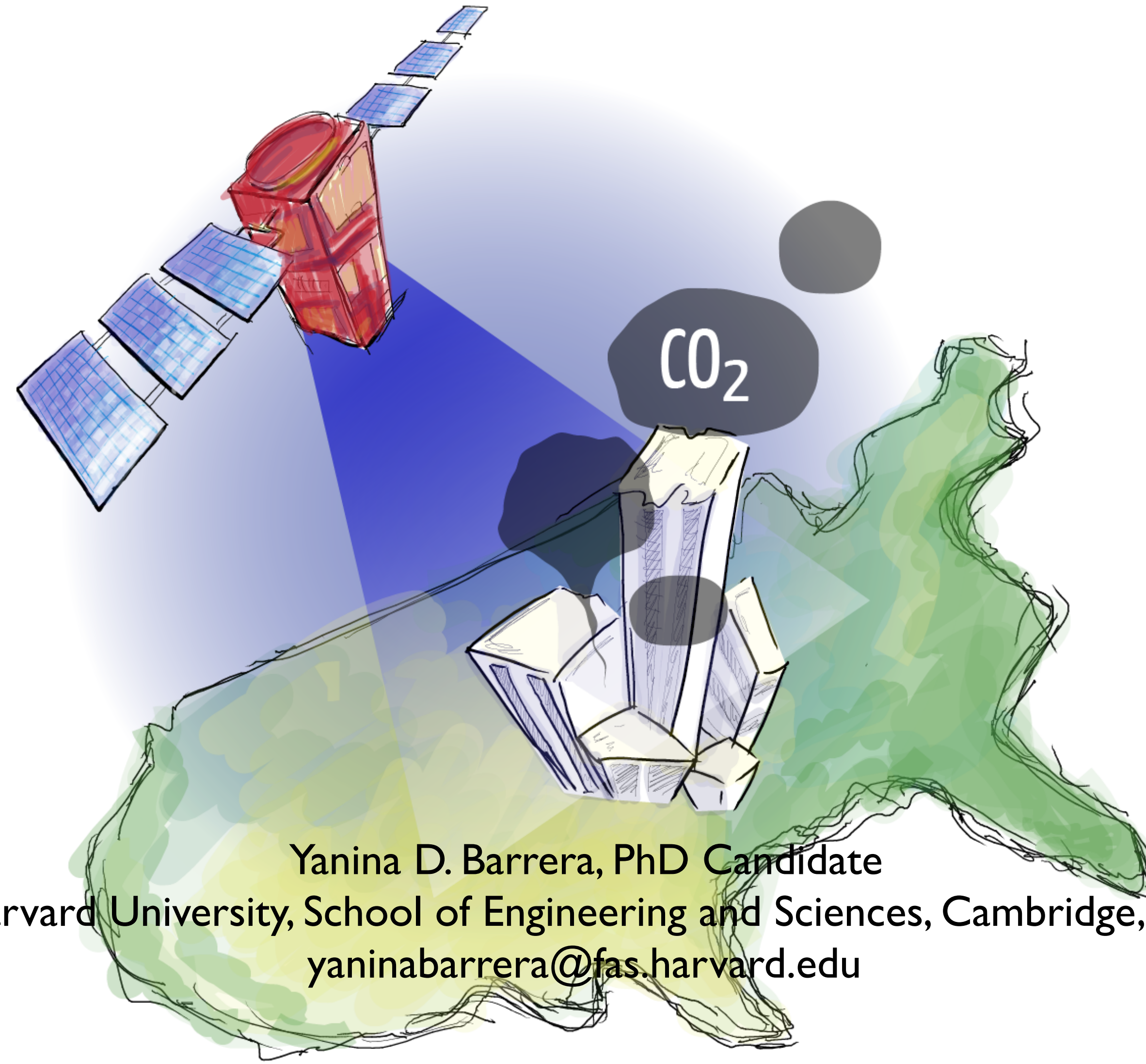
Air Pollution Knows No Boundaries



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What air pollutants do you think are of major concern, when combusting coal?

- Carbon dioxide!
- Particulate matter
  - Toxic metals such as mercury compounds
- Sulfur dioxide emissions
- Nitrogen dioxide emissions

Pause for Thought

What events prompted air quality regulations?

How did we get here?

Timeline of Air Pollution Events & Regulation

1948 Donora Smog

control of hazardous air pollutants

U.S. Air Pollution Control Act of 1955

U.S. Clean Air Act Amendments of 1967

Controlling stationary & mobile sources

U.S. Clean Air Act Amendments of 1990

1952 London's Great Smog

UK's Clean Air Act of 1956

USA Clean Air Act Amendments of 1970

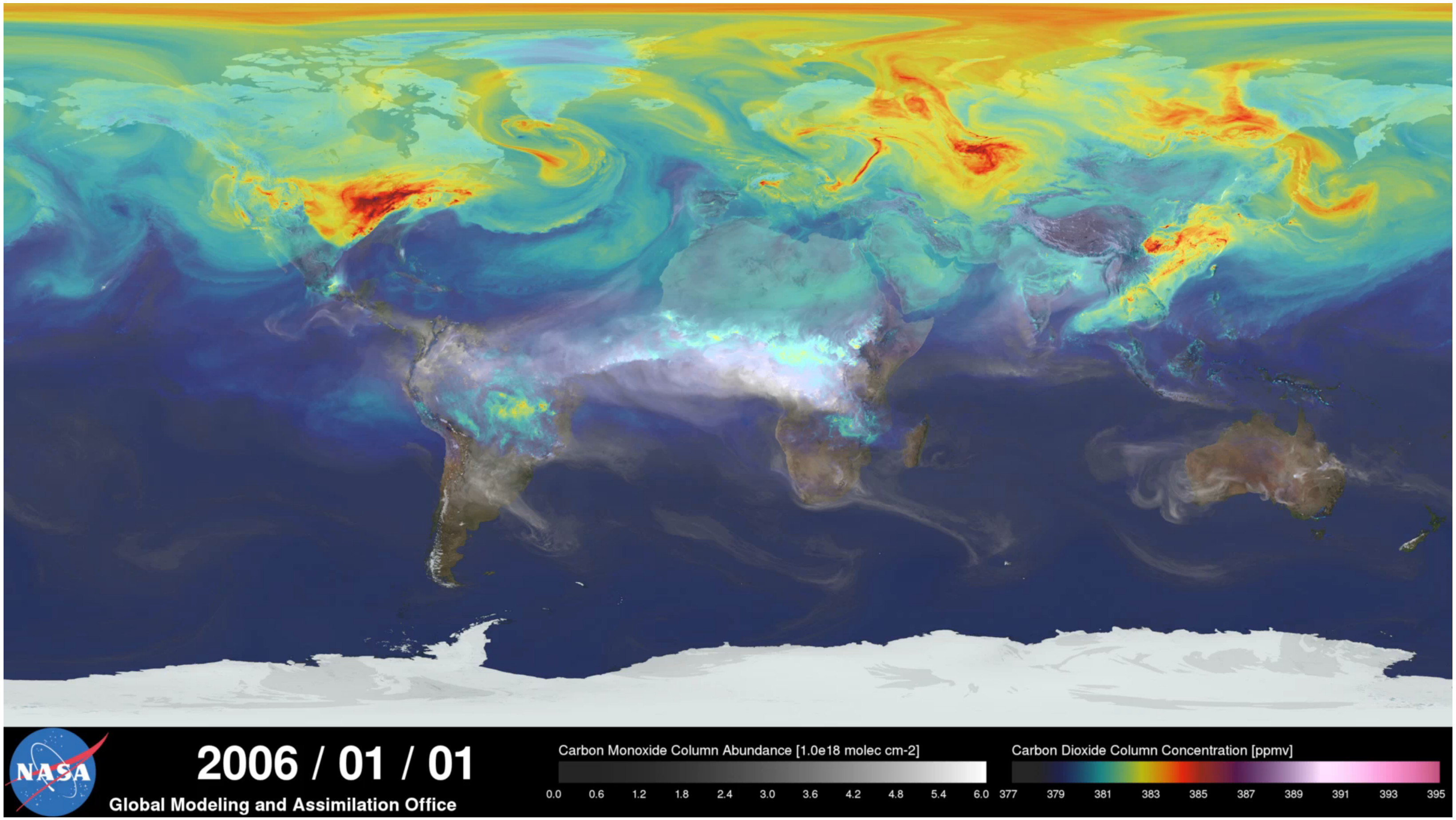
EPA established

Source: The Washington Post (top), Hulton Getty(bottom)

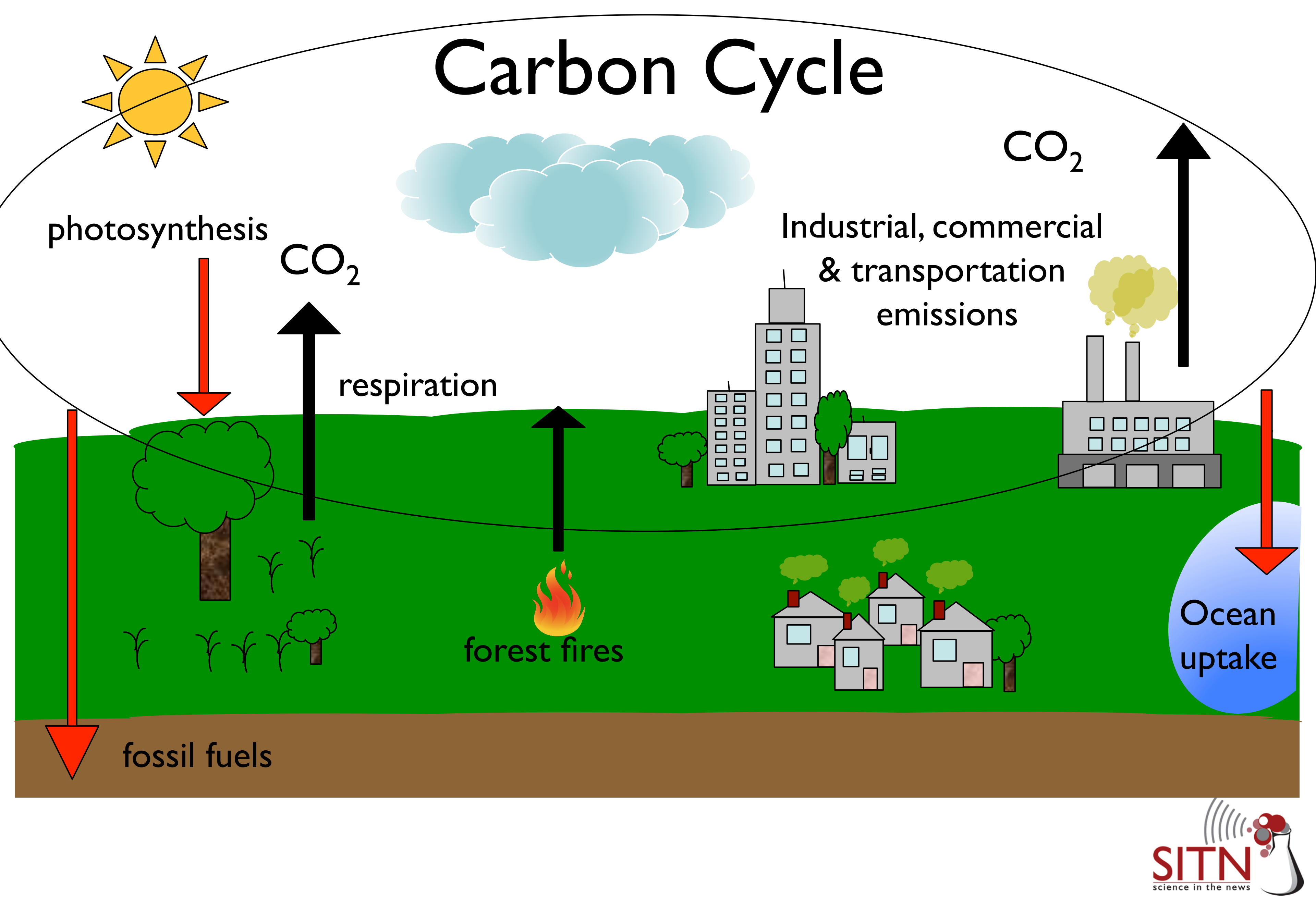
The Paris Climate Agreement
We will take action!

Source: New York Times, Christophe Petit Tesson/European Pressphoto Agency

But this problem is global!



Source: Bill Putman, NASA Goddard


Carbon Cycle
photosynthesis
CO_2
respiration
CO_2
Industrial, commercial & transportation emissions
forest fires
Ocean uptake
fossil fuels
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science in the news

Roadmap for the evening

I. How do we use models to understand air pollution in cities?

II. What cutting-edge technology do we use on the ground, in the air, and in space?

III. What do these instruments and models tell us?

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science in the news

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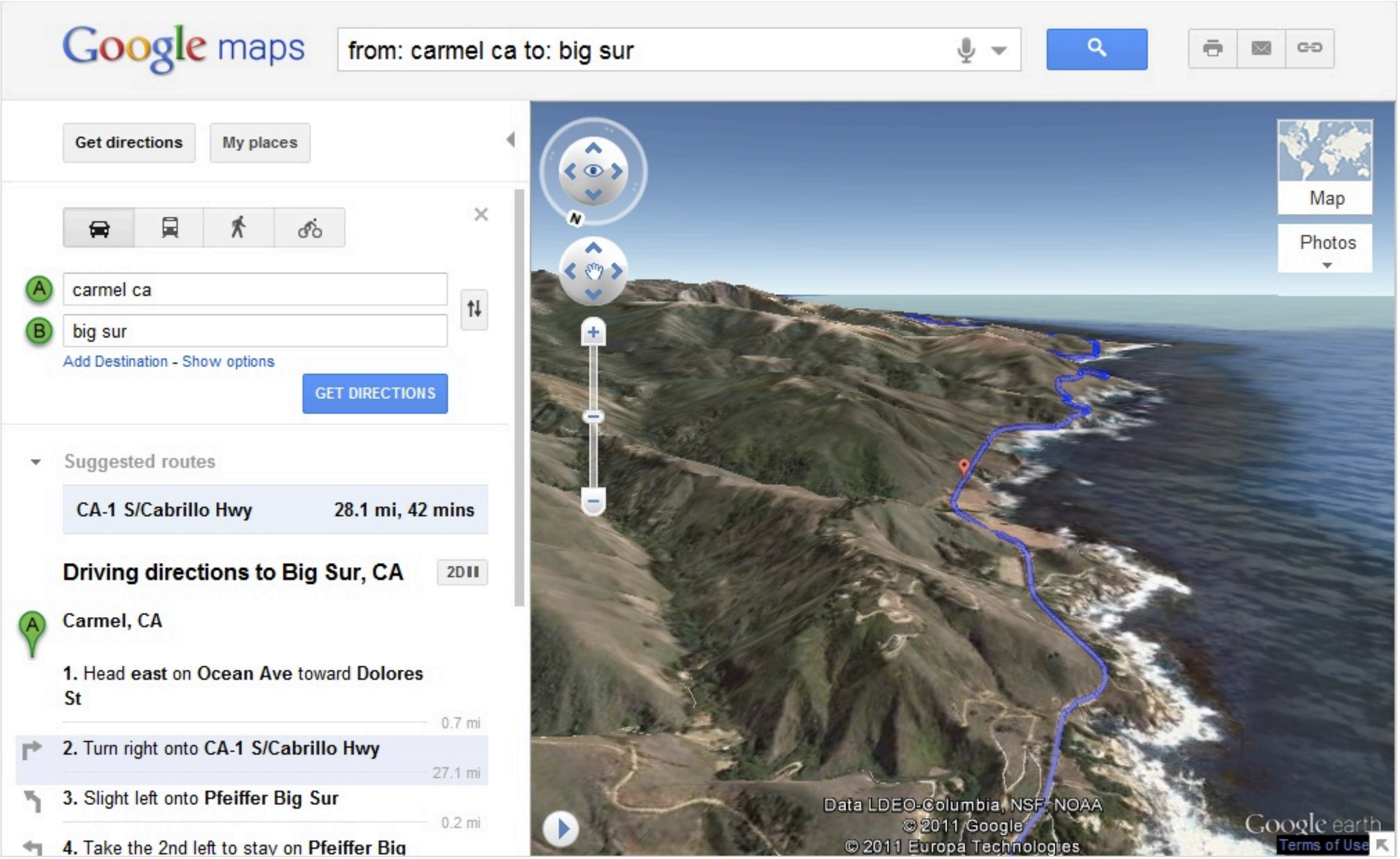
What is a model?

