On Sustainability as a Cyber-Physical-Social System

The XGEM Initiative Multiscale Integration of Methane Monitoring for Impact Characterization and Mitigation

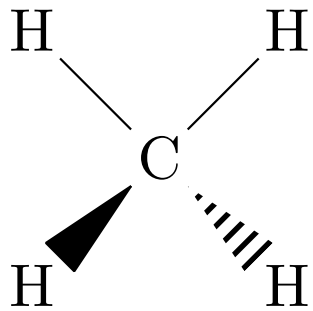
Wesley T. Honeycutt

Systems Realization Laboratory Conversations Series
University of Oklahoma

September 19th, 2021

Methane (CH_4) Basics

- Simplest aliphatic compound
- Colorless, odorless
- T_{bp}=161.5 °C
- Fuel source
  $CH_4 + 2\,O_2 \xrightarrow{\Delta} CO_2 + 2\,H_2O$;
  $\Delta H = -891\,\mathrm{kJ\,mol^{-1}}$
- Feedstock for many chemical processes



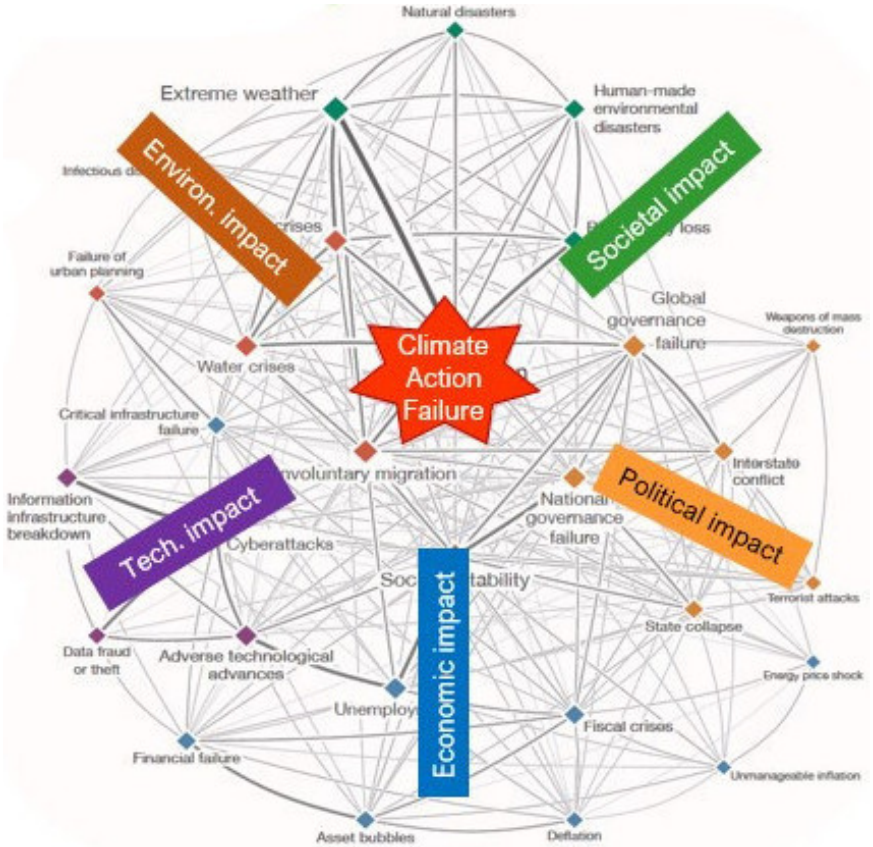
Emissions

- Naturally by abiotic geochemical processes
- Biotic output
  - Methanogens (bacteria, archaea)
  - Ruminants
  - Minor sources: termites, rice, many other vertebrates
- By-product of chemical syntheses
- Leakage

Greenhouse Gas

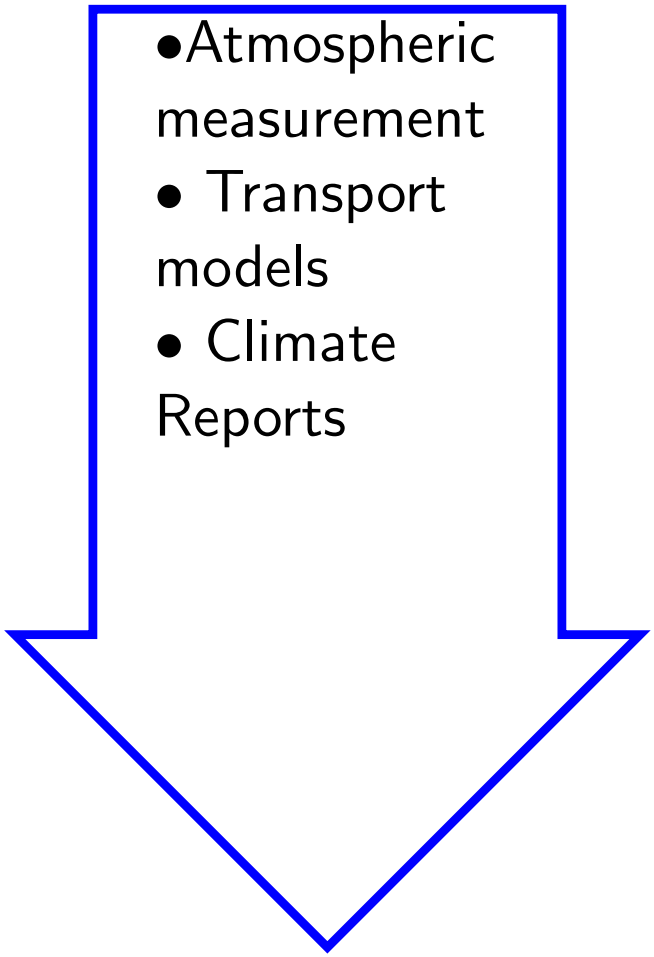
CH_4 is responsible for about 20% of radiative forcing.

