

# Powering the World With Wind, Water, and Sunlight

**Mark Z. Jacobson**

Atmosphere/Energy Program

Dept. of Civil & Environmental Engineering

Stanford University



Thanks to Mark Delucchi, Cristina Archer, Elaine Hart, Mike Dvorak, Eric Stoutenburg, Bethany Corcoran, John Ten Hoeve

Singularity University Summer Program

NASA Ames Research Center, July 8, 2011



# What's the Problem? Why Act Quickly?

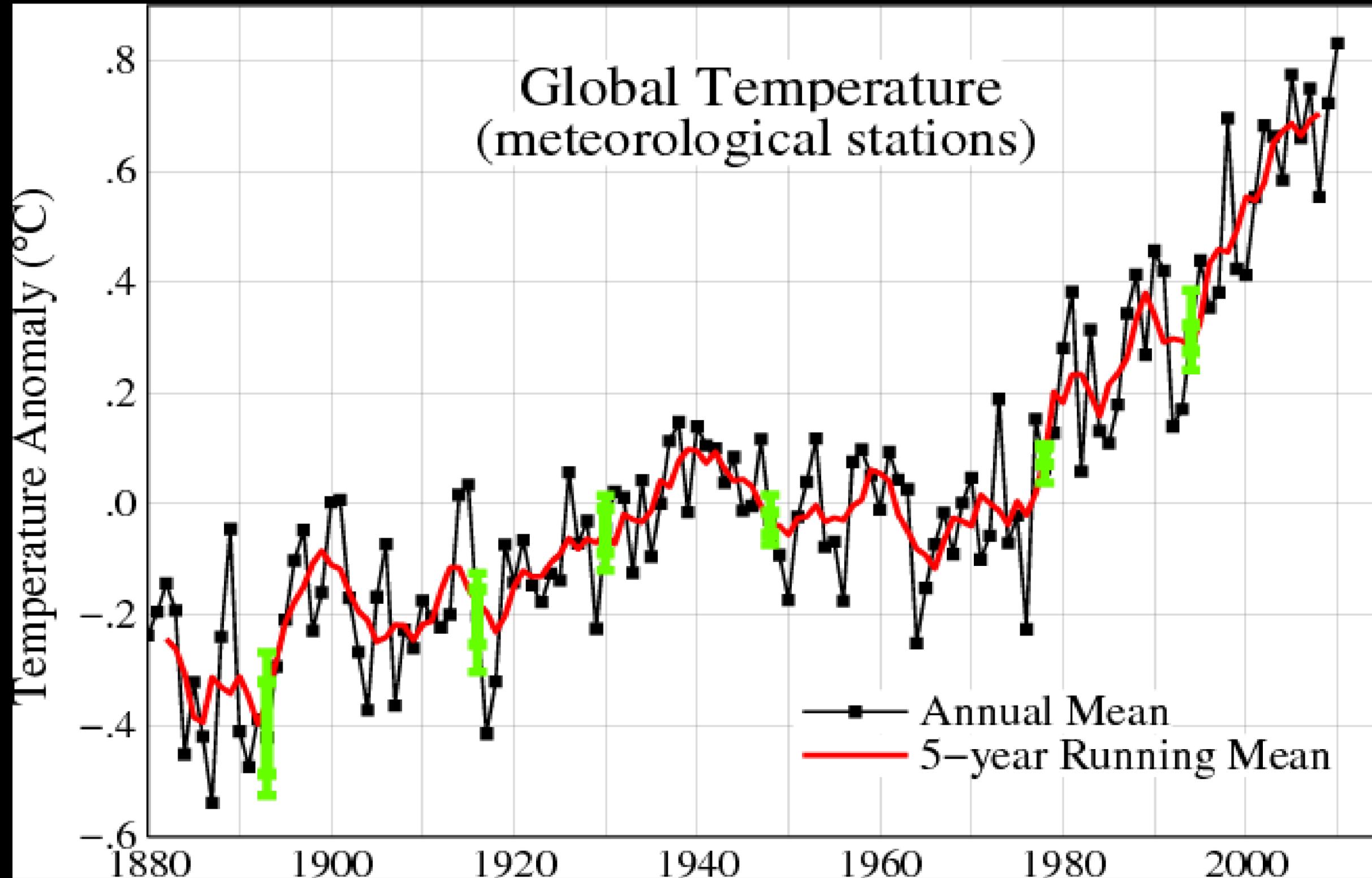
A. Temperatures are rising rapidly

B. Arctic sea ice area is decreasing quickly

C. Air pollution mortality is one of five leading causes of death worldwide, and higher temperatures contribute to deaths