- A model is not the real world but a human construct to help us understand real world systems
- “Model” means both the computer program and the concept
- Models are accepted if it finds supporting evidence
- Models and experiments (or observations) can work together in order to get a better understanding of what we are trying to learn and in order to evaluate uncertainties

Pause for thought



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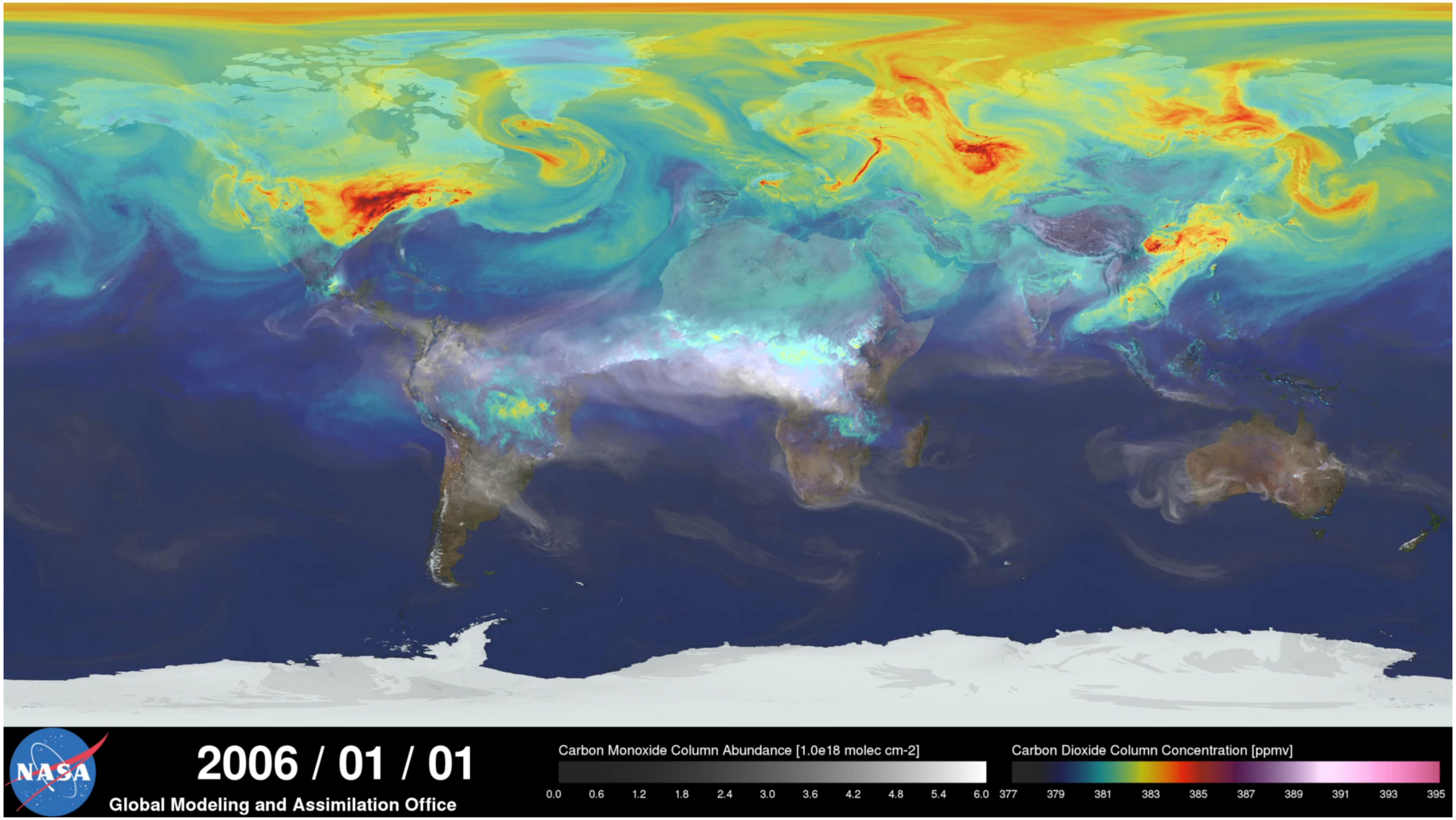
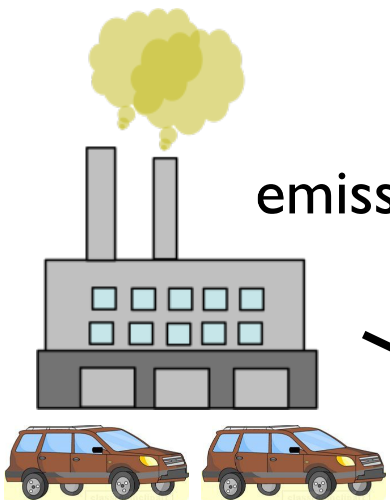
But how do we build models to study air pollution in cities?

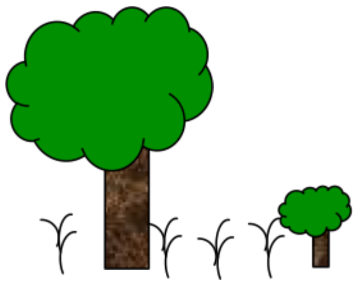


Source: NASA Goddard Space Flight Center (bottom), NC university (top)

Model Parts



emission sources



carbon cycle of the biosphere

Optimized temporal and spatial CO_2 emissions

weather/wind information

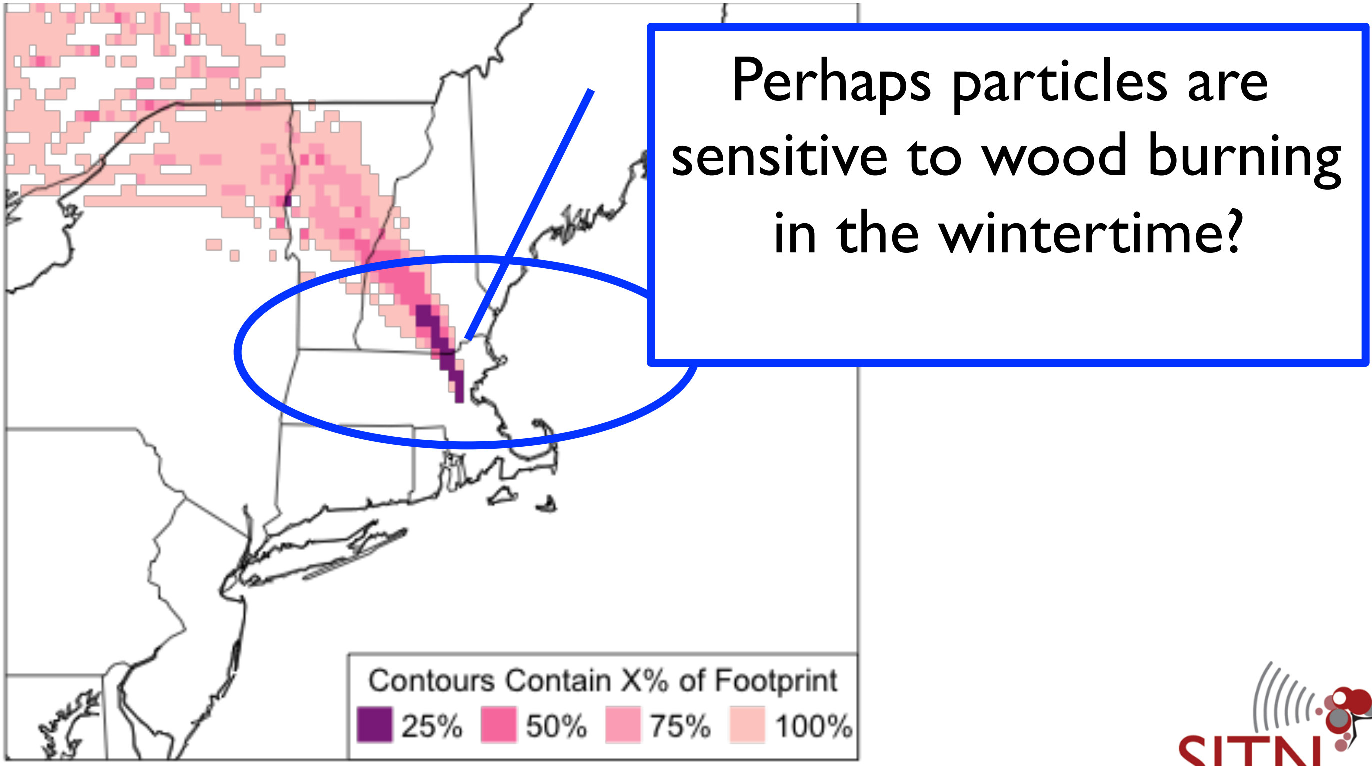
measurements/ observations

Model product showing sensitivity footprint

Footprint showing sensitivity of the *particles* that see surface observations

Date:
Nov. 11th, 2012

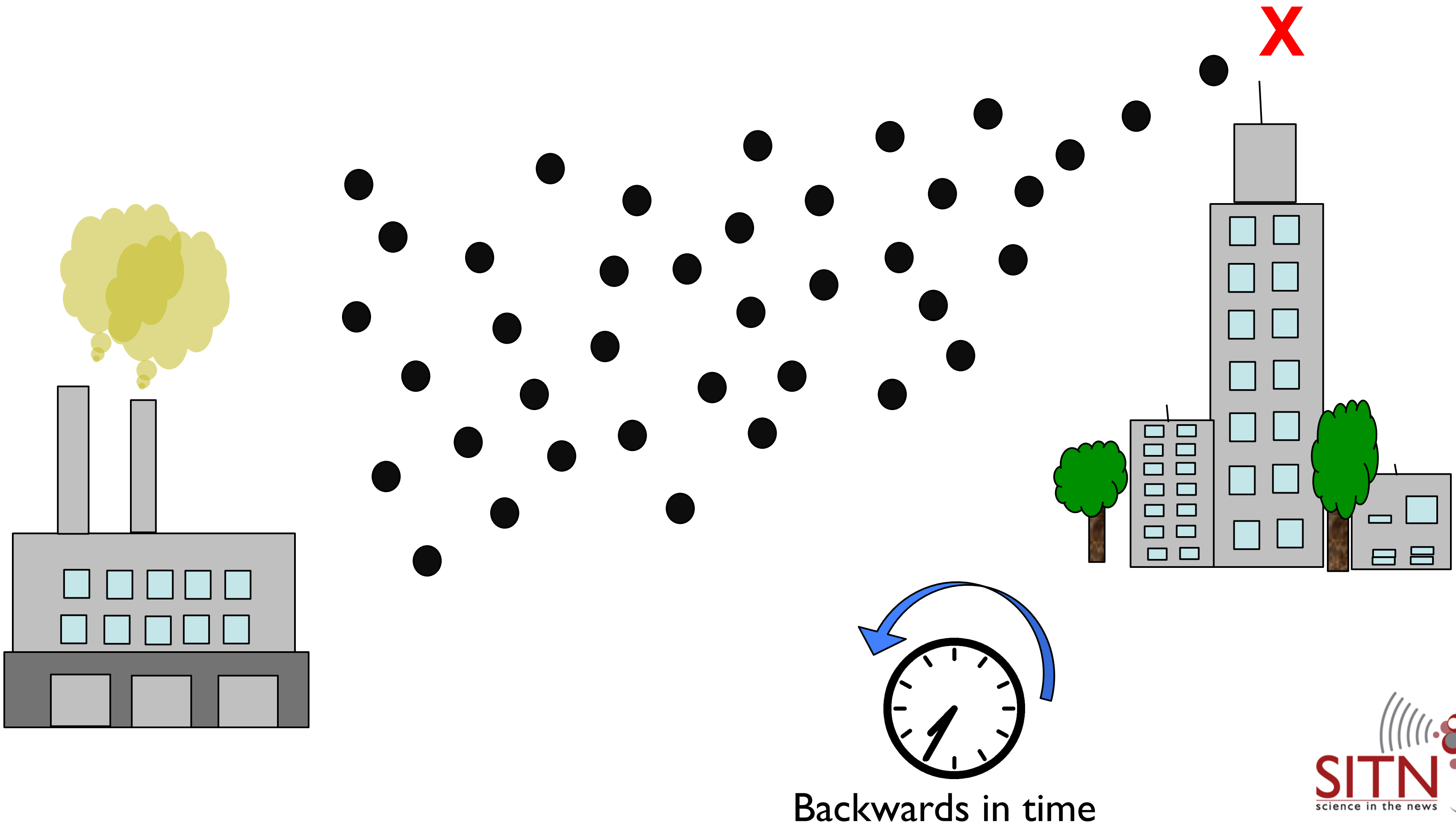
16 hours backwards in time



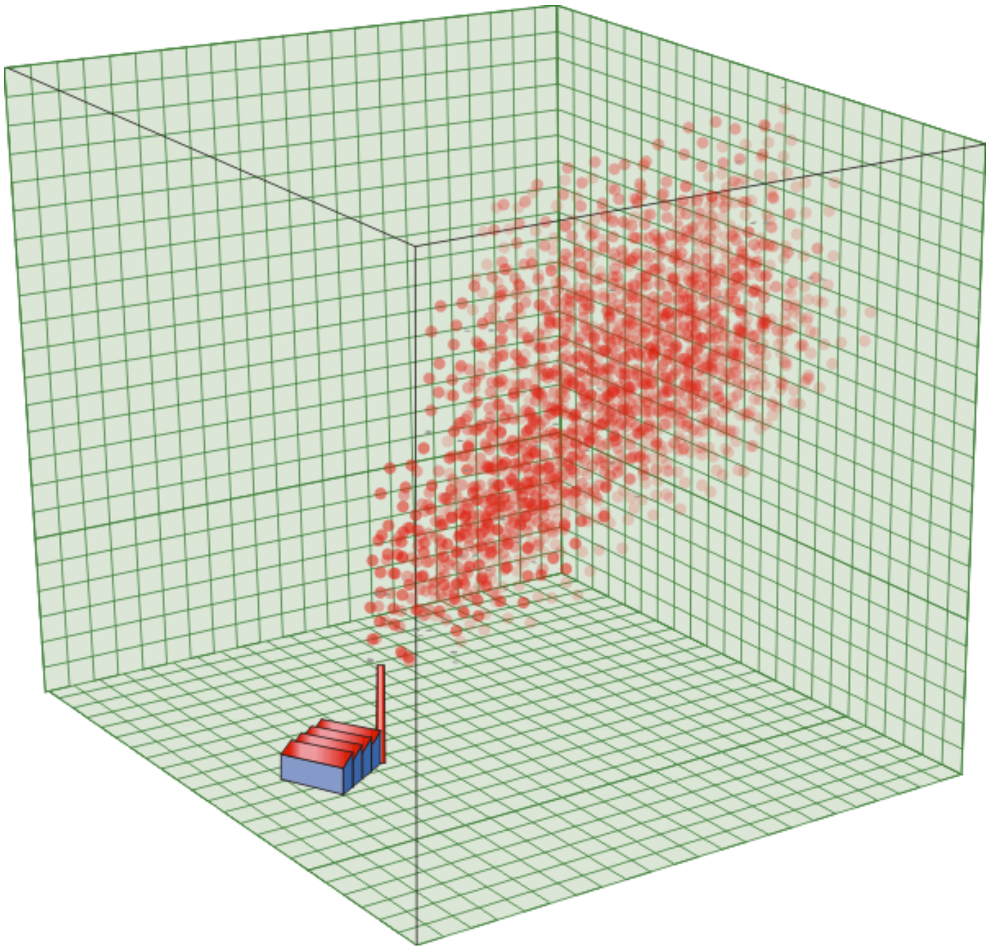
Source: Thomas Nehrkorn, AER, and Yanina Barrera, Harvard University

SITN science in the news

We get these products by using a transport model!