The Web of Climate Action Failure



World Economic Forum Global Risks Interconnection Map, 2020

Top-Down and Bottom-Up



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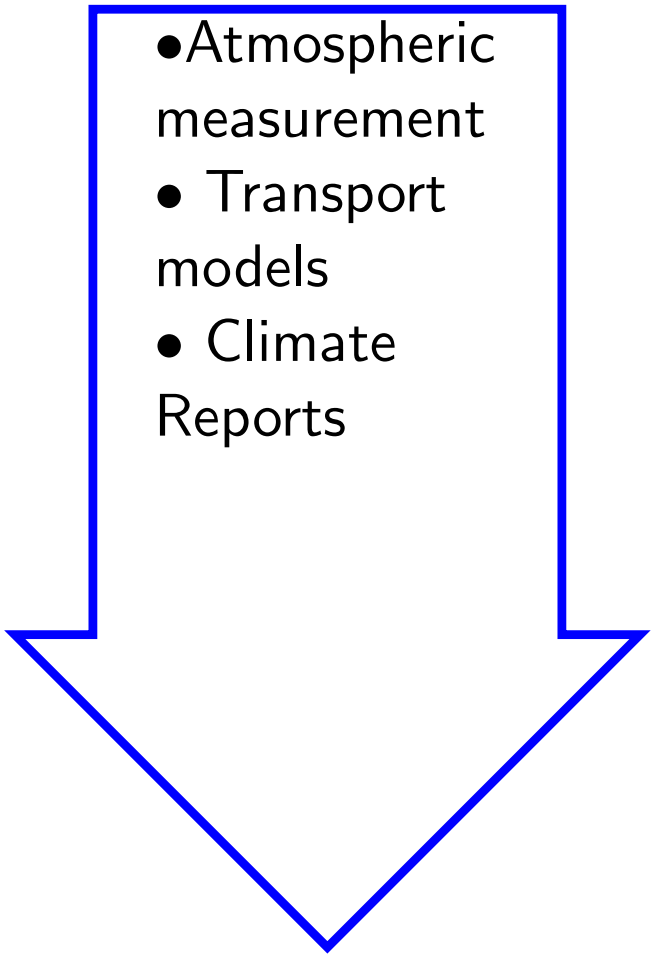
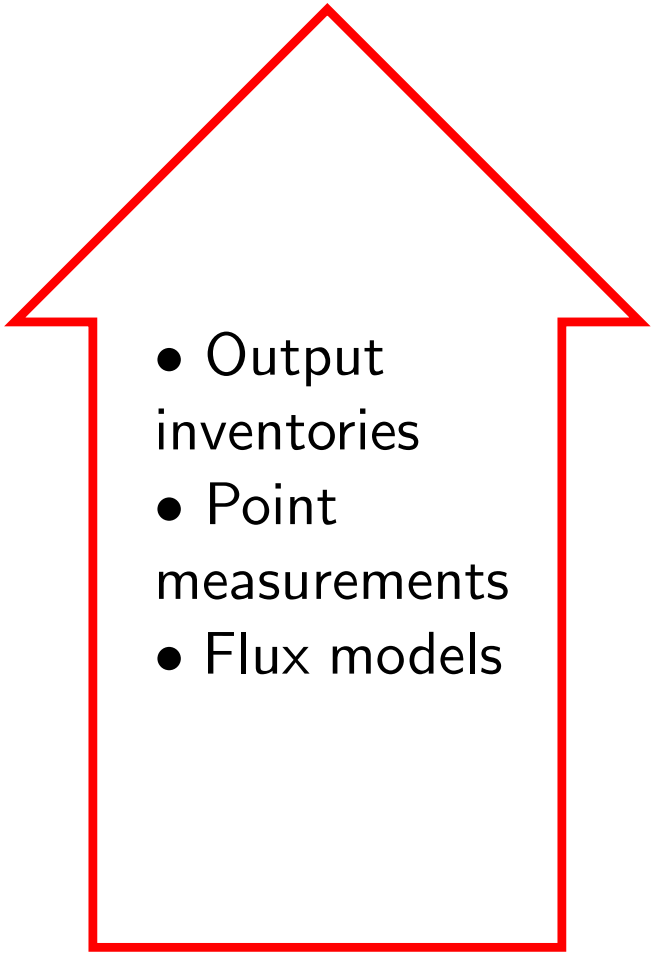
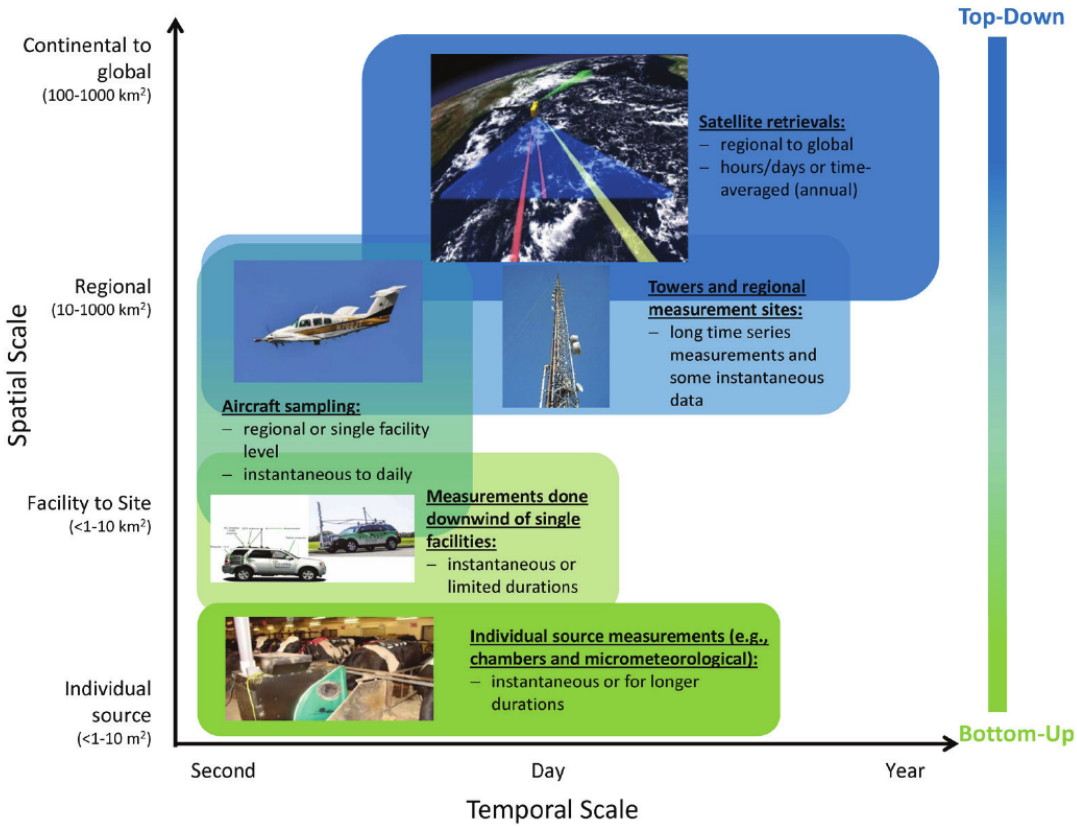


