Integrating Low-cost Sensor Systems and Networks to Enhance Air Quality Applications

GAW Report No. 293

Presented by Dr. Carl Malings

Morgan State University & NASA Goddard Space Flight Center

on behalf of the editors, authors, and contributors

WORLD METEOROLOGICAL ORGANIZATION

UN environment programme

IGAC

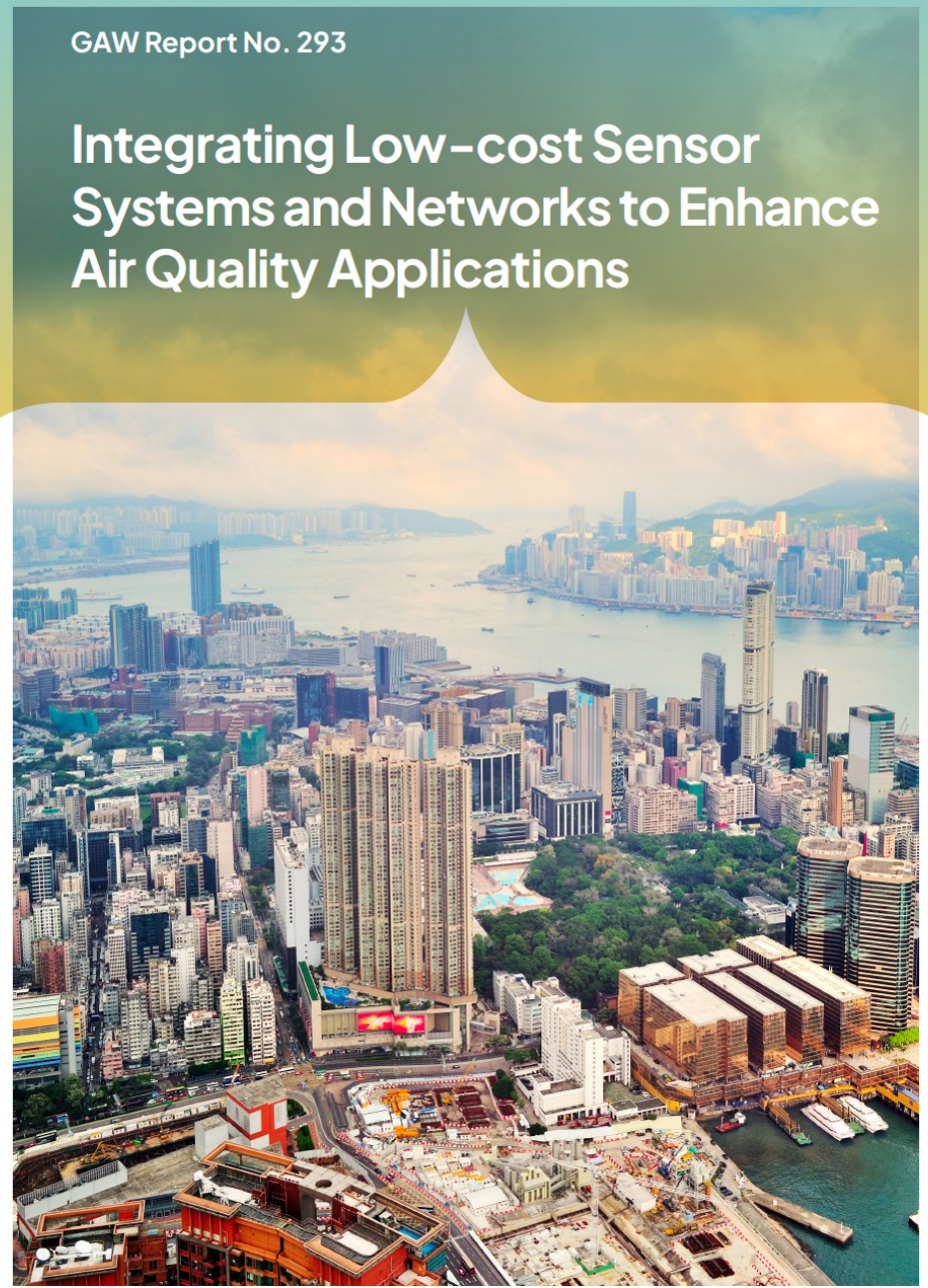
ICAS+CAMS-Net 2024

28 August 2024

Bengaluru, India

Executive Summary

- Despite challenges, low-cost sensors (LCS) represent a key tool for filling gaps in existing global and local air quality monitoring networks and contributing information for policy-relevant air quality products.
- Methods that use networks of LCS with tens to hundreds of sensors and combine LCS data with other information sources can provide a deeper insight into the causes and consequences of poor air quality.
- Known LCS data quality limitations should be explicitly accounted for in such application methods.
- LCS networks require physical and cyber infrastructure, technical capacity, community involvement, and institutional and financial support for effective sustained operations leading to positive societal impacts.