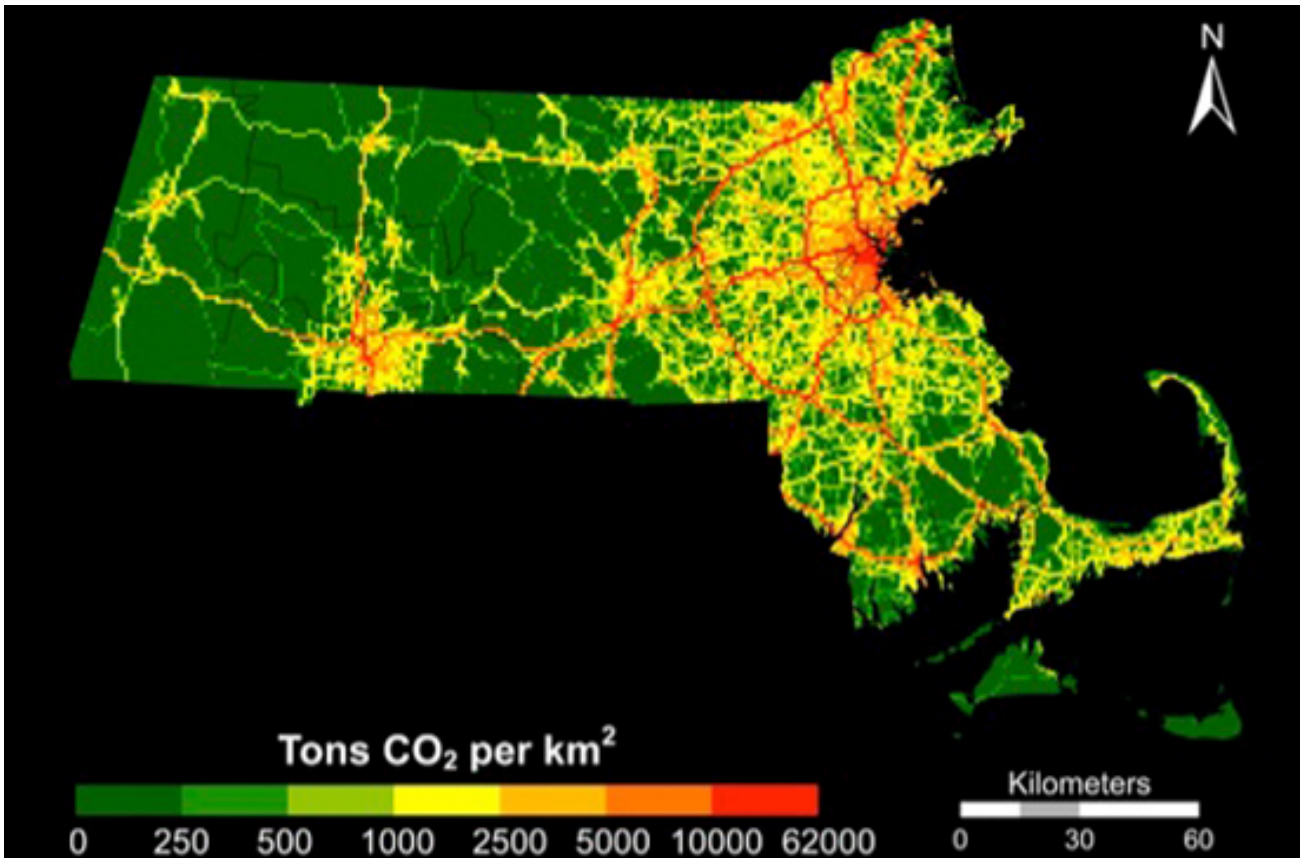
3-D transport of particles



- We can track particles on a horizontal grid (map)
- We can track particles vertically in the atmosphere and identify air pollution sources most influencing CO_2 levels!

Source: John Lin and Christoph Berbig, SoundPlan air pollution study

Integrate information about emission sources → on-road CO_2 emissions inventory



On-road transportation is responsible for 28% of all U.S. fossil-fuel CO2 emissions

Source: Gately, et al., Boston University

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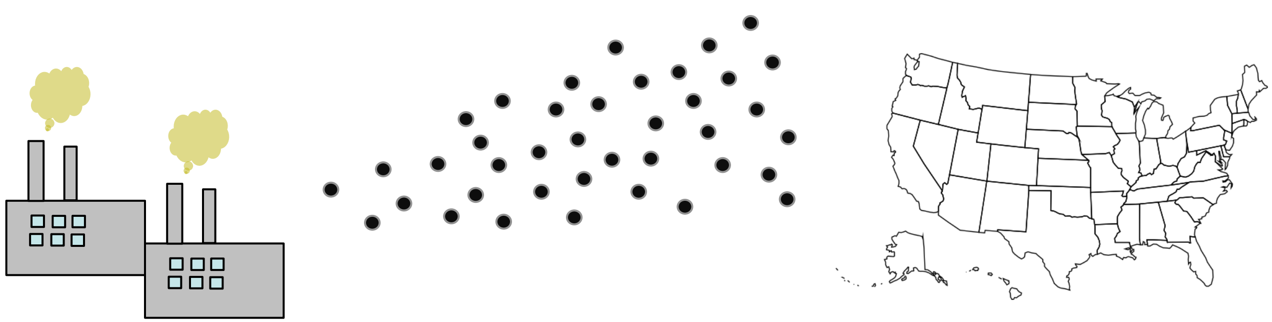
Part I Summary

- Transport models are heavy computationally and expensive to run but helps us study air pollution locally and regionally, at the observation site in consideration
- Information of the winds can helps us understand where the air pollution came from
- Emissions inventory helps us identify emissions sources as we track particles backwards in time on a map!



BREAK for Questions

Roadmap for the evening

I. How do we use models to understand air pollution in cities?

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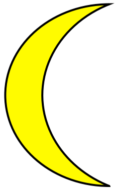
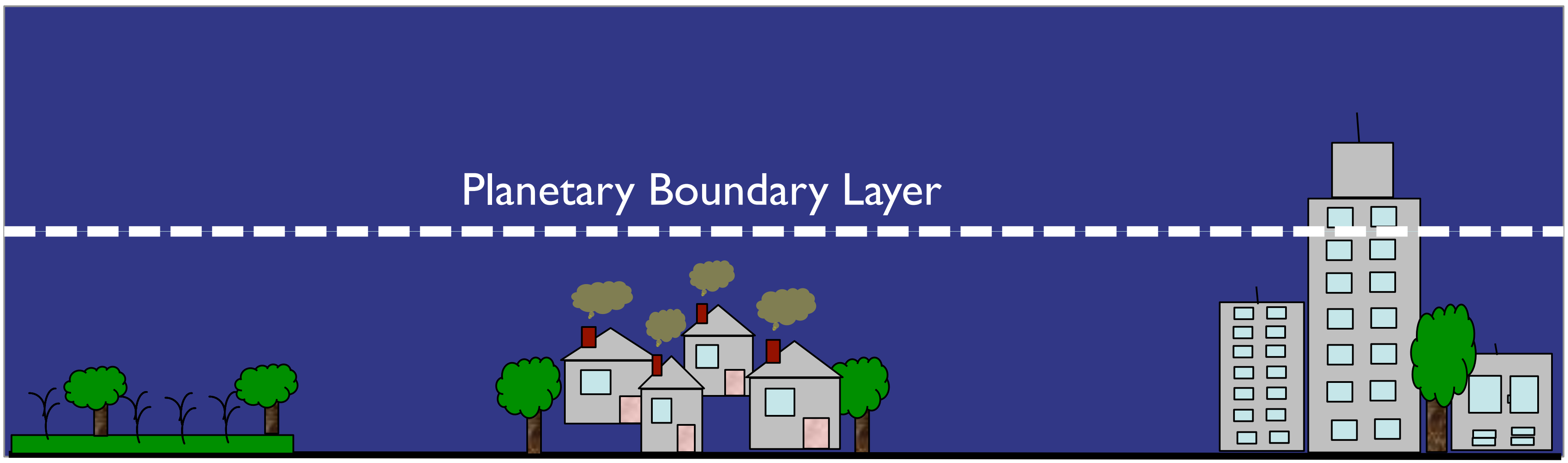


The air we breath - nighttime

Planetary Boundary Layer (PBL)

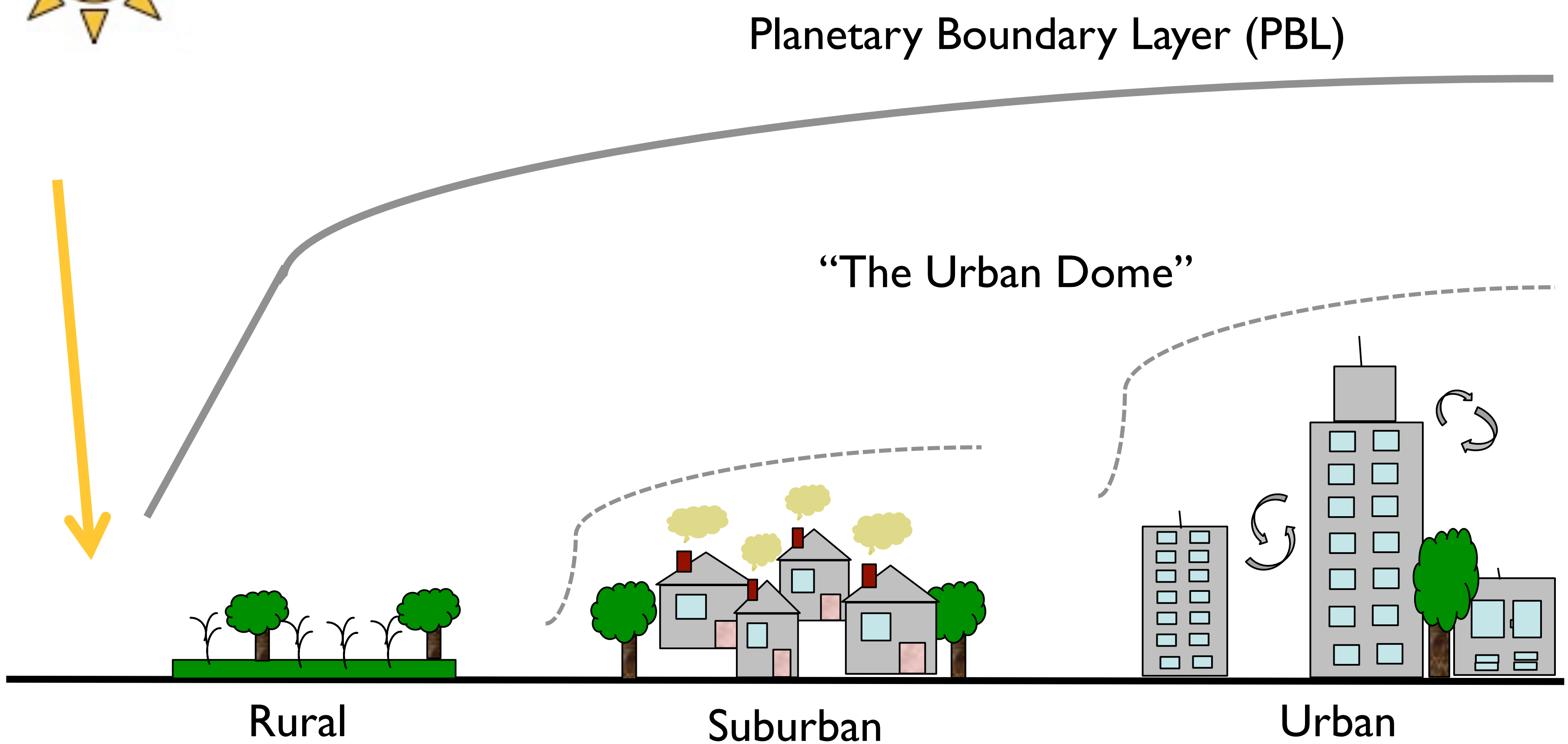


Rural

Suburban

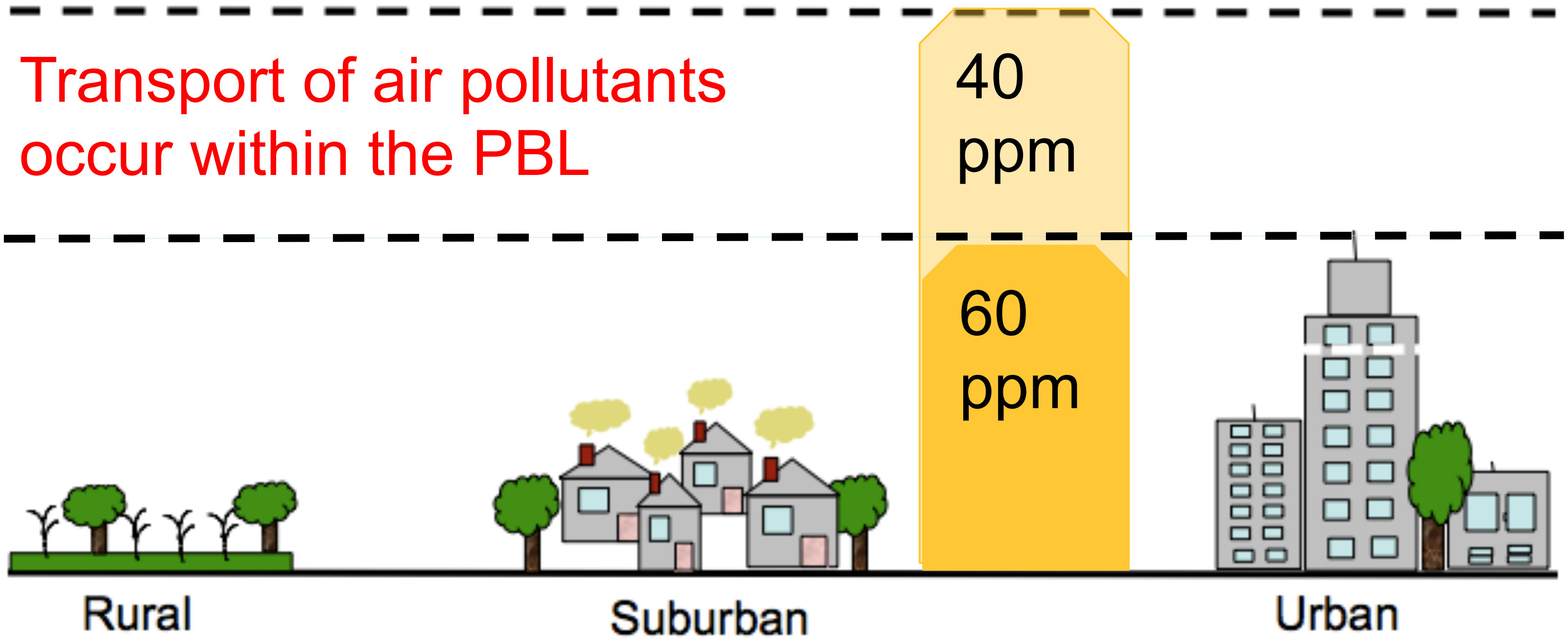
Urban

The air we breath - daytime



Why do we care about the PBL?

Height of PBL helps us determine our concentrations at the surface



How do we measure this layer?