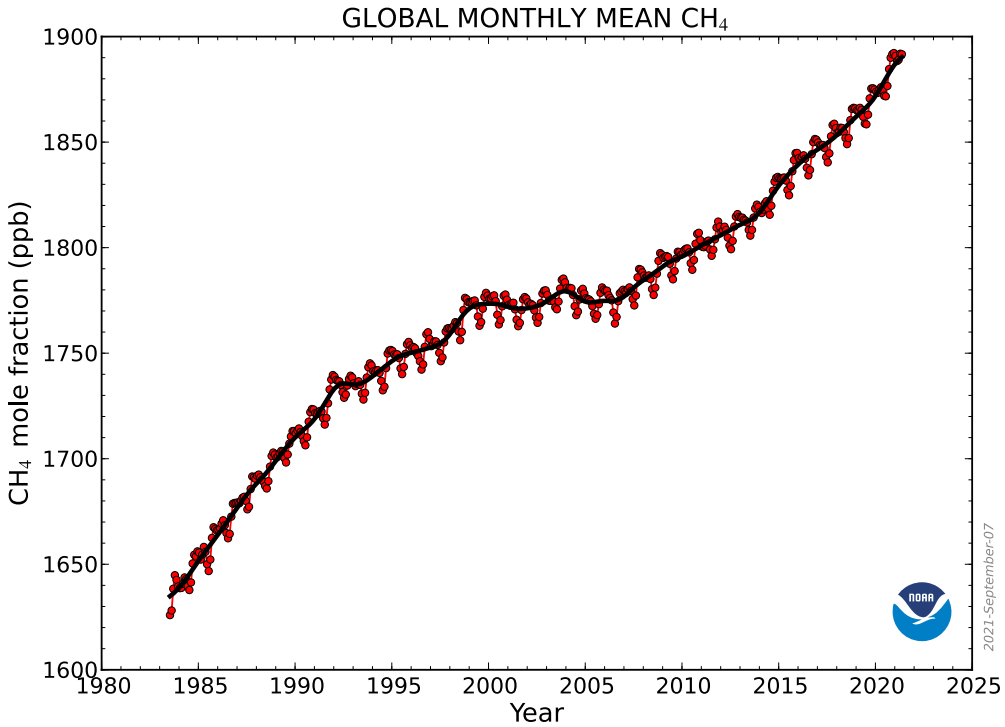


Spatio-temporal Scales

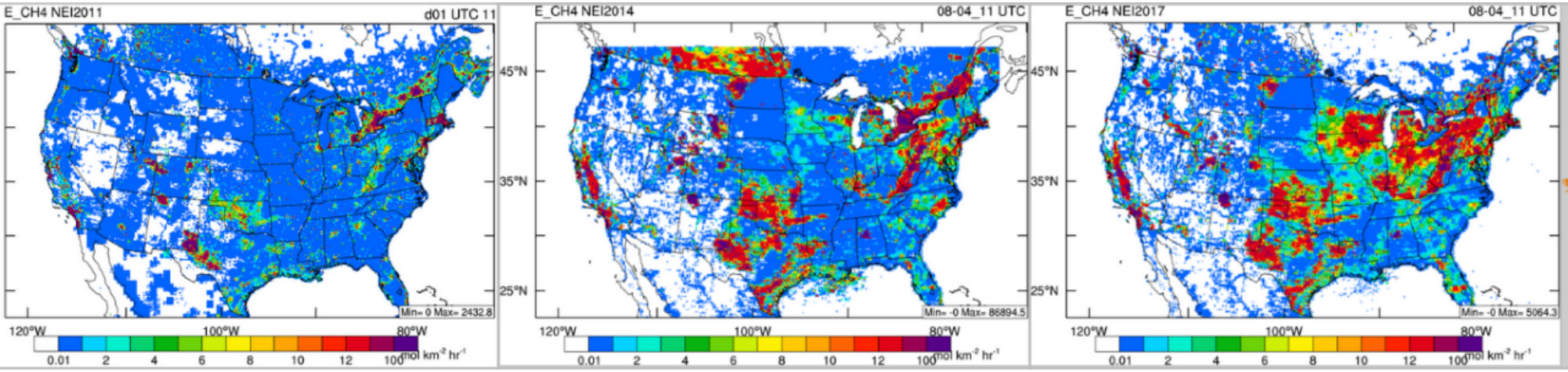


Top-Down: Global Levels

May 2021: 1891.6 ppb
May 2020: 1874.4 ppb
Last updated: September 07, 2021



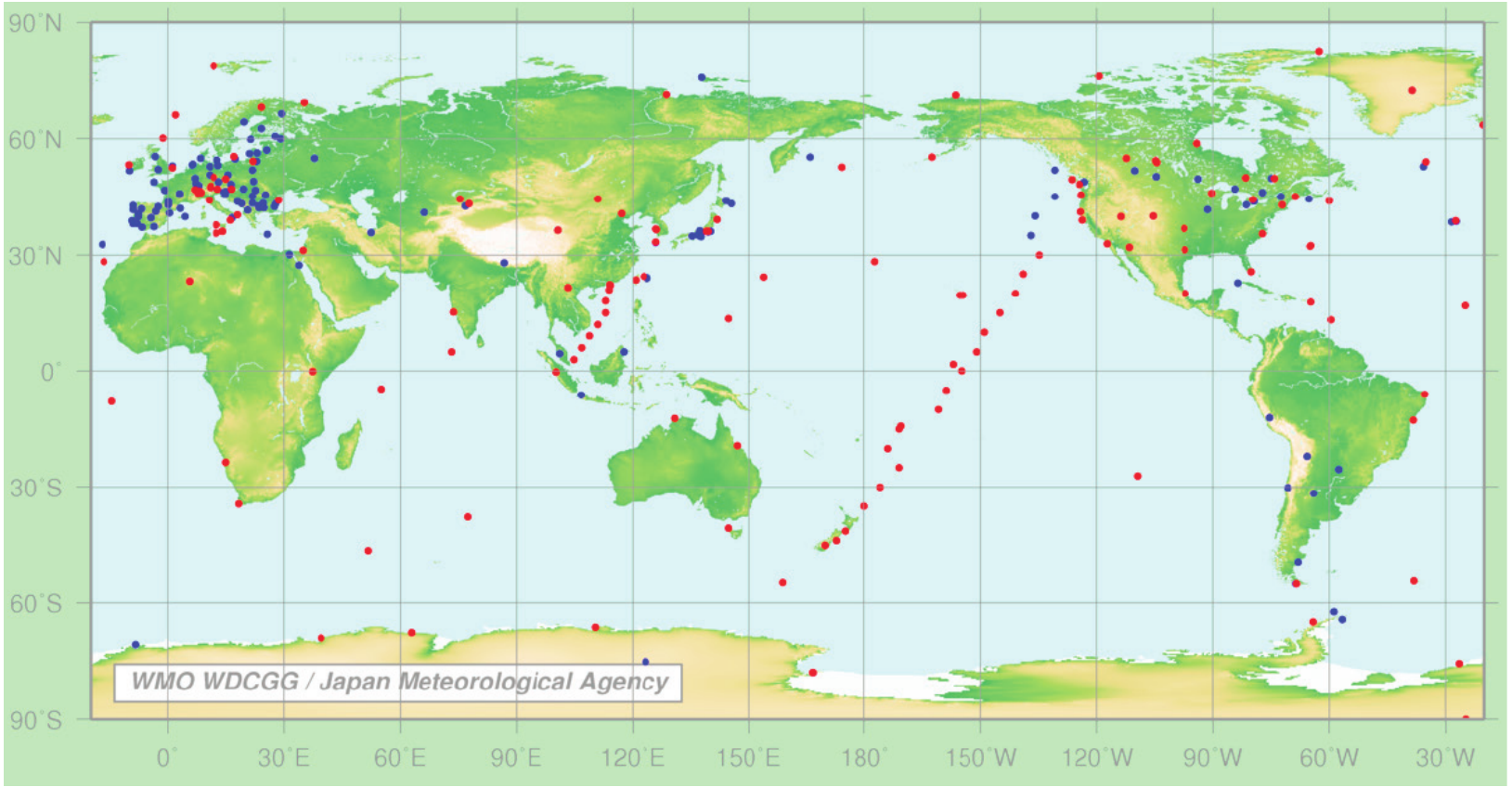