D. Higher population and growing energy demand will result in worsening air pollution and climate problems over time.

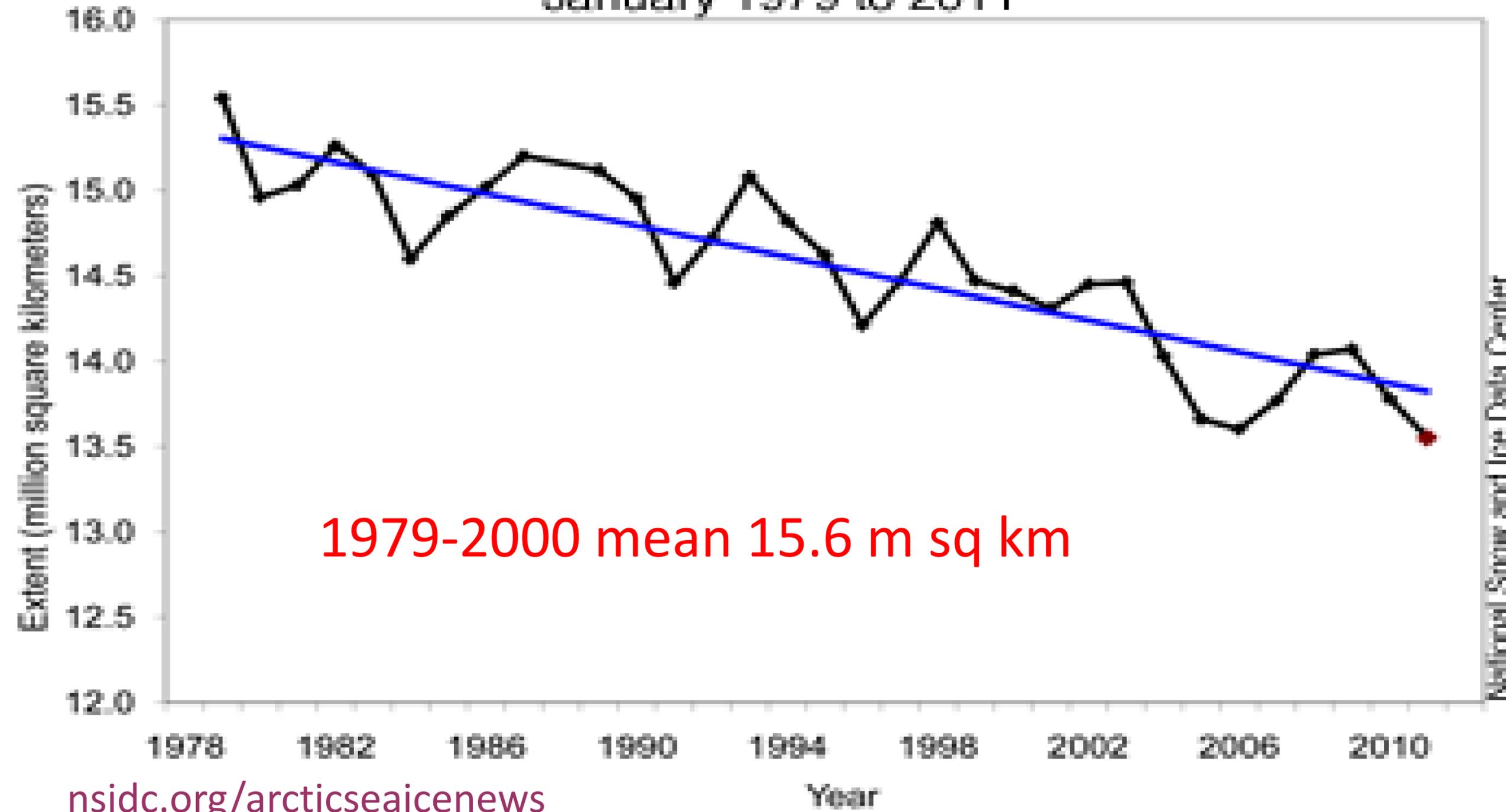
# Mean Global Temperature Anomalies



- Warmest years
1. 2010/2005
  2. -
  3. 2009
  4. 2007/1998
  5. -
  6. 2002
  7. 2003/2006
  8. -
  9. 2001/2004
  10. -