Lidar ("Light Detection and Ranging") Technology

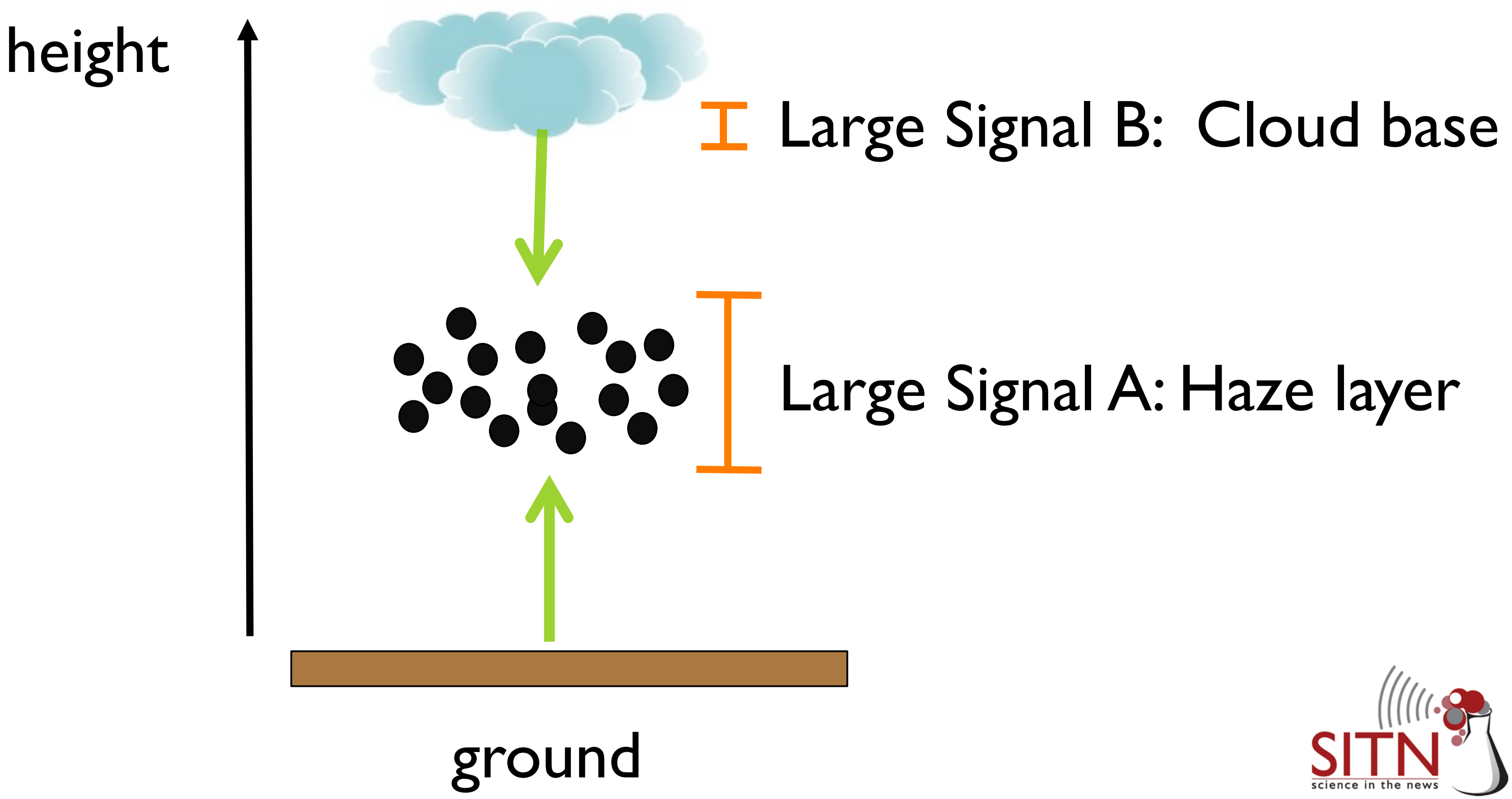
Lidar Technology Detects Backscattering!

return of light

- Backscattering deflection of light particles at an angle of 180°
- Lidar can measure the “intensity” of backscatter at each height point in the atmosphere

pulse of light

one Lidar pulse = many returns



Lidar measures backscatter from the atmosphere

return of light

pulse of light

<u>Question:</u>

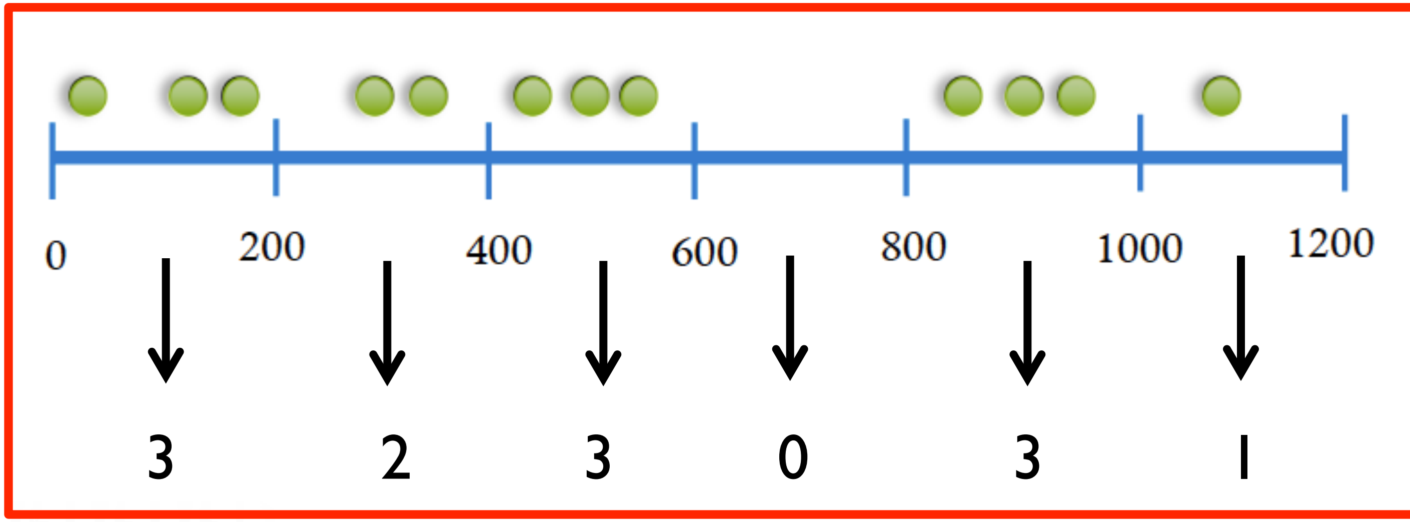
How do we determine the height of the bottom of the cloud with Lidar?

Calculate height of clouds or structures

$$\frac{(\text{travel time}) \times (\text{speed of light})}{2} = \text{height}$$

distance

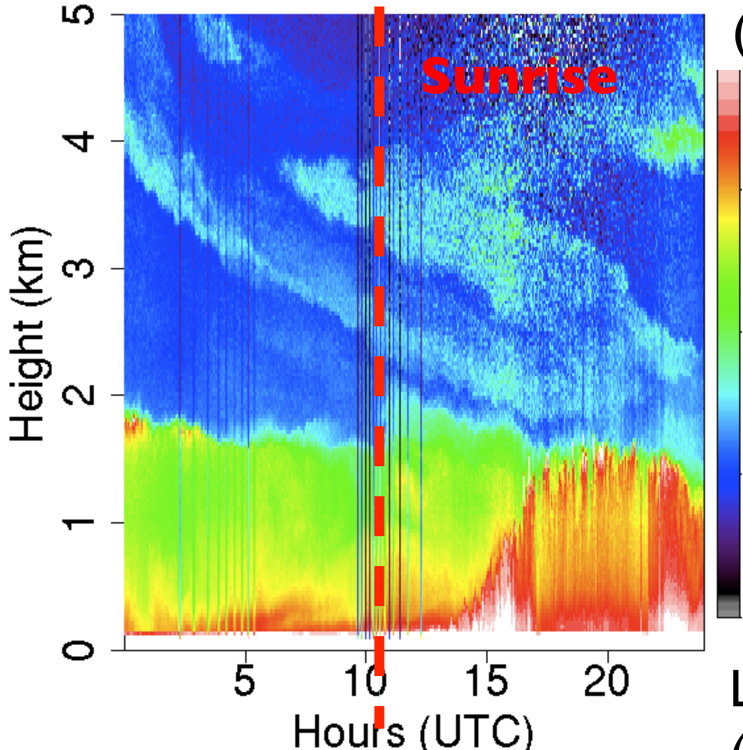
Lidar stores the amount of light returned as "photon" counts in bins every 200 nanoseconds



Computer program stores information and we download data to analyze

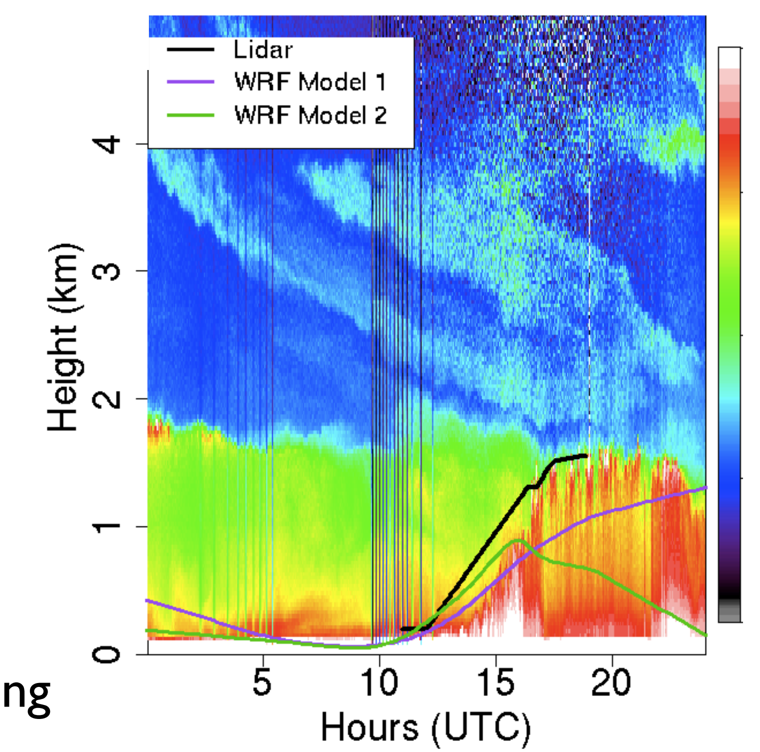
Source: Sigma Space Corp.

We can image atmospheric structures!



More backscattering (more particles!)

Less backscattering (fewer particles!)

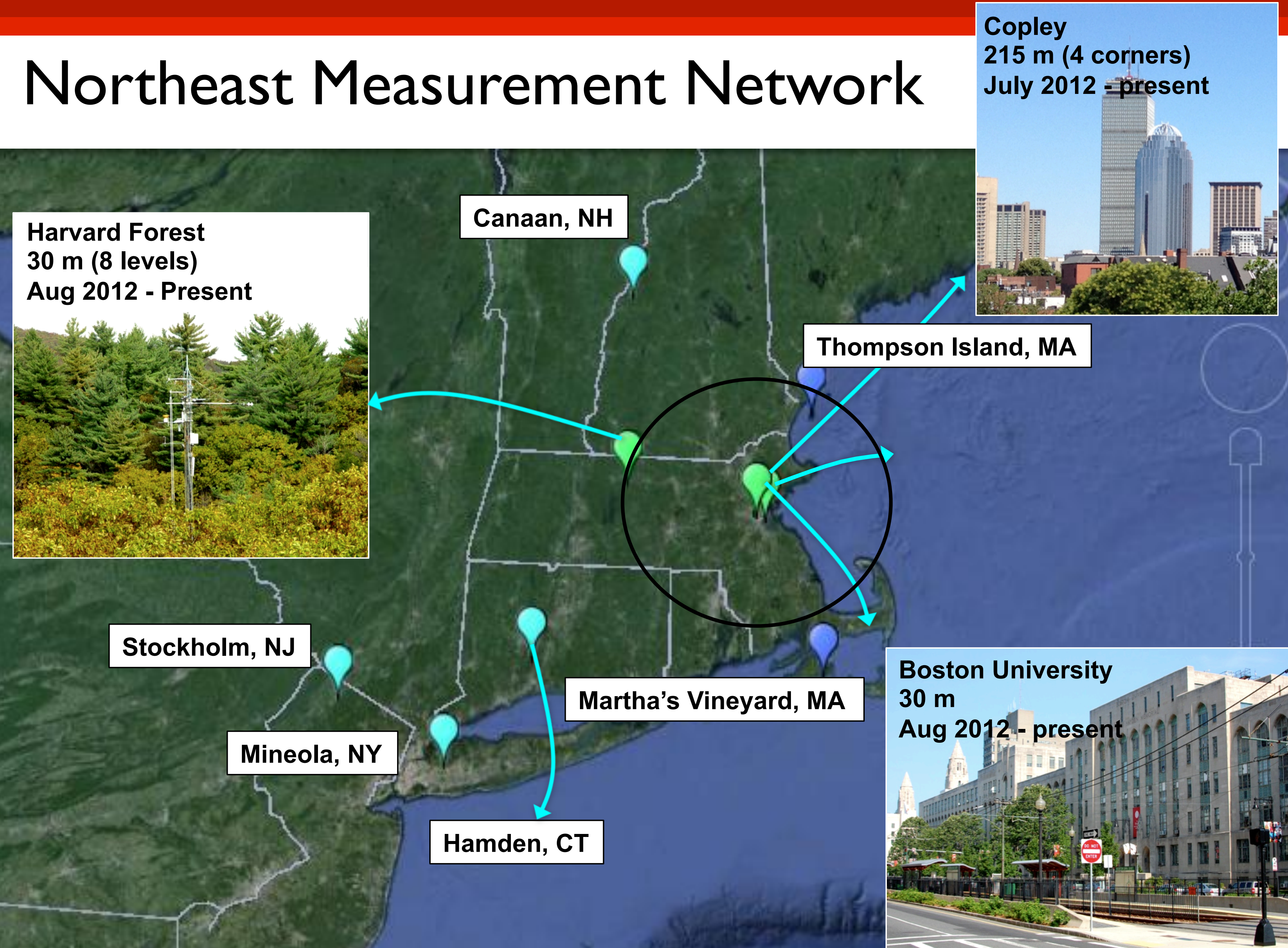


Source: Yanina Barrera, Harvard University

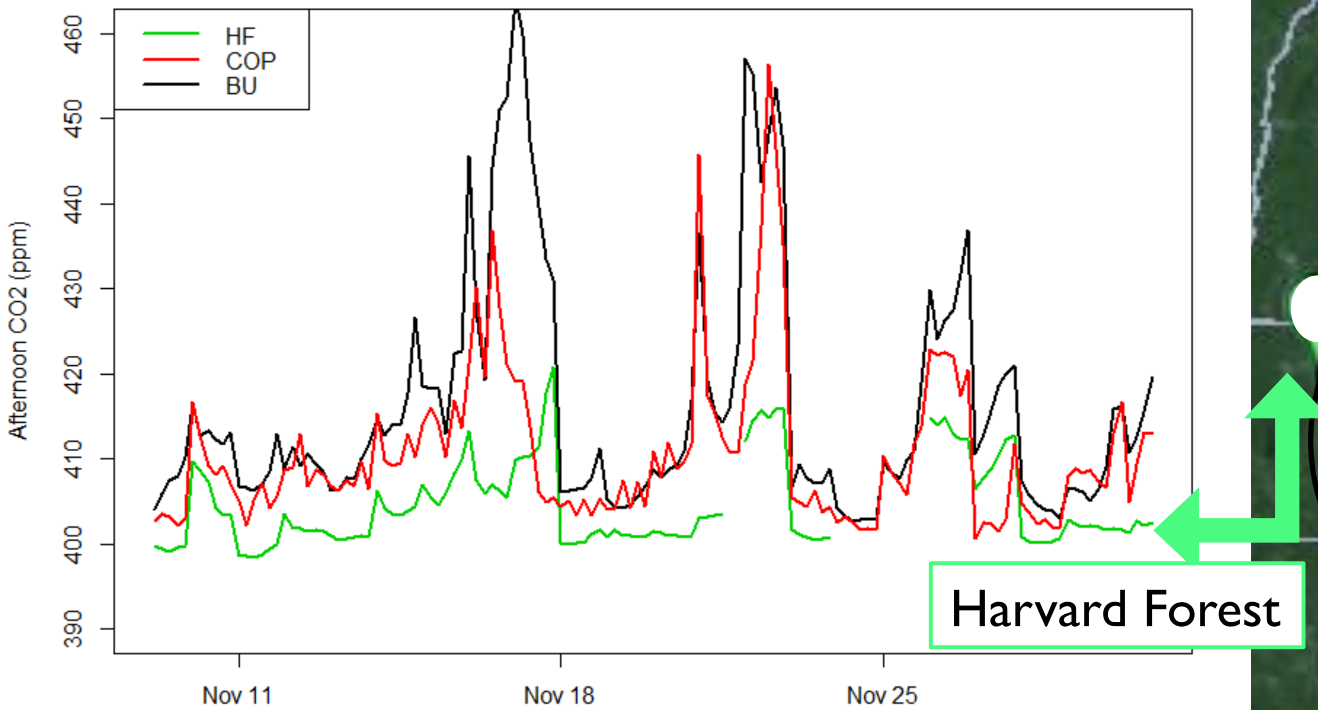
Great! We can use Lidar technology to measure the height of the Planetary Boundary Layer…..