Top-Down: Atmospheric Predictive Models



Courtesy of Xiao-Ming Hu at OU CAPS

Does this match reality?

How do we measure this?



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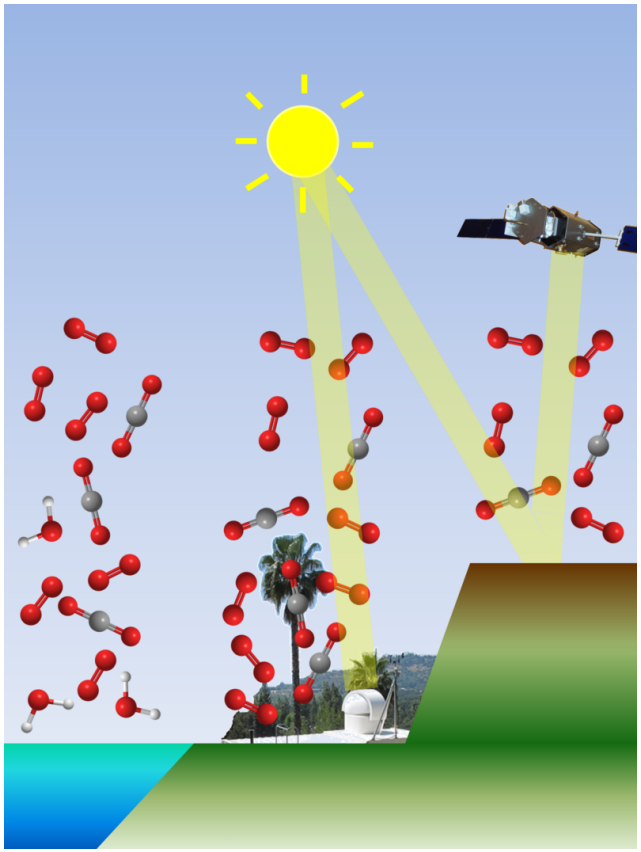