# Arctic Sea Ice 1979-2011

Average Monthly Arctic Sea Ice Extent  
January 1979 to 2011



Lowest years  
2011  
2005  
2006  
2007  
2009

# Norilsk, Russia



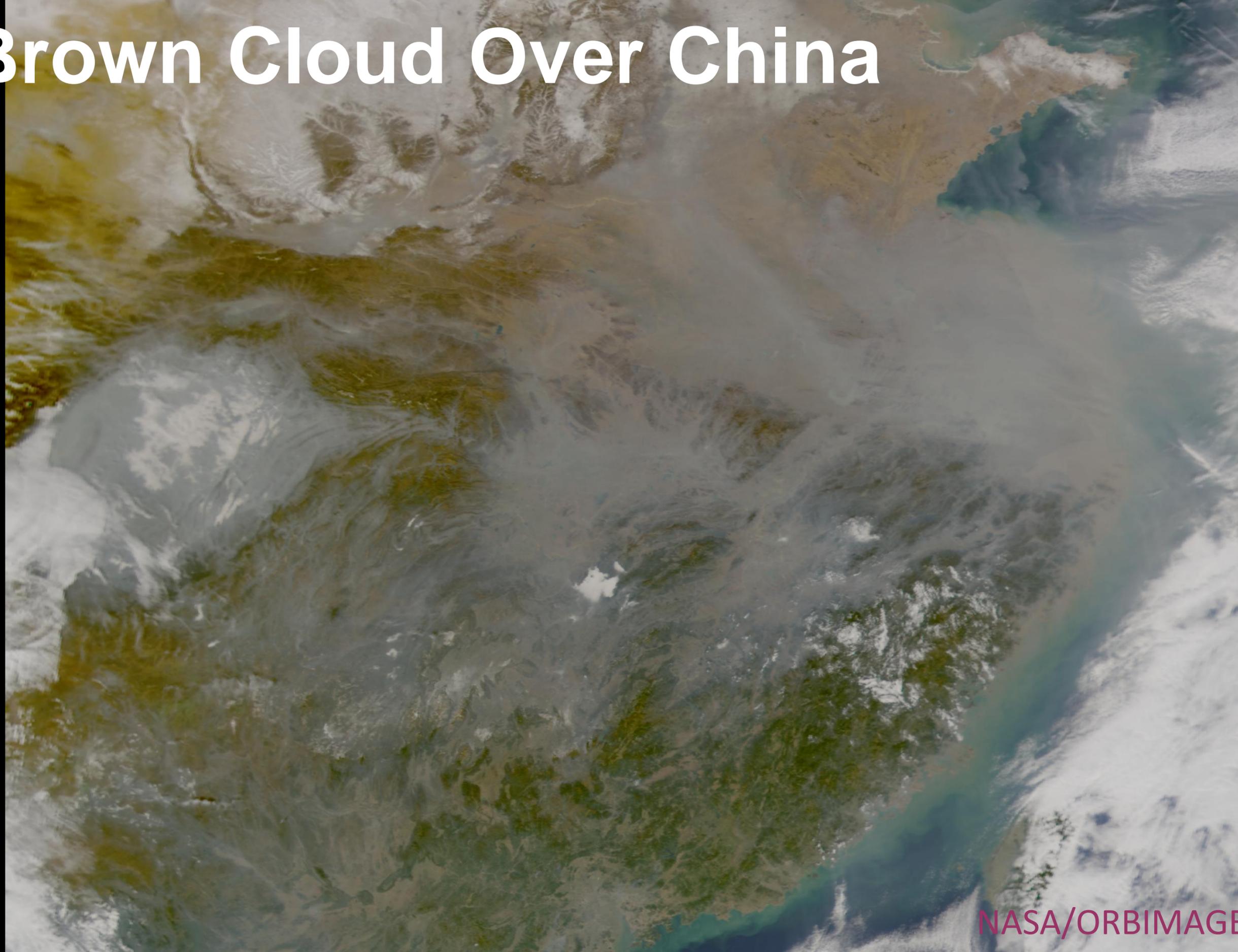
# Sukinda, India



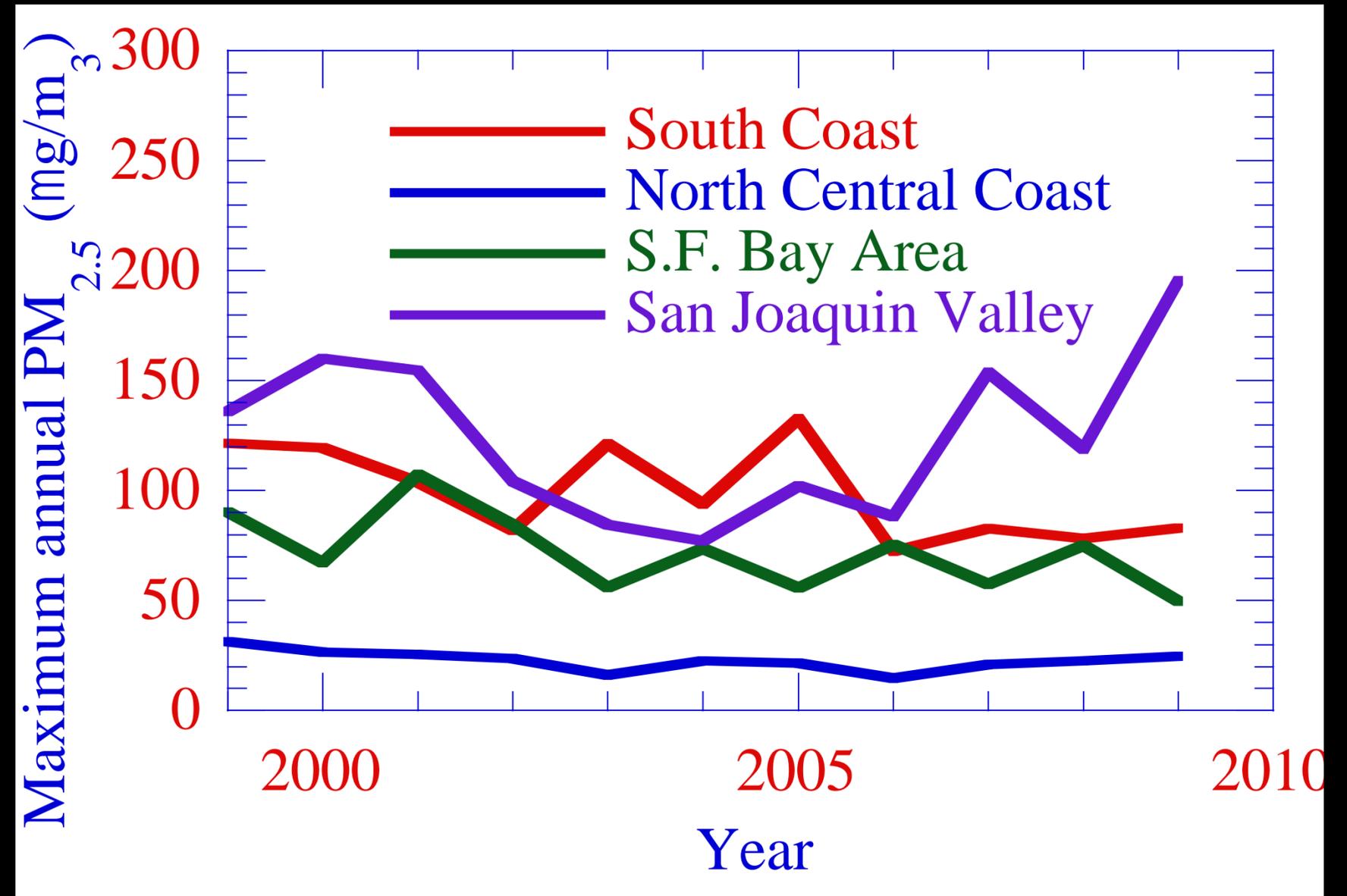
# Linfen, China



# Asian Brown Cloud Over China



# Lung of LA Teenage Nonsmoker in 1970s & PM Trends in California



Each 10  $\mu\text{g}/\text{m}^3$  PM<sub>2.5</sub> in yearly avg. reduces life 5-10 mon. (Pope et al., 2009);  
~18,000 (5600-23,000) PM<sub>2.5</sub> deaths/yr Calif. (ibid.); 50,000-100,000  
deaths/yr U.S.; 2.5-3 mill/yr world. Average person in big U.S. city loses 2 yrs.