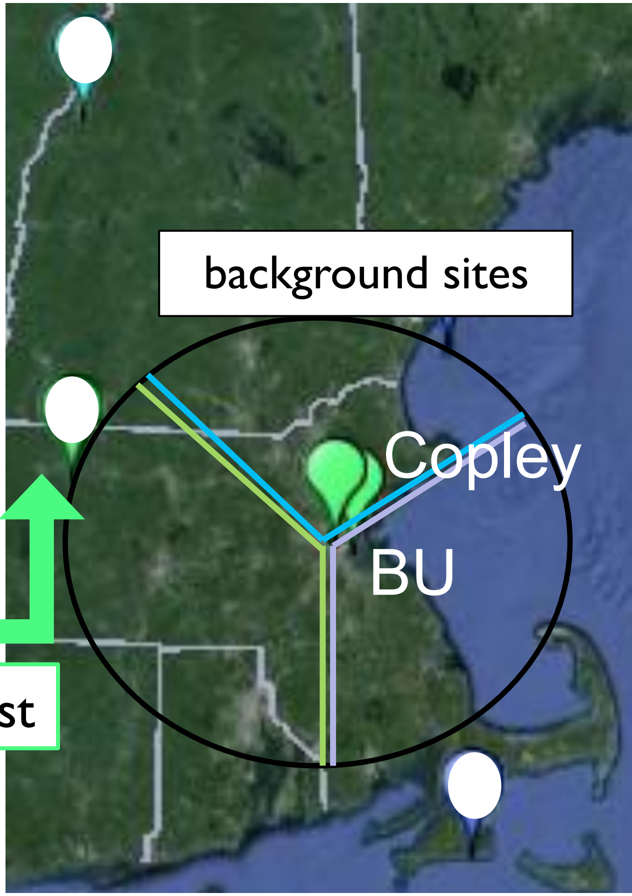
But where do we measure carbon dioxide emissions?

Northeast Measurement Network



CO_2 results from Earth Networks

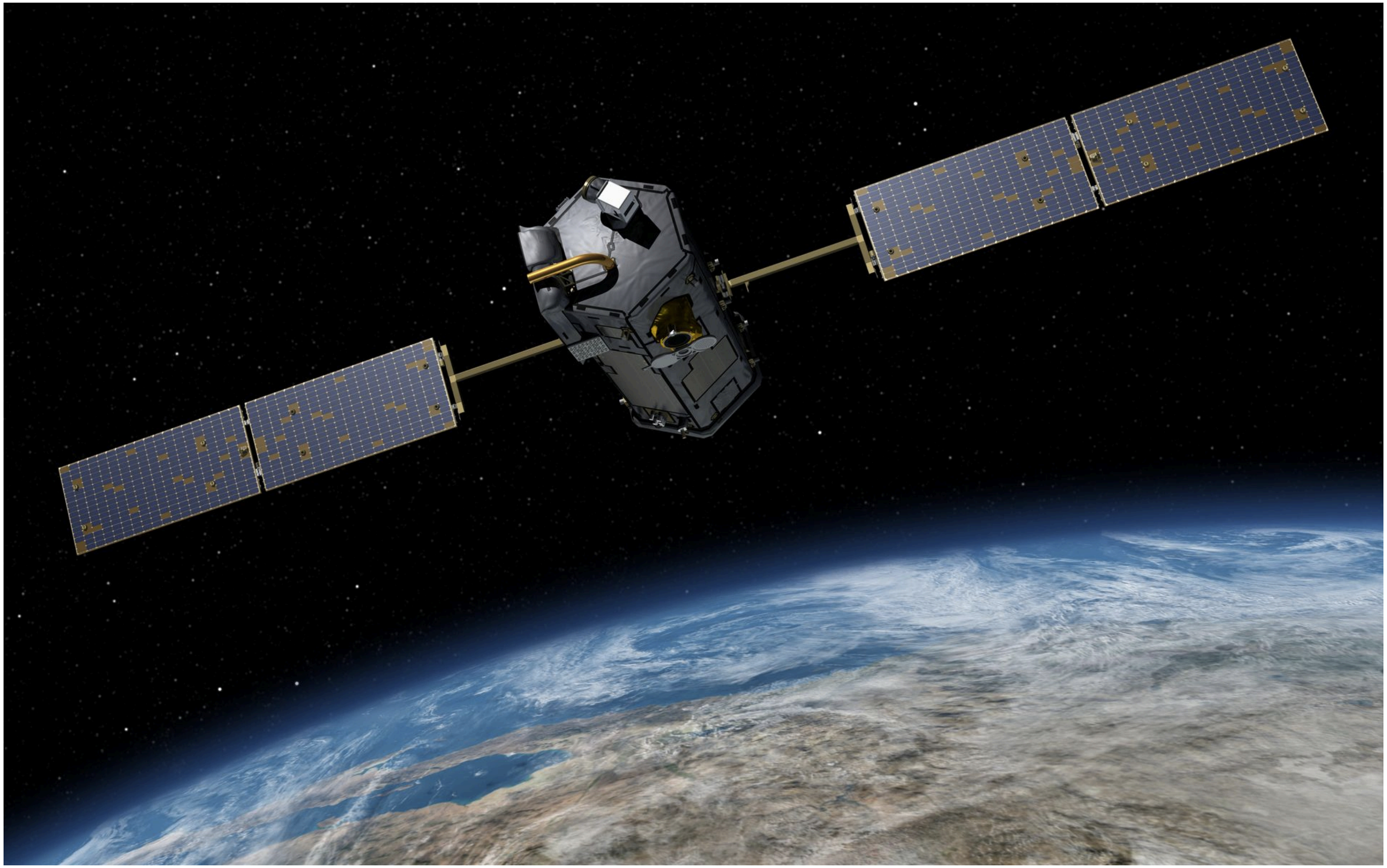




Good "background" to compare "enhancements" in CO_2 observations

Source: Maryann Sargent and Steven Wofsy, Harvard University, NASACMS project

Orbiting Carbon Observatory 2 (OCO-2) NASA Satellite



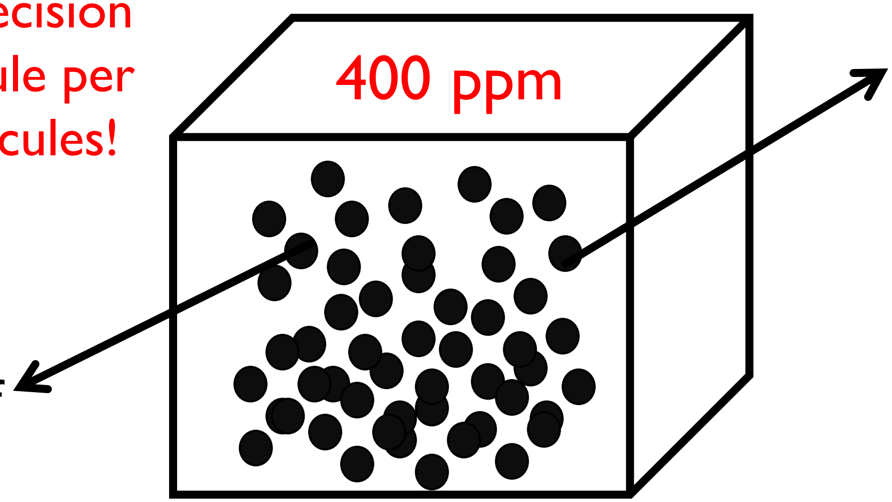
Source: NASA's Jet Propulsion Laboratory

How well can OCO-2 measure carbon dioxide levels on earth?

- OCO-2 measures carbon dioxide levels with a precision of about 1 part per million, or ppm. What does that mean?
- Today's carbon concentration, is 400 ppm

→ The highest it has been in at least 800,000 years!

Measure with precision of 1 CO2 molecule per million air molecules!



1 million molecules of air

400 molecules of CO_2

What does one ppm mean to us?

- Recent monthly average at Mauna Loa, Hawaii, observatory

~ 4 ppm difference in 1 year!

February 2016: 404.02 ppm
February 2015: 400.26 ppm
Last updated: March 7, 2016

Source: NOAA

BREAK for Questions

BREAK for Intermission

Roadmap for the evening

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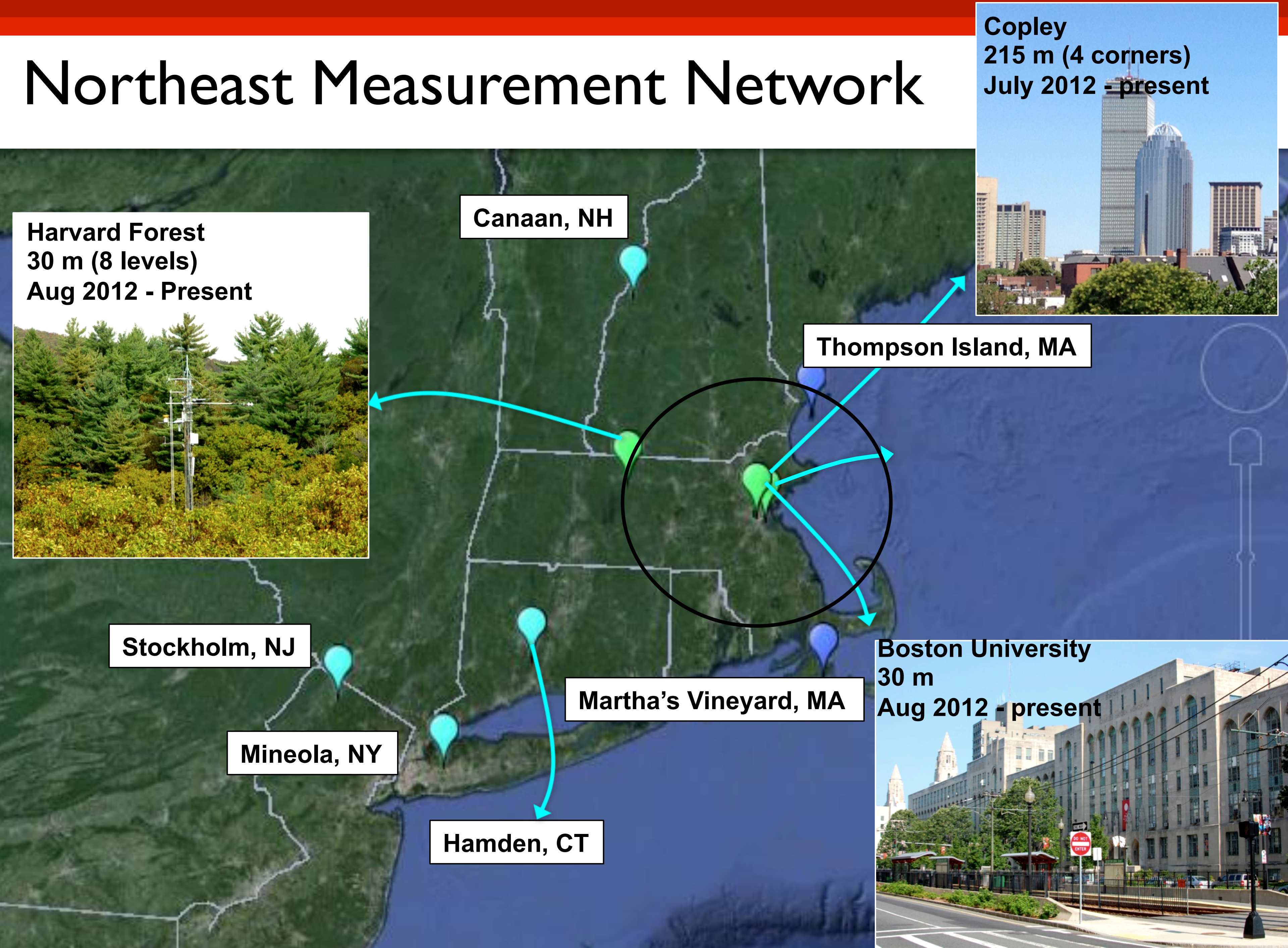
Northeast Measurement Network