Graphic borrowed from Wikipedia

Covering Ground

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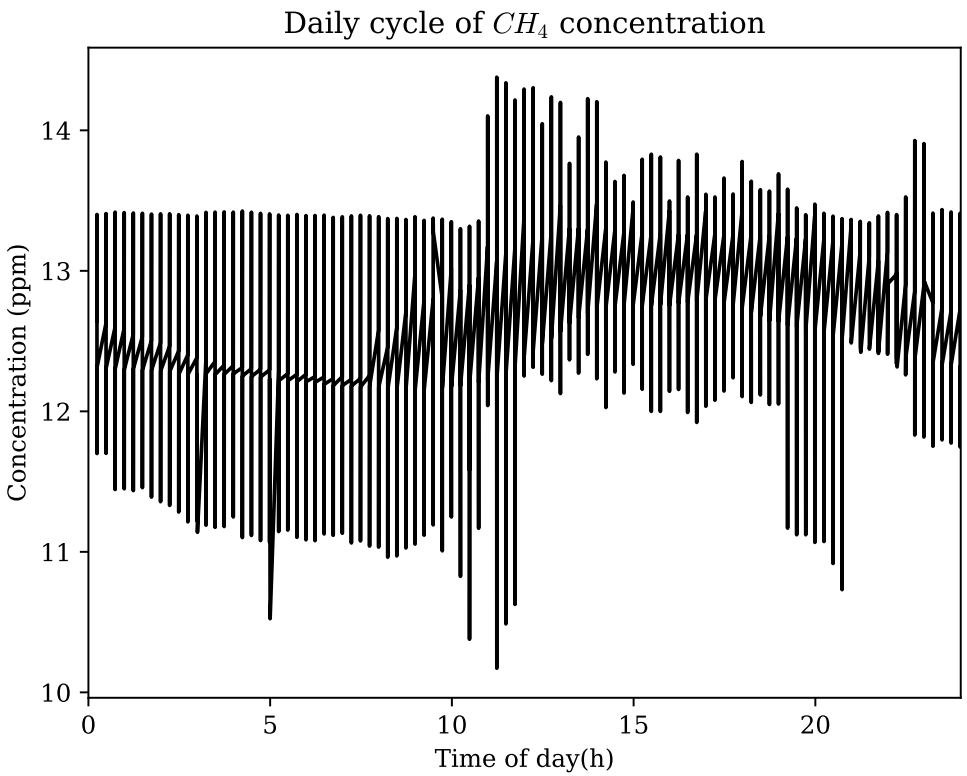