# Steps for Determining Solution to Problems

## 1. Rank energy technologies in terms of

Carbon-dioxide equivalent emissions

Air pollution mortality

Water consumption

Footprint on the ground and total spacing required

Resource abundance

Ability to match peak demand

## 2. Evaluate replacing 100% of energy with best technologies in

terms of resources, materials, matching supply, costs, politics

# Electricity/Vehicle Options Studied

## Electricity options

Wind turbines

photovoltaics (PV)

Geothermal power plants

Tidal turbines

Wave devices

Concentrated solar power (CSP)

Hydroelectric power plants

Nuclear power plants

Coal with carbon capture and sequestration (CCS)

## Vehicle Options

Battery-Electric Vehicles (BEVs)

Solar Hydrogen Fuel Cell Vehicles (HFCVs)

Corn ethanol (E85)

Cellulosic ethanol (E85)

# Wind Power, Wind-Driven Wave Power



# Hydroelectric, Geothermal, Tidal Power



Torgeir Aune / Hammerfest Strom

# Concentrated Solar Power, PV Power



Torresol Gemasolar Spain, 15 hrs storage,  
Matthew Wright, Beyond Zero



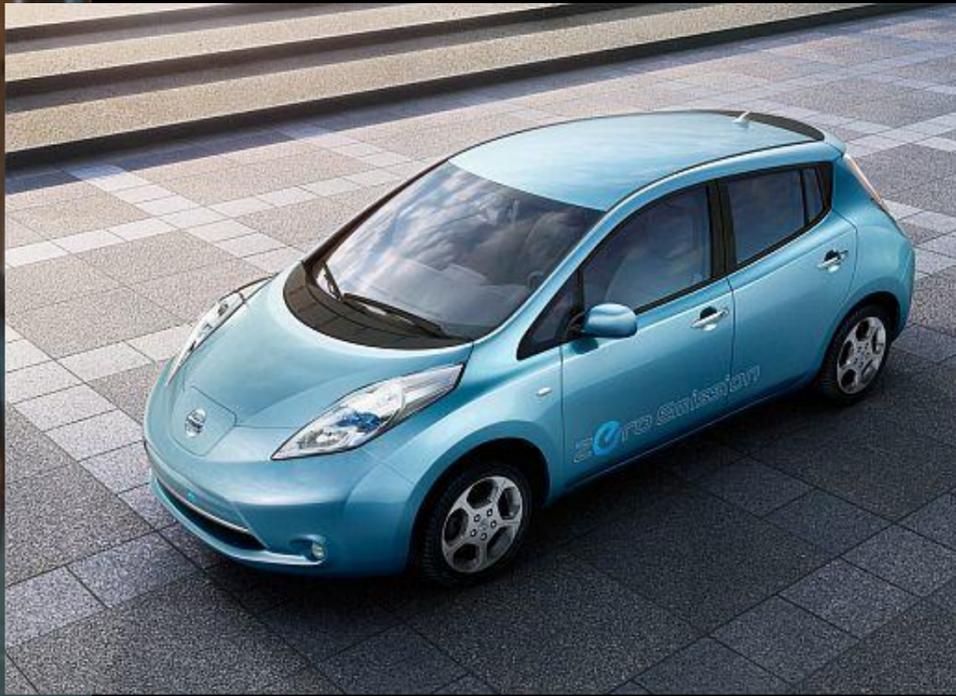
[www.solarthermalmagazine.com](http://www.solarthermalmagazine.com)

[i.treehugger.com](http://i.treehugger.com)

# Electric/Hydrogen Fuel Cell Vehicles



Tesla Roadster all electric



Nissan Leaf all electric



Tesla Model S all electric



Hydrogen fuel cell bus



Electric truck



Hydrogen fuel cell-electric hybrid bus

[click to enlarge](#)