WORLD METEOROLOGICAL ORGANIZATION

UN environment programme

IGAC

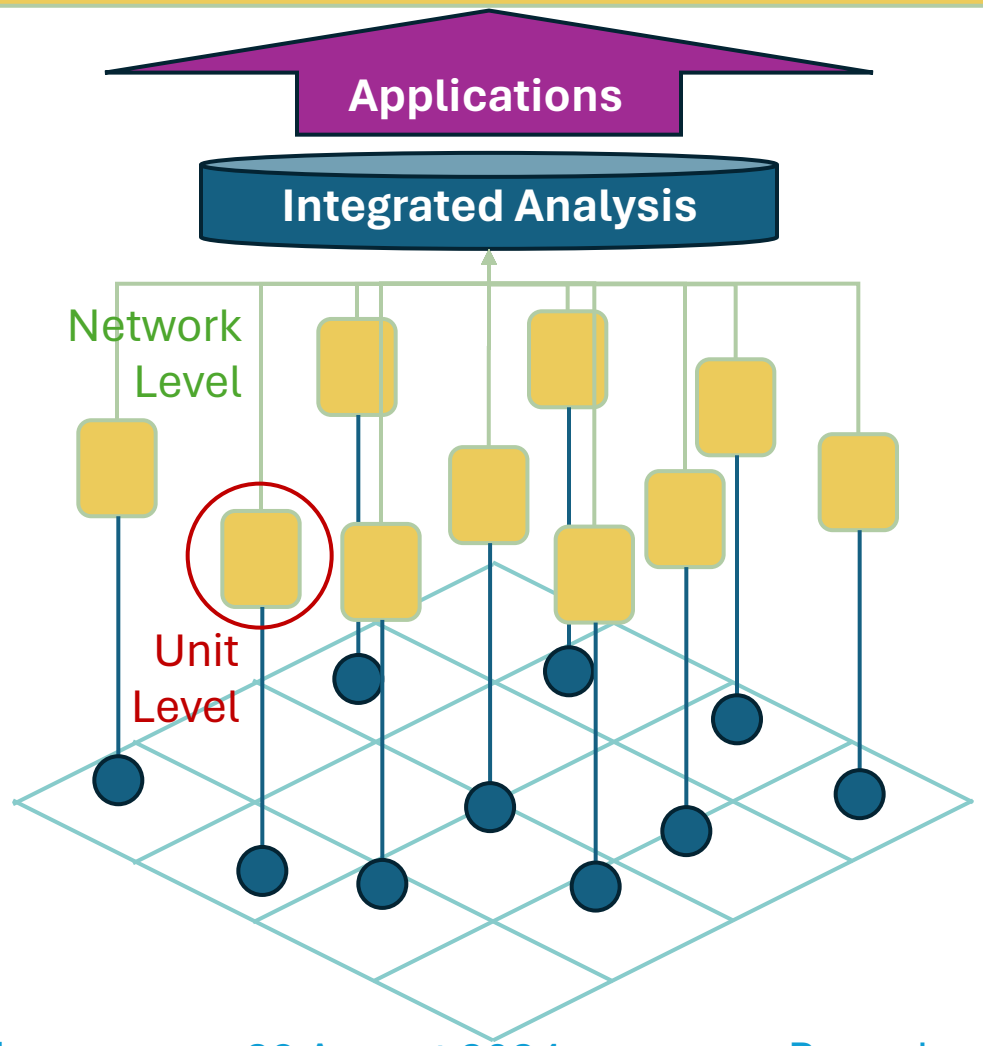
ICAS+CAMS-Net 2024

Authors

- International team of experts in low-cost air quality sensor applications.
  - ***Coordinating Lead Author:*** Carl Malings
  - ***Lead Authors:*** Kofi Amegah, Colleen Marciel F. Rosales, Sara Basart, Naomi Zimmerman, Sebastián Diez
  - ***Contributing Authors:*** Jan-Michael Archer, África Barreto, Jianzhao Bi, Russ Biggs, Nuria Castell, Priyanka deSouza, Tim Dye, Ryo Fujita, Michael R Giordano, Marisa E. Gonzalez, Christa Hasenkopf, Amirhossein Hassani, Collins Gameli Hodoli, Jelle Hofman, Nicolás Jorge Huneeus, Rohan Jayaratne, Jesse Kroll, Lorenzo Labrador, Radouane Leghrib, Robert C. Levy, Tomas Marques, Leila Droprinchinski Martins, Ethan McMahon, Mohammed Iqbal Mead, Luisa T. Molina, Anastasia Montgomery, Lidia Morawska, Zhi Ning, Richard Peltier, Olalekan Popoola, Néstor Rojas, Armando Retama, Philipp Schneider, Kerolyn Shairsingh, Joanna Strużewska, Beiming Tang, Martine Van Poppel, Daniel M. Westervelt, Yang Zhang, Mei Zheng
  - ***Editorial Board:*** Johannes Flemming, Jessica Seddon and R. Subramanian