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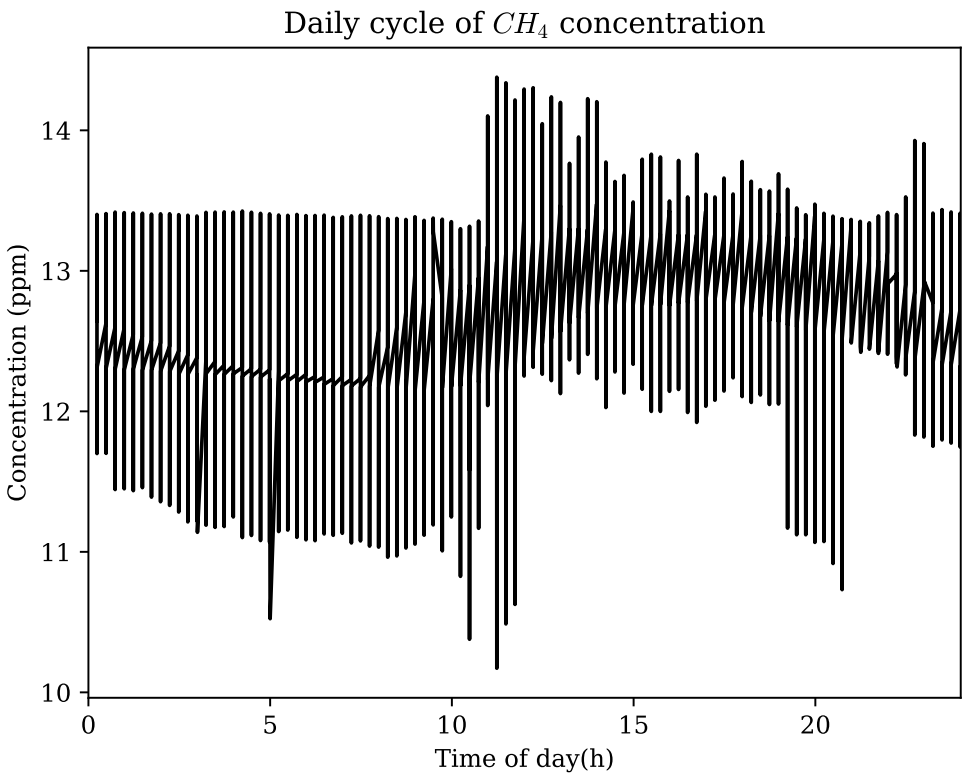
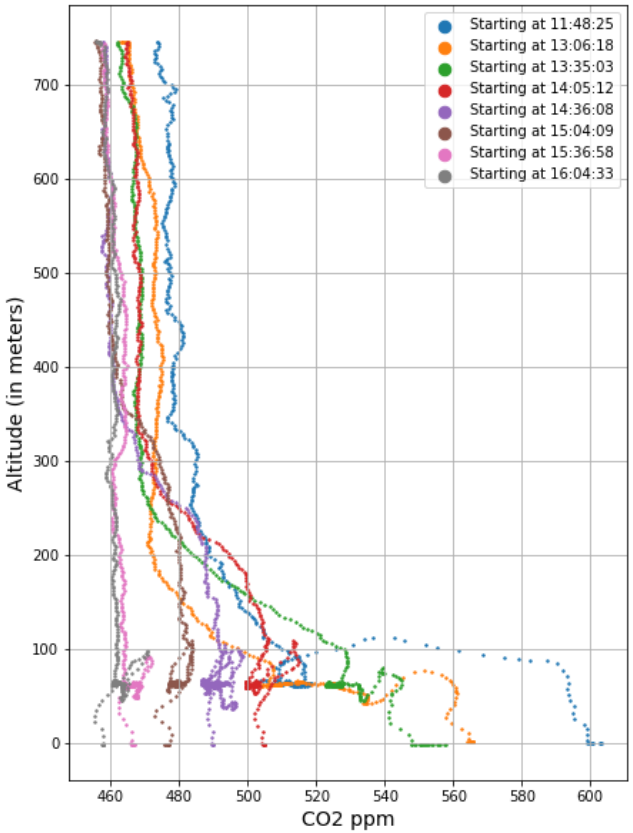
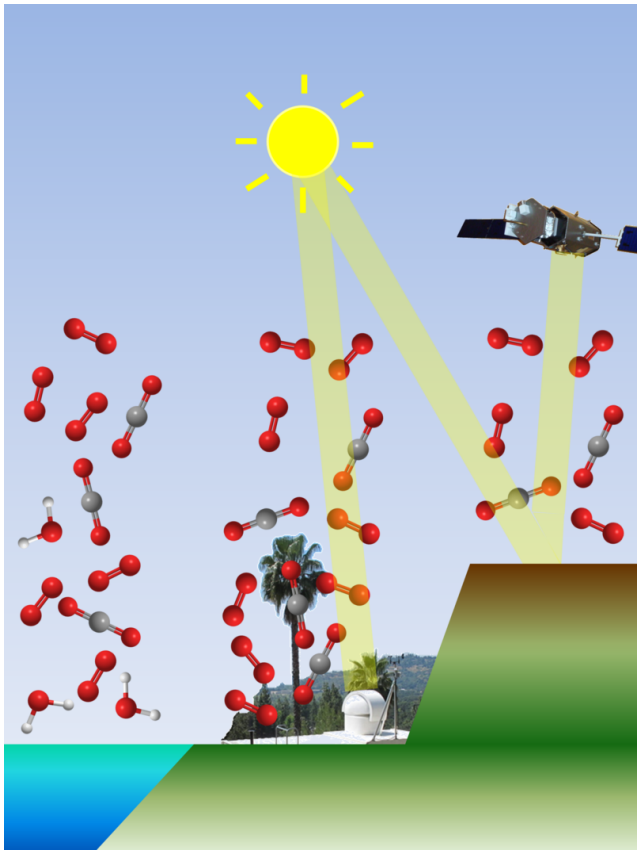


The Column Problem



Courtesy of Elizabeth Pillar-Little at OU CIMMS

Total Column Measurements Average Constituents



Graphic borrowed from Wikipedia

Let's just measure more columns!

