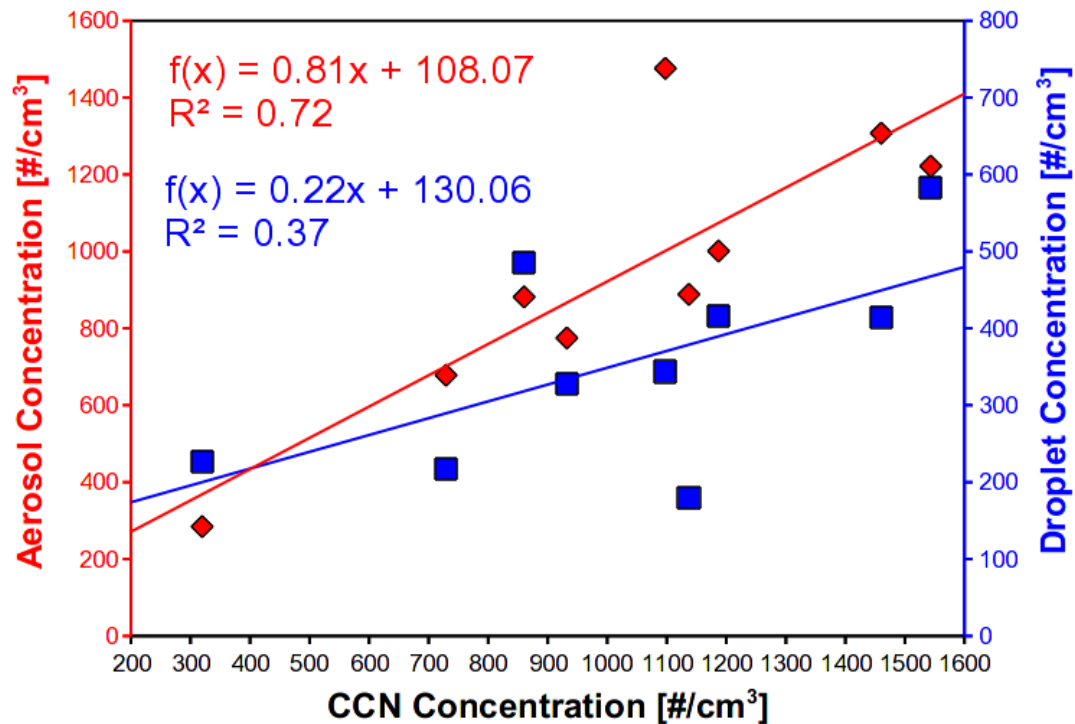


Source: National Climatic Data Center, 2000. Climate of 1999 - Annual Review.
Online at <http://www.ncdc.noaa.gov/climate/research/1999/ann/ann99.html>

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>.