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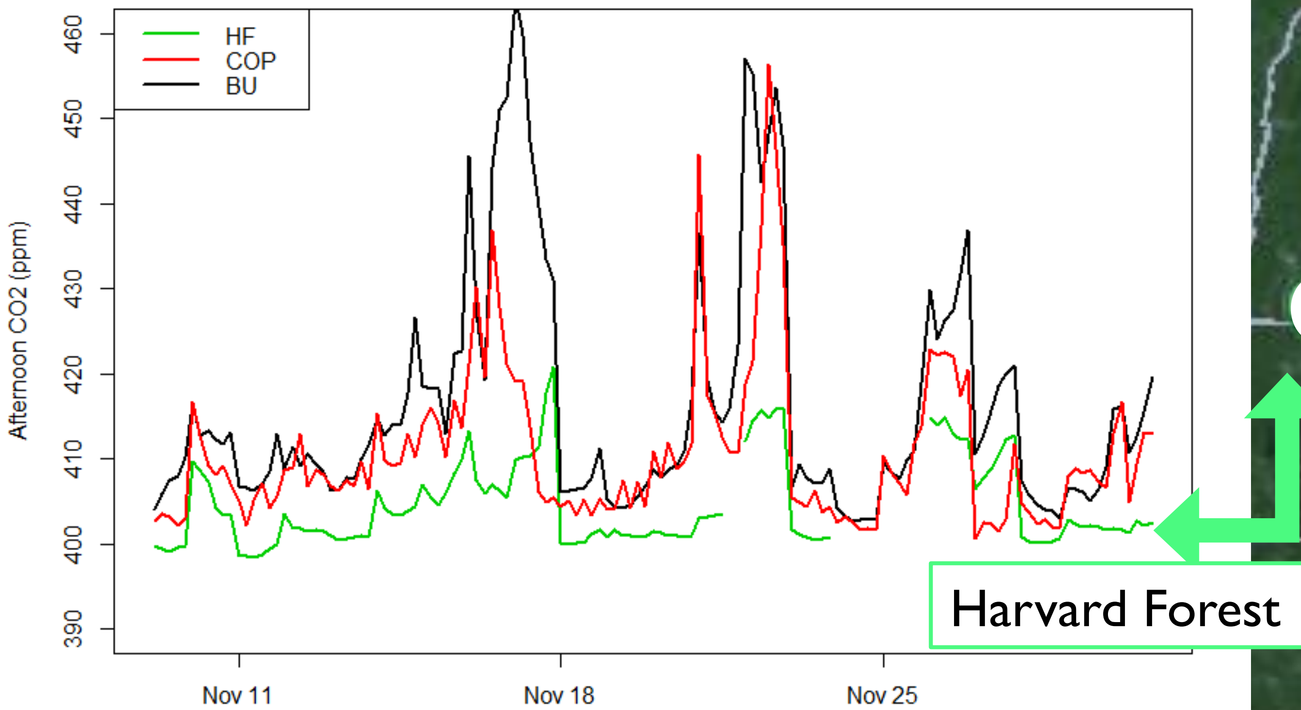
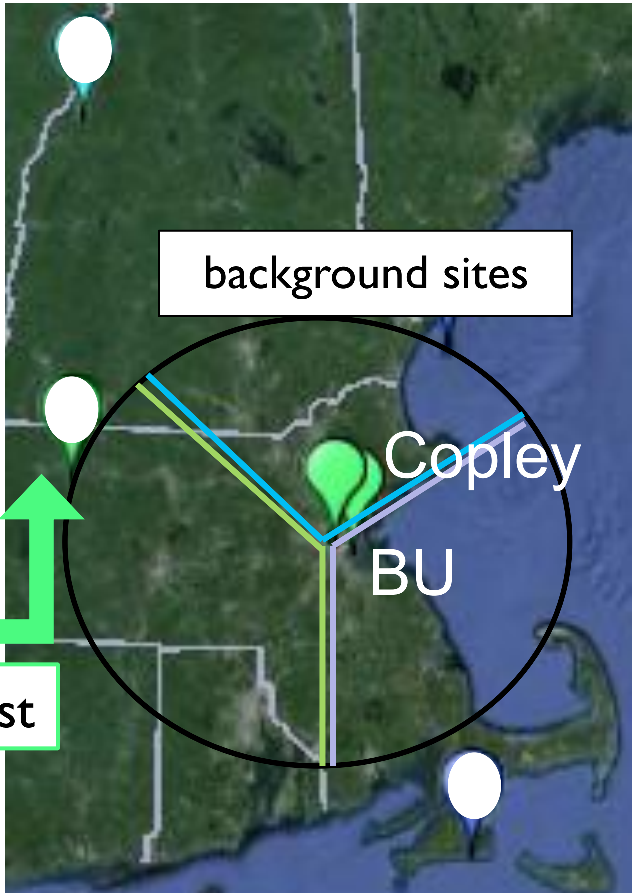
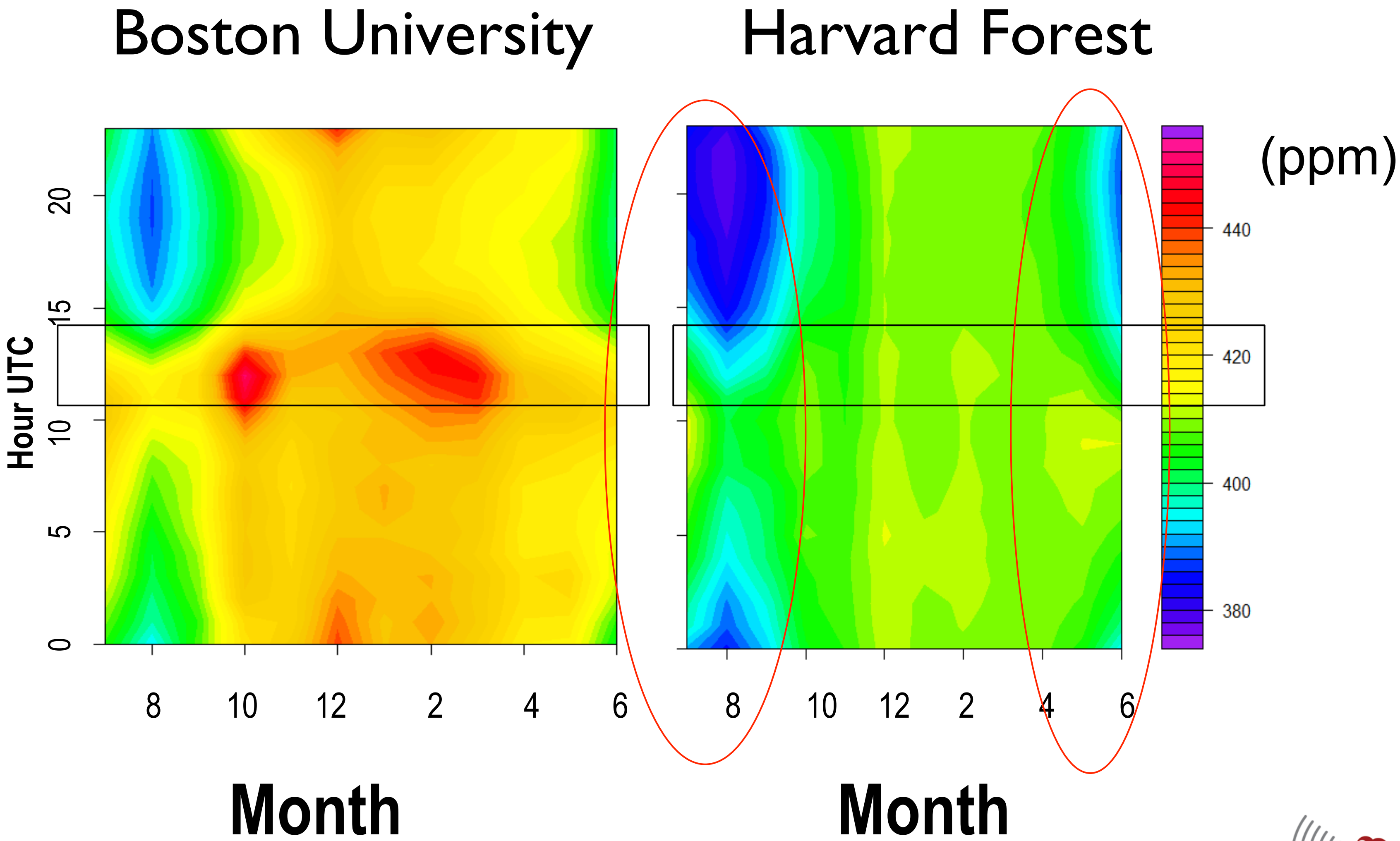




Good "background" to compare "enhancements" in CO_2 observations

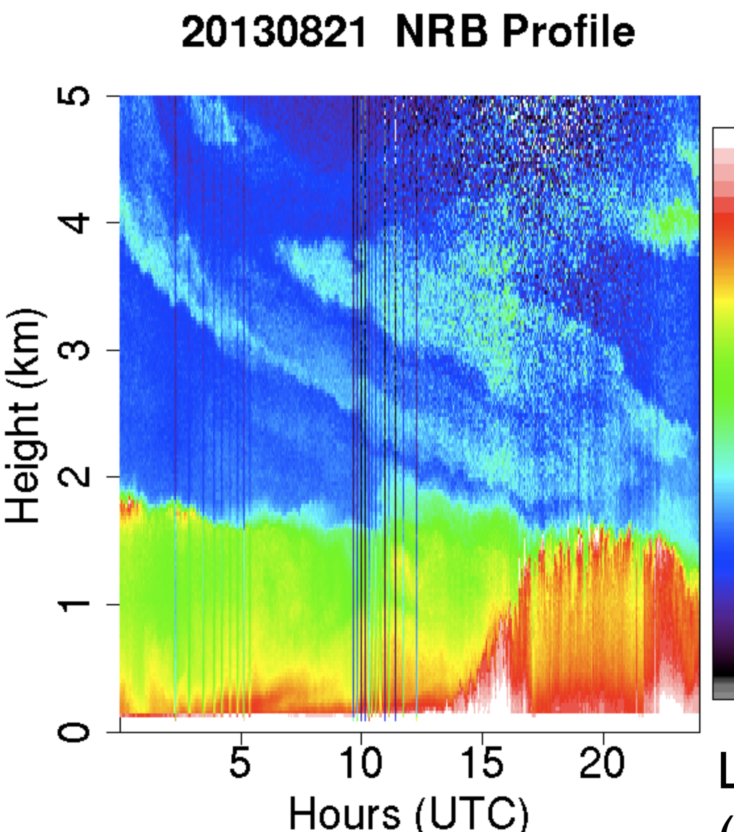
Source: Maryann Sargent and Steven Wofsy, Harvard University, NASACMS project

CO_2 concentration results



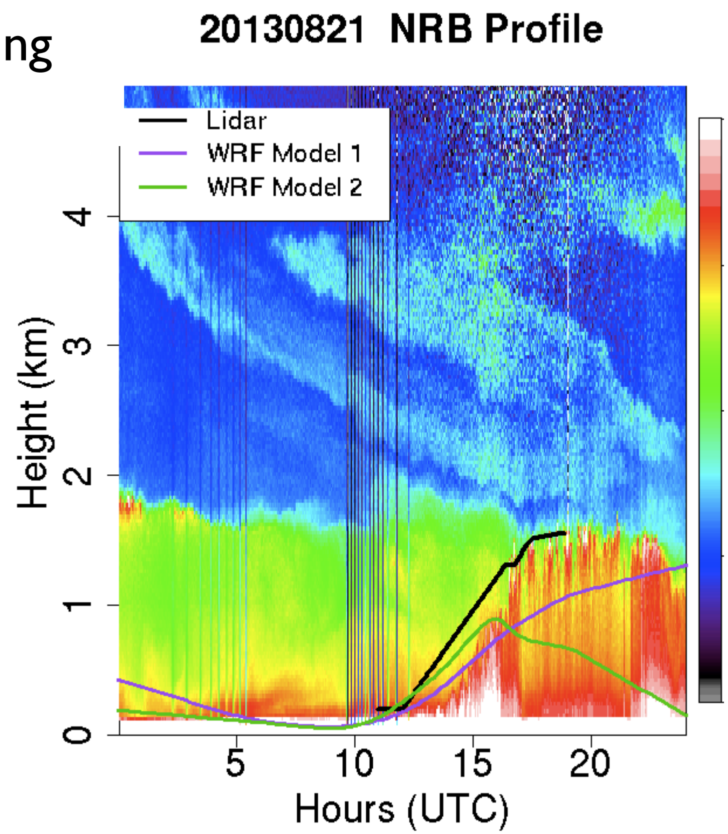
Source: Maryann Sargent and Steven Wofsy, Harvard University, NASA CMS project

We can image atmospheric structures!



More backscattering (more particles!)

Less backscattering (less particles!)



Source: Yanina Barrera, Harvard University

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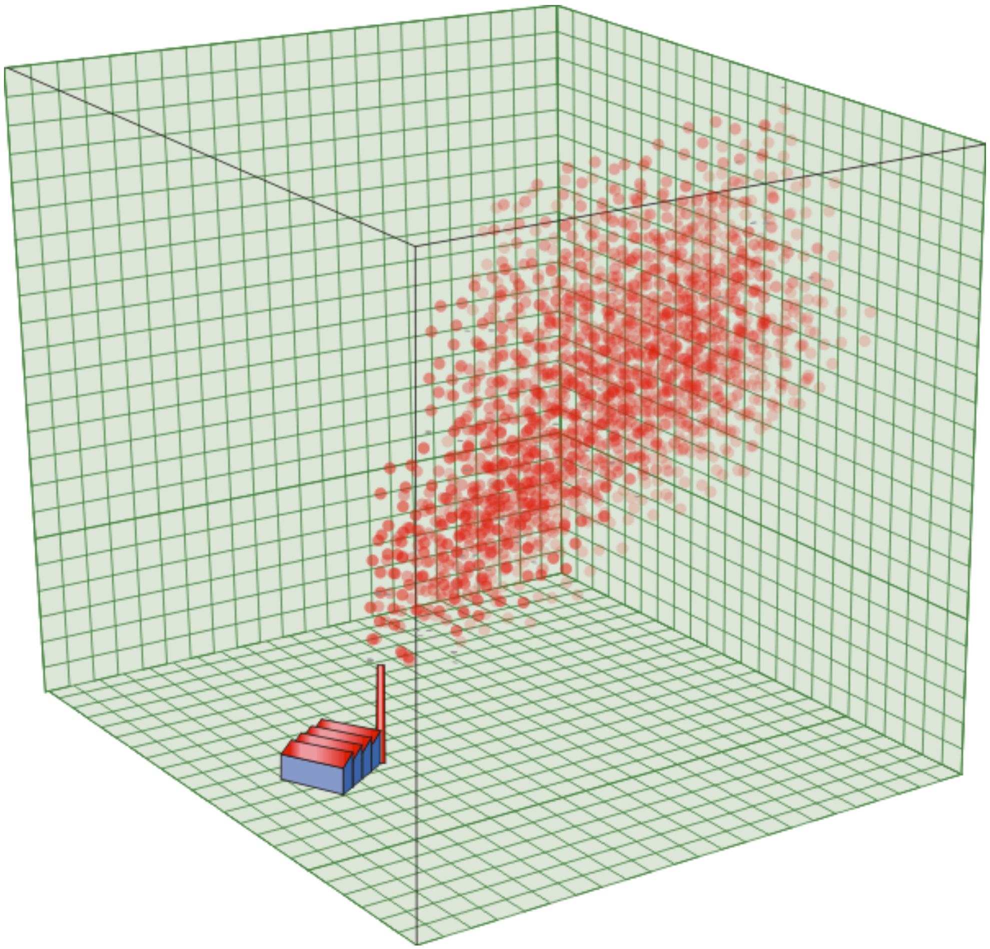
What if the PBL height does not agree with our Lidar observations?

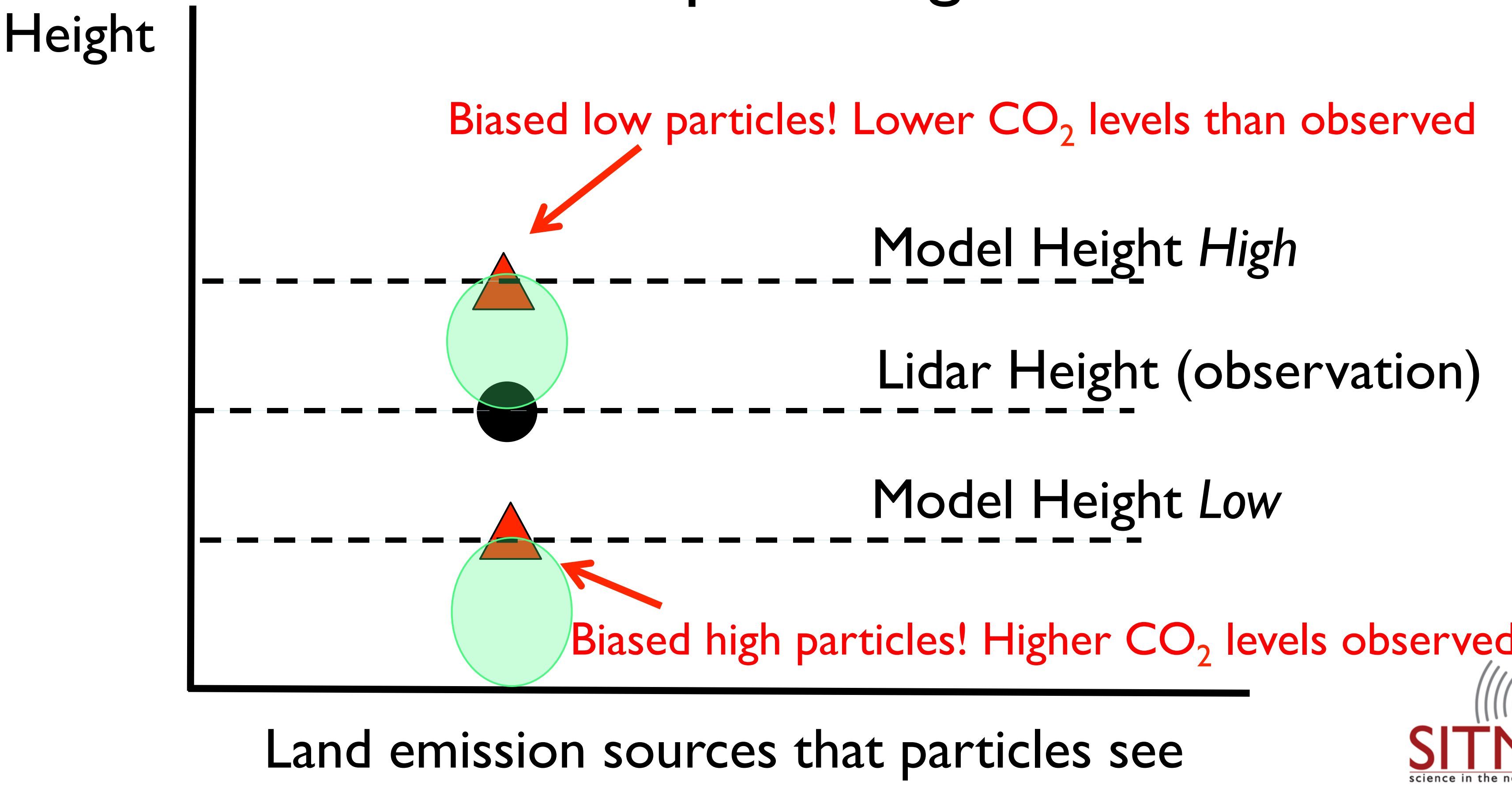
3-D transport of particles



- We can track particles on a horizontal grid (map)
- We can track particles vertically in the atmosphere and see what air pollution source most influence CO2 levels!