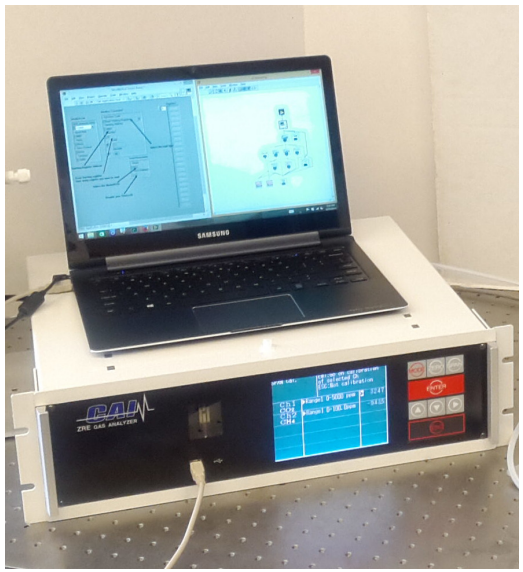
~~Let's just measure more columns!~~

CH_4 Sensor Technology is Terrible

The Duality of CH_4 Sensors

$C_{LOD} = 16.7$ppm

\$5



$C_{LOD} = 1$ppm

\$50,000

The Blind Men and the Elephant

The ~~Blind Men~~ Honeycutt House and the ~~Elephant~~ Cat

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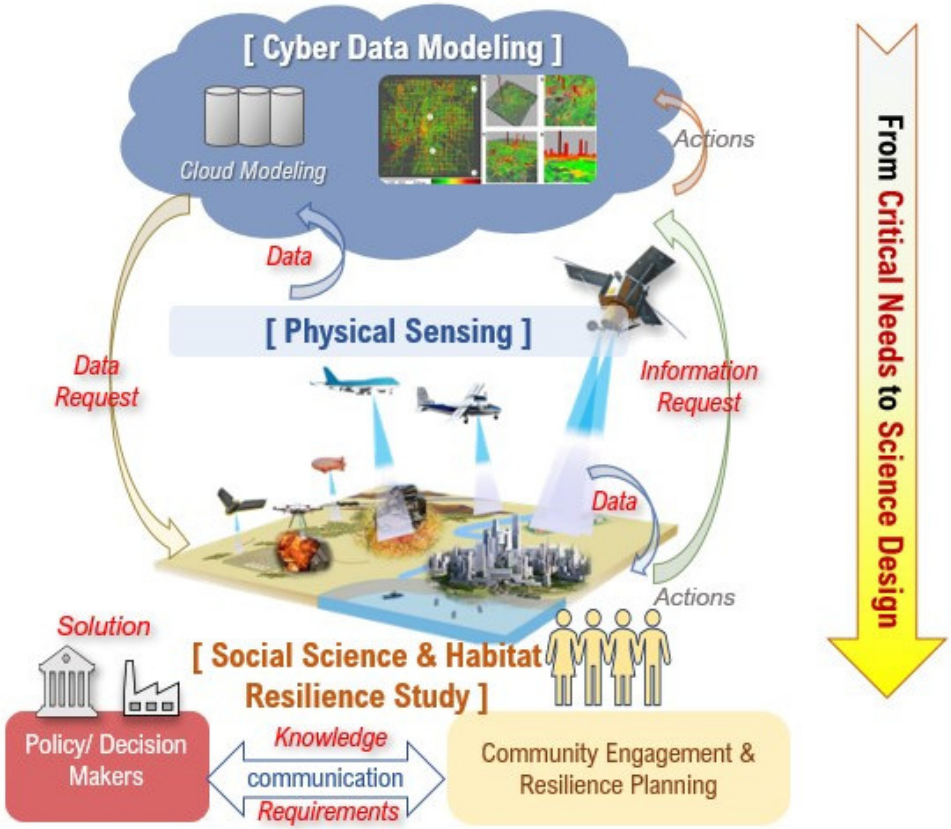
We Need an Integrated "Whole Cat" Approach



The Gift: Oklahoma Recovers from the Dustbowl

Michael Vance1: https://www.flickr.com/photos/miklvance/46249282192/in/photostream/

The Gift: Shale Gas Revolution

Health Impacts of CH_4

- Methane is biologically inert
  - 24-h and 90-d limit is 5,000 ppm (with no explanation)
  - Miners must evacuate at 2,500 ppm
- Yet it is a mild anesthetic
  - Mice die in 70% $CH_4 + O_2$ but not in $N_2 + O_2$
  - Animals show decreased locomotion in 50-90% CH_4
- Nearly all tests are acute exposure, not low-level chronic
- CH_4 rarely comes alone

National Research Council (US) Committee on Toxicology. Emergency and Continuous Exposure Limits for Selected Airborne Contaminants: Volume 1. Washington (DC): National Academies Press (US); 1984. METHANE. Available from: https://www.ncbi.nlm.nih.gov/books/NBK208285/

The Curse

W.carter; Wikimedia Commons

The Curse

Quiz: Who Bears this Curse?

How are waste gases distributed in the modern world?

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D Poor and marginalized communities are over-exposed due to planning decisions.

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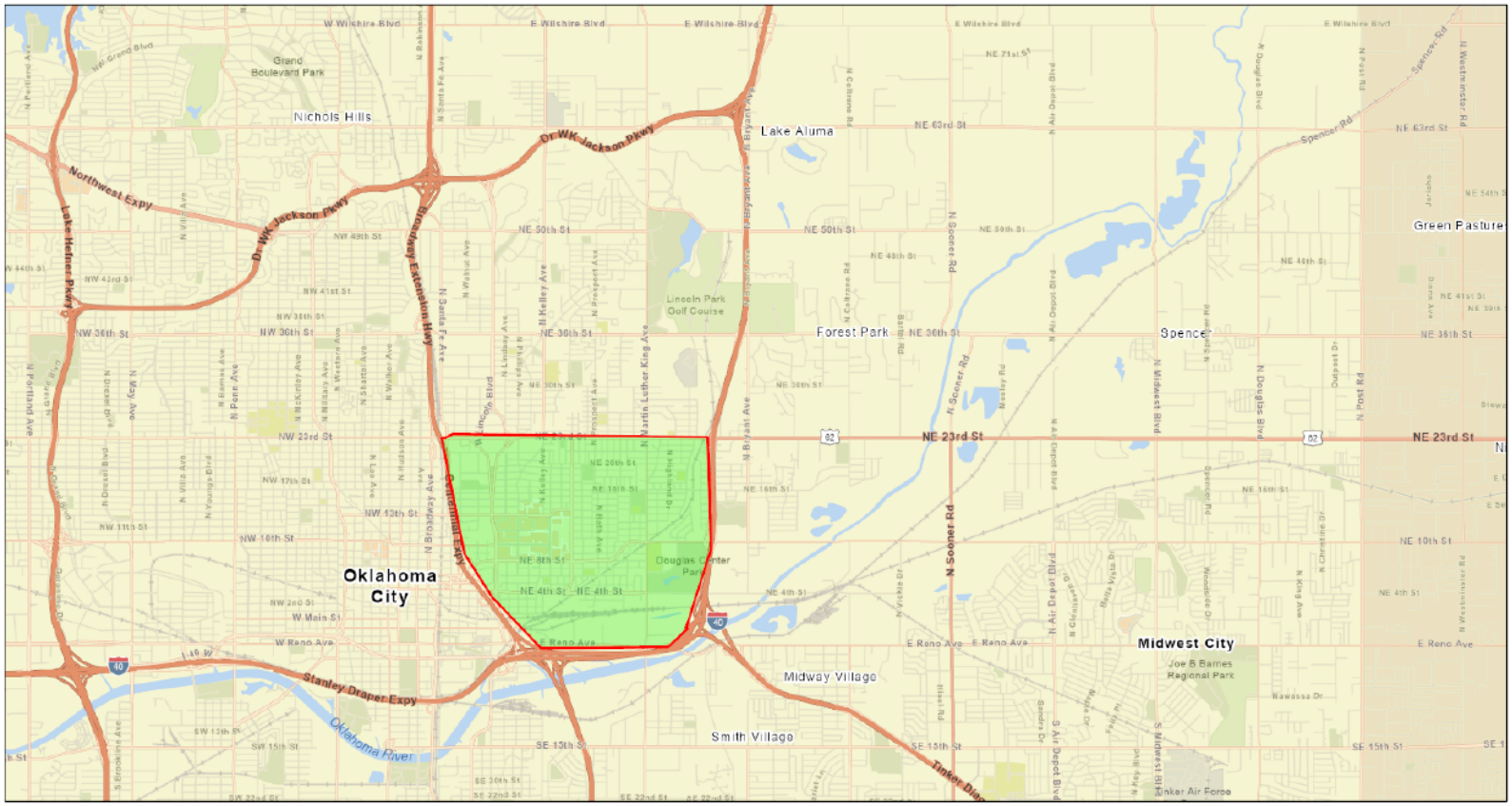
Environmental Justice Index for Oklahoma City