Source: John Lin and Christoph Berbig, SoundPlan air pollution study

Particles may be biased low or high to land emission sources… If we do not model the height of the lowest layer of atmosphere right!



Develop Framework for Identifying "Good Dates" for Transport Modeling

- If Lidar measurements do not agree with transport model
  ✗ → Do not use/rely on these dates and model results

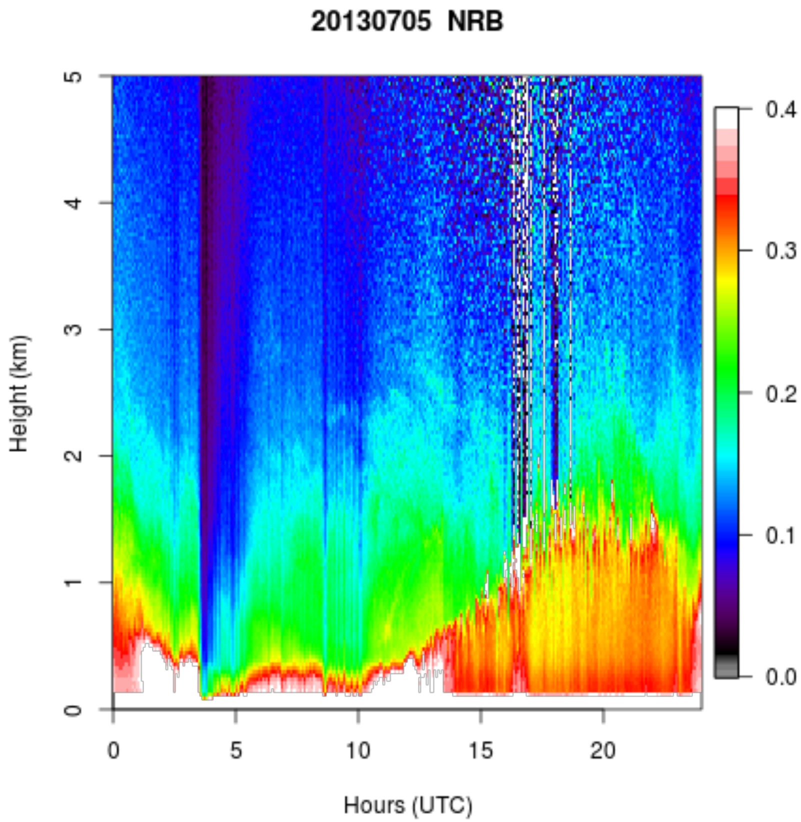
- If Lidar measurements do agree well with transport model
  ✓ → Study transport of air pollution in cities

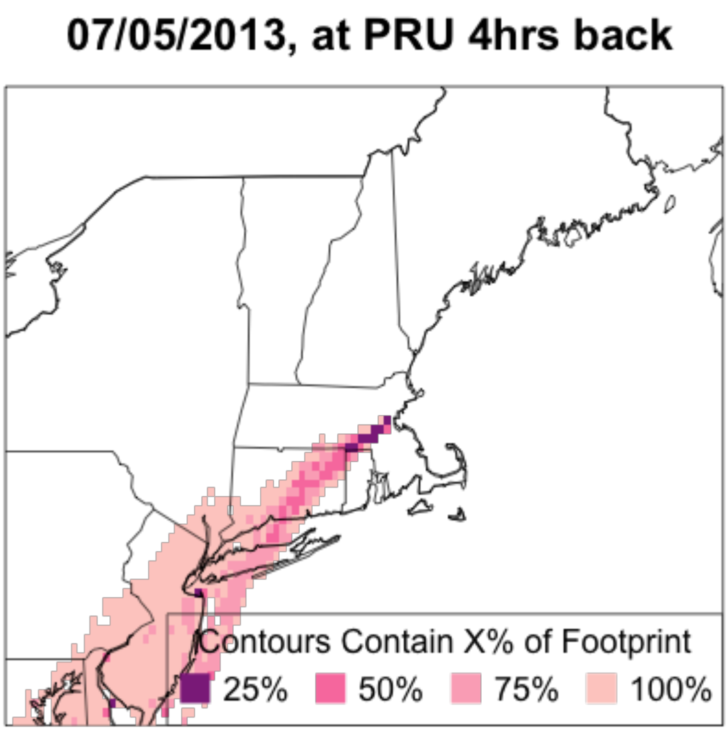
- Framework used to identify uncertainties in model results!

Let’s look at an example of a “good date” to perform this type of modeling…..

What does it look like when we track particles in Boston?

Can you guess a major source of particle pollution?





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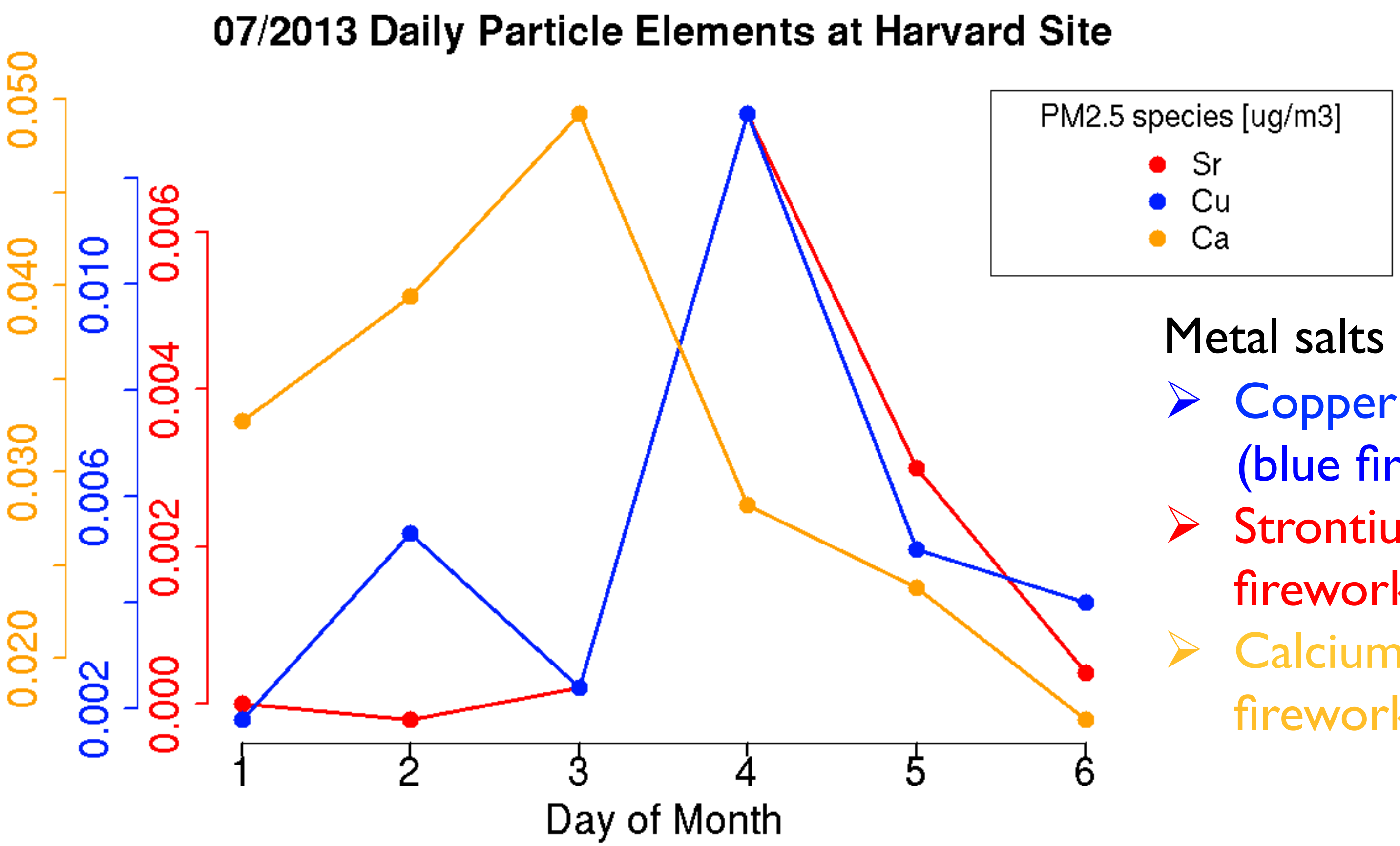
July 4th Fireworks!



Metal salts commonly used:

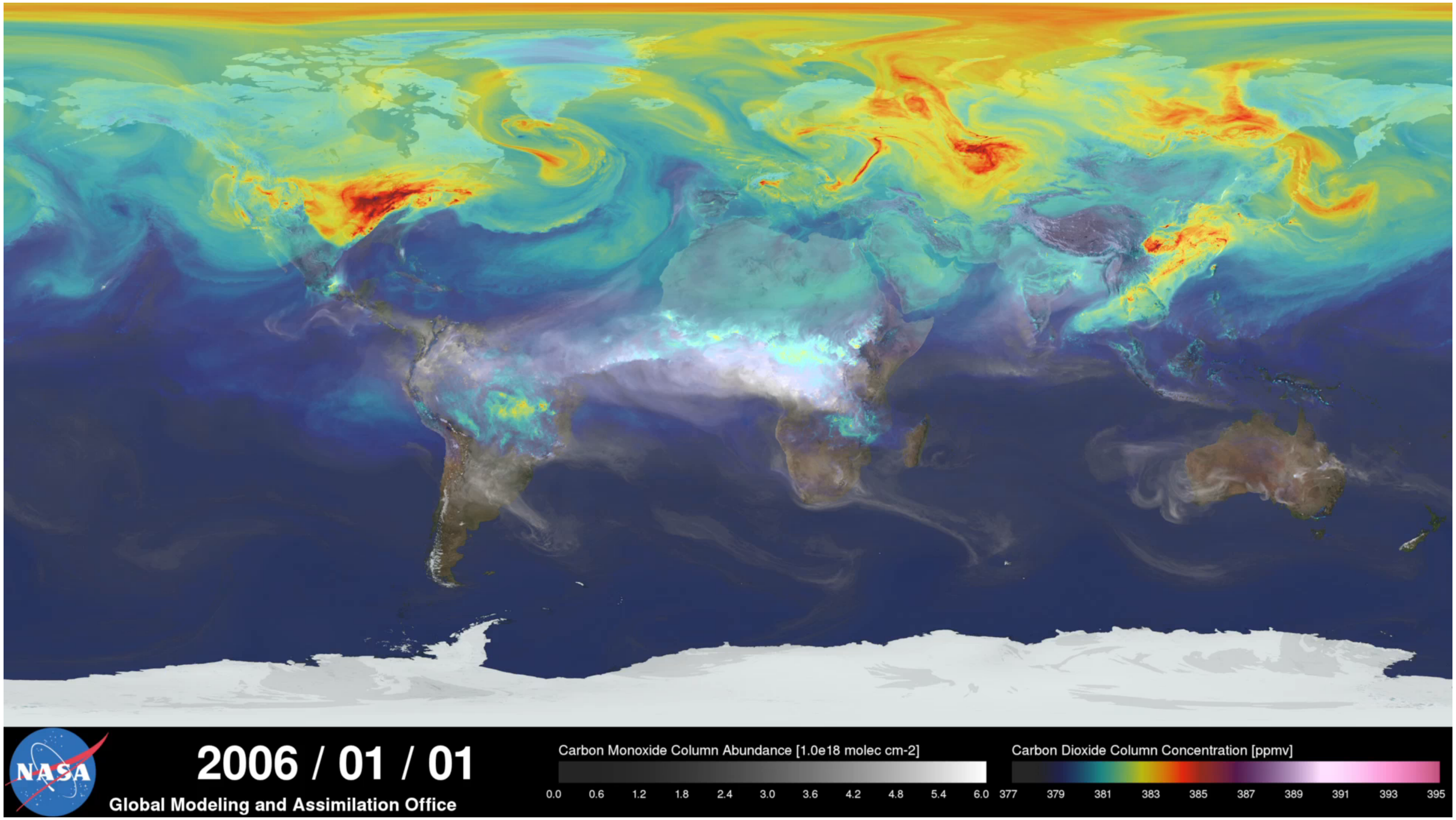
- Copper chloride (blue fireworks)
- Strontium carbonate (red fireworks)
- Calcium chloride (orange fireworks)

Pause for Thought

- How much CO_2 emissions will the carbon cycle continue to absorb in the presence of climate change?

We don't know…..we must keep track of these changes on a global scale!

Global Simulation of CO_2



Conclusion

- Atmospheric scientist use various high-precision instrumentation networks to understand levels of air pollution
- The carbon cycle is complicated so these observations do not tell us the whole picture!
- We need models to incorporate complex processes of the carbon cycle, and combine information from industrial emissions inventory, as well as those from the biosphere
- Air pollution knows no boundaries! We need to understand the transport and places where we as humans can reduce energy-related carbon emissions
- The Paris Climate Agreements calls for us to understand the areas in which cities, states, and countries can improve its energy infrastructure

Thank you!

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Division of Medical Sciences

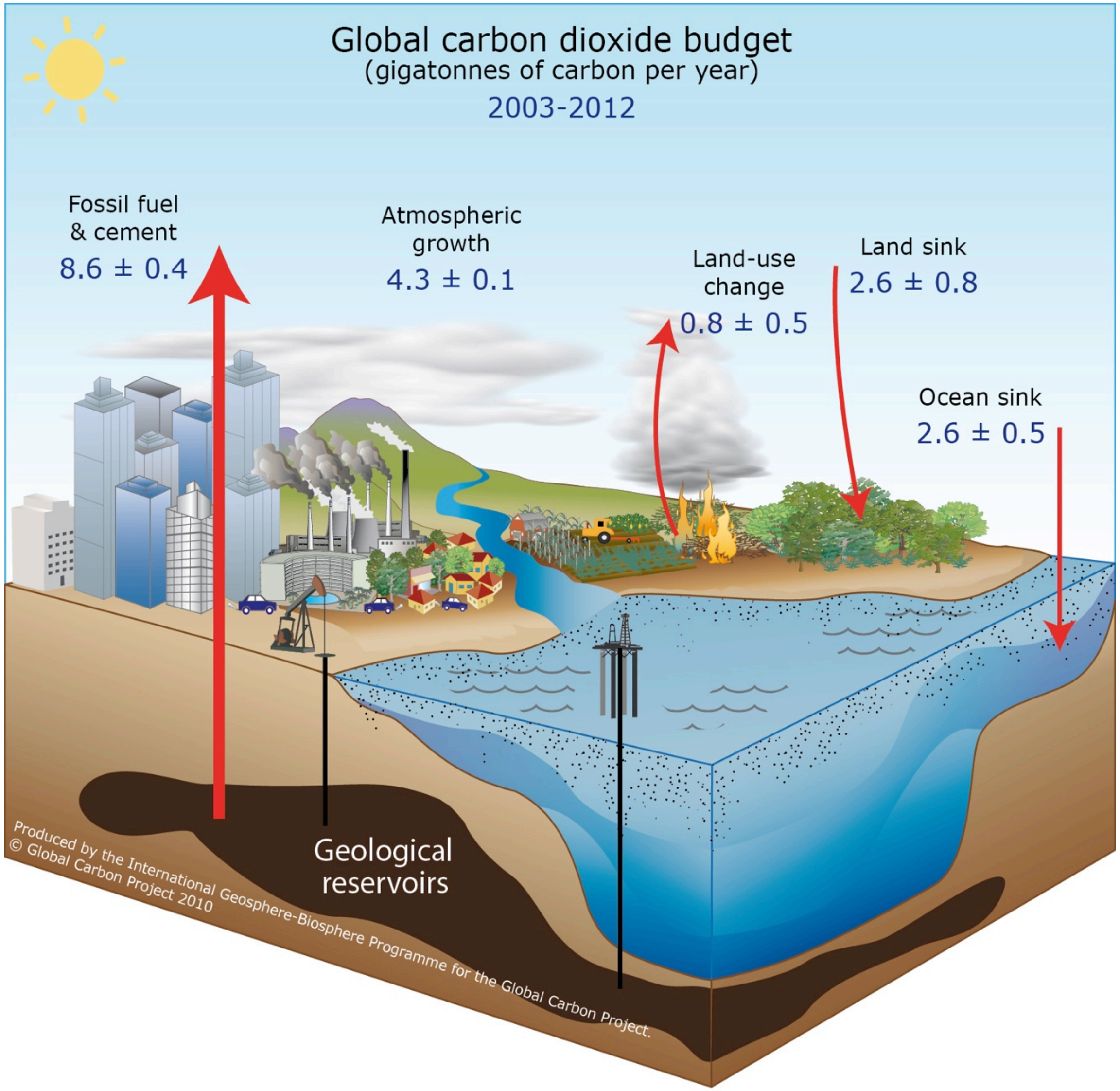
The Harvard Graduate School of Arts and Sciences (GSAS)

The Harvard Graduate Student Council (GSC)

The Harvard Biomedical Graduate Students Organization (BGSO)

The Harvard/MIT COOP

The Carbon Budget



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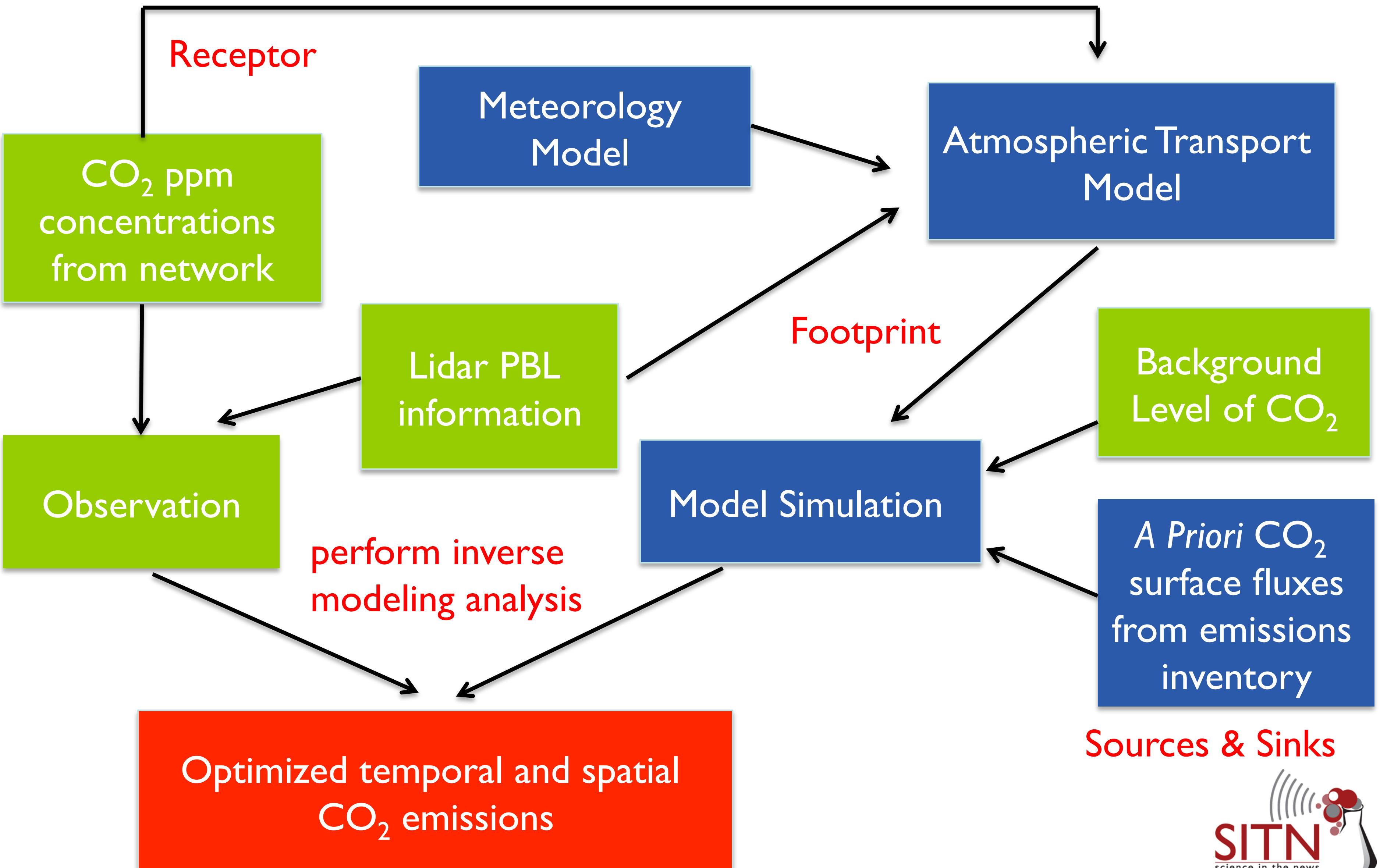
Modeling Framework



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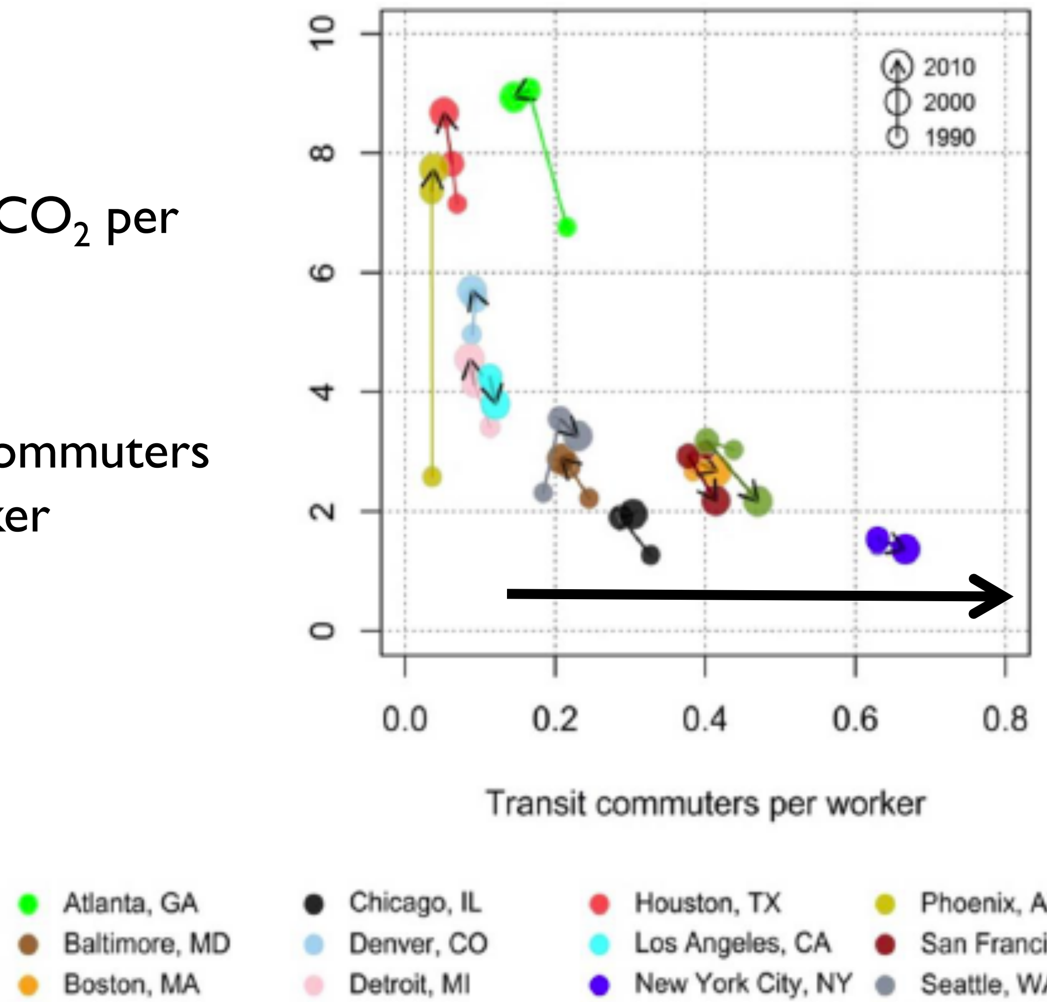
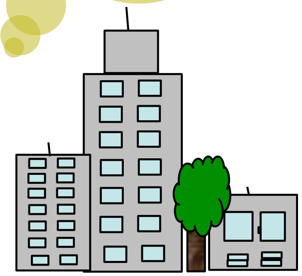
All cities are not created equally!

<u>y-axis:</u>
1 ton of CO_2 per person

<u>x-axis:</u>
Transit commuters per worker



+70% of energy-related carbon emissions [*Gurney et al., 2015*]

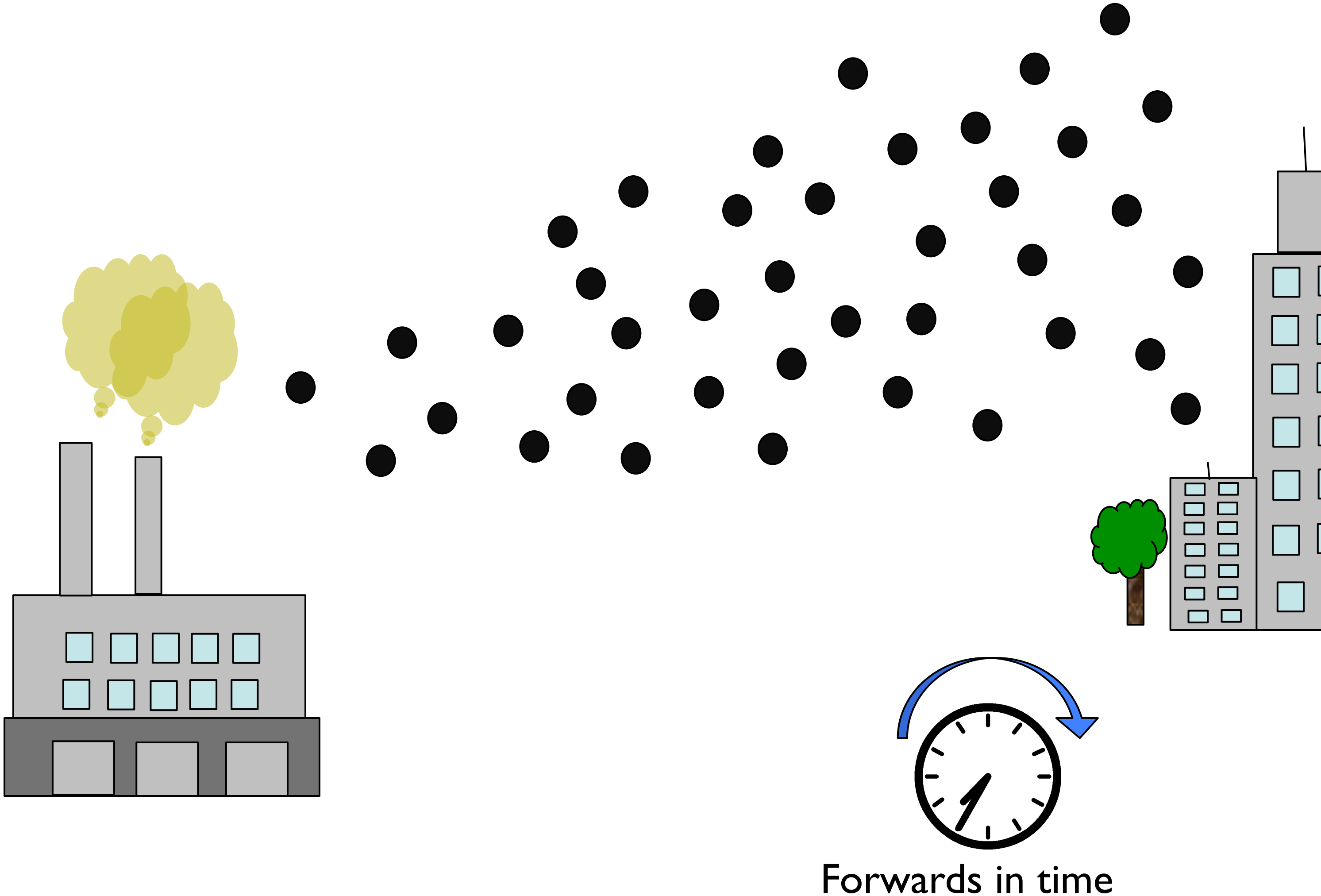


Source: Connor Gately, Boston University

Scattering and backscattering

- Atmospheric gases scatter the red/ orange colors at sunset
- Aerosols (suspended particles), haze, and fog, scatter more and that's why we see the grey/white colors in the background and in clouds
- Backscattering deflection of light particles at an angle of 180°

We get these products by using a transport model



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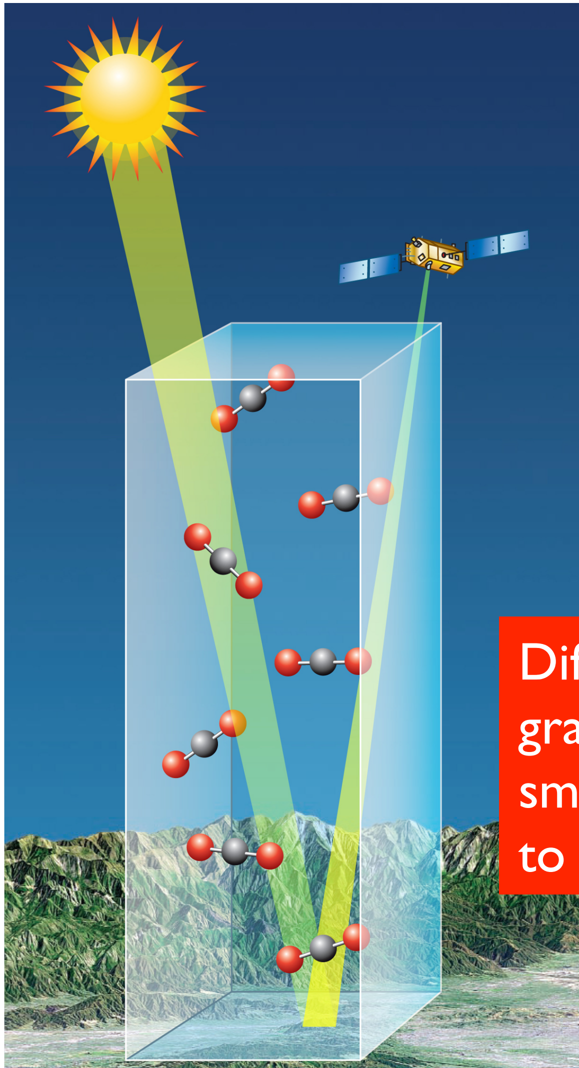
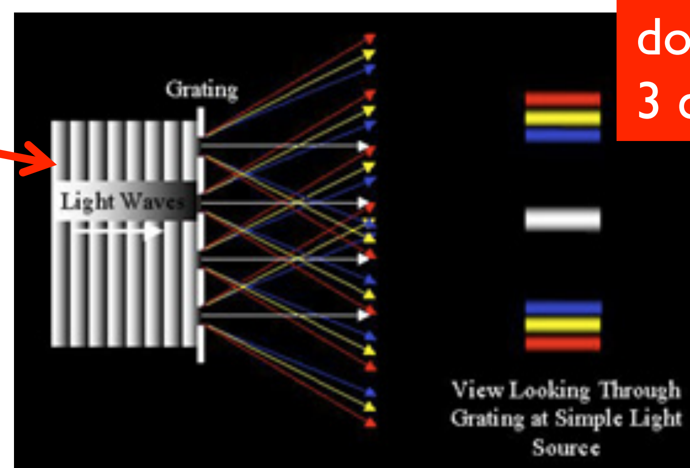
How does OCO-2 work?



Source: NASA's Jet Propulsion Laboratory

- Measures the intensity of light reflected from the sun on air volume containing air pollution W
- What makes OCO-2 different from instruments used on ground?
  - They can measure up to 17,500 different colors so any shift in light intensity provides higher precision of estimating CO2
  - CO2 absorbs light at specific colors

Diffraction grating with small grooves to spread light



Your camera does this using 3 colors!

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