Courtesy of Lee Fithian, OU Gibbs College of Architecture

Environmental Justice Index for Oklahoma City

$$I_{EJ} = I_{indicator} \times (I_{block} - I_{US}) \times Pop_{block}$$

the User Specified Area, OKLAHOMA, EPA Region 6

Approximate Population: 9,385

Input Area (sq. miles): 4.58

SDAT Study Area

Selected Variables	State Percentile	EPA Region Percentile	USA Percentile
EJ Indexes			
EJ Index for PM2.5	83	59	72
EJ Index for Ozone	84	61	74
EJ Index for NATA* Diesel PM	91	69	77
EJ Index for NATA* Air Toxics Cancer Risk	84	60	73
EJ Index for NATA* Respiratory Hazard Index	86	63	75
EJ Index for Traffic Proximity and Volume	93	75	78
EJ Index for Lead Paint Indicator	92	87	86
EJ Index for Superfund Proximity	91	72	77
EJ Index for RMP Proximity	85	64	76
EJ Index for Hazardous Waste Proximity	91	82	78
EJ Index for Wastewater Discharge Indicator	81	62	78

What's near the 35-split South of 23rd?

- Concrete production facility
- Industrial freight companies
- Railroad depot for petrochemicals
- Oil storage tanks
- Oklahoma City Oil Field
- *Innovation District

Caleb Long; Wikimedia Commons

Innovation District

Oklahoma City Innovation District

Are we thinking this through?

How will changes to an environment impact the people that live and work there?

- Do we really want to put more people in a risky site?
- Are the designs proposed going to help or hinder?
- Did we consider how the new loads may exacerbate emission accumulation?
- Is the plan future-proof for a warming world?

How can we create the feedback loop?


BIG IDEA CHALLENGE
VICE PRESIDENT FOR RESEARCH AND PARTNERSHIPS
X-GEM: Enhancing Future Community Sustainability via Greenhouse Gas Emissions Monitoring
Corresponding PI: Binbin Weng (Electrical & Computer Engineering)
Theme PIs: Ming Xue (Meteorology), Wesley Honeycutt (Biological Survey), Lee Fithian (Architecture/Planning/Landscape), Edward Sankowski (Philosophy), Farrokh Mistree (Aerospace & Mechanical Engineering)
ECE
AME
PE
Biological Survey
Social Science
Political Science
City Planning
Geo-Carb
Meteorology
Geology
1

BIG IDEA CHALLENGE
VICE PRESIDENT FOR RESEARCH AND PARTNERSHIPS

X-GEM Team:

THEME 1: Collaborative Community Engagement | Lead: **Edward Sankowski**
Senior Personnel (SP): **Sara Mata; David Ferris; Anthony Levenda**

THEME 2: Habitat Design and Modeling | Lead: **Lee Fithian**
SP: **Wenwen Cheng; Meghan Wieters; Zahed Siddique; Nathan Snook;**

THEME 3: Sensing Data Assimilation and Modeling | Lead: **Ming Xue**
SP: **Xiaoming Hu; Sean Crowell; Xuguang Wang; Netra Regmi**

THEME 4: UAS Sensing and Deployment | Lead: **Wesley Honeycutt**
SP: **Elizabeth Pillar-Little; Wilson Merchan Merchan; Yingtao Liu**

THEME 5: Integrated Cyber-Physical-Social System for Decision Making | Lead: **Farrokh Mistree**
SP: **Janet K. Allen; Saeed Salehi; Christan Grant; David Ebert**

Specific Questions: Can we make a better sensor?

- Binbin Weng proposes an on-chip optical sensor with waveguides that would be inexpensive to produce.
- Wesley Honeycutt (me) proposes high surface area mesoporous adsorbent selective for CH_4.
- Wilson Merchan-Merchan proposes joining CH_4 sensing with particulate matter sensing.
- Yingtao Liu proposes using novel 3D printed devices to enhance collection.

Specific Questions: Can we sense more effectively?

- Liz Pillar-Little propose UAS sounding with better sensor technology.
- Wesley Honeycutt (me) proposes expansion of wide 2D sensor arrays.
- Xiao-Ming Hu and Ming Xue propose enhanced modeling with weather monitoring technology.
- Sean Crowell proposes enhanced satellite data collection techniques.

Specific Questions: Can we work better with humans?

- Ed Sankowski, Betty Harris, and Sara Mata propose listening to the effected populations.
- Anthony Levenda proposes working with planning initiatives at the state level.
- Lee Fithian proposes forced circulation of gas in urban canyons to ventilate emissions.
- Wenwen Cheng proposes designs to impact urban heat islands to enhance ventilation.

Specific Questions: Can we treat this as a CPSS?

Farrokh Mistree, Janet Allen,. . .
I suspect you can guess what they propose.

Contacts/Thanks

Honeycutt Household
Dr. Claire Curry
Gram
Briar

XGEM Co-PI's
Dr. Binbin Weng
Dr. Lee Fithian
Dr. Farrokh Mistree
Dr. Edward Sankowski
Dr. Ming Xue

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