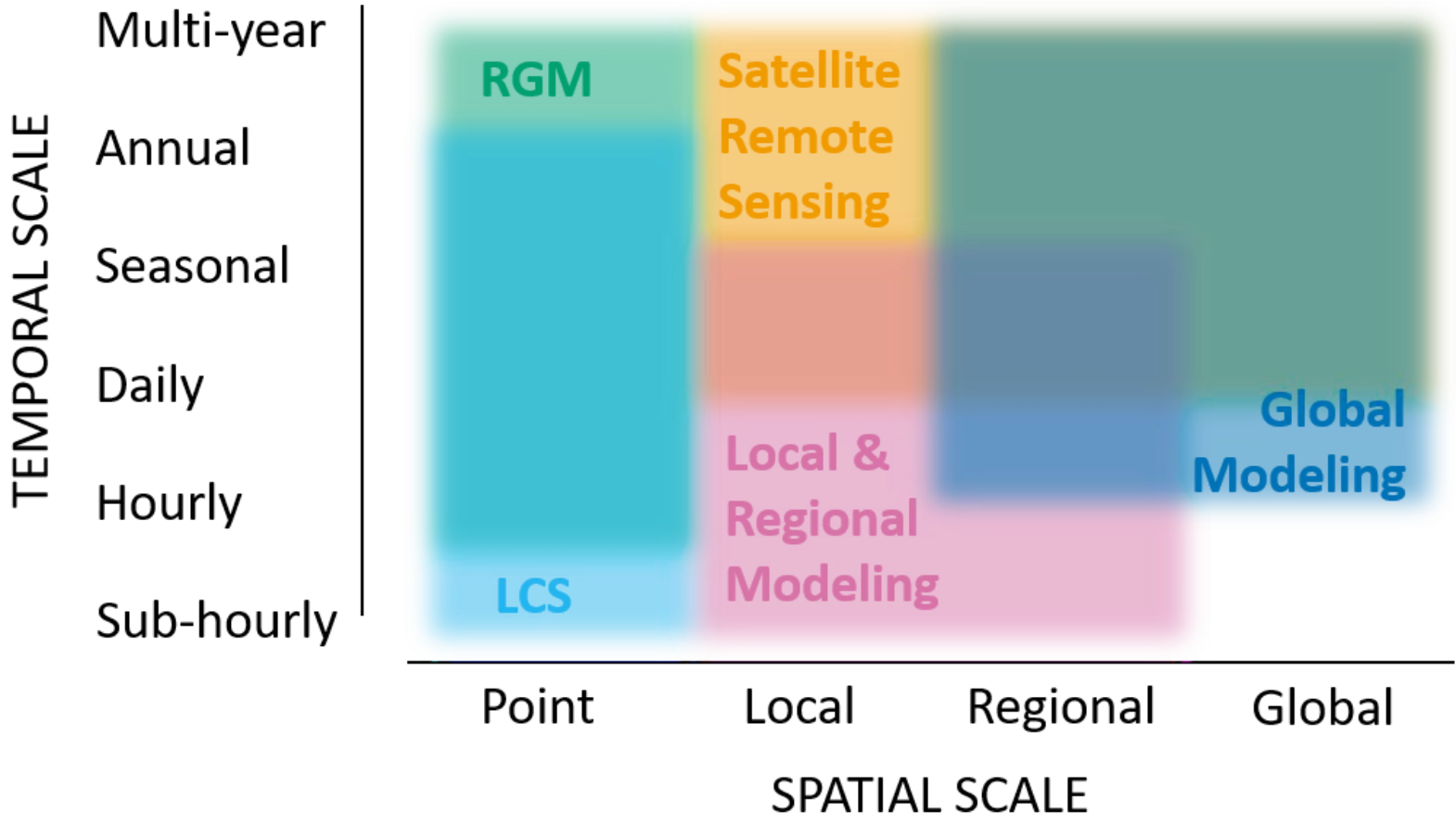
Chapter 1: Objectives of this Document

- Low-cost air quality sensor systems (LCS) are a key emerging class of technologies for expanding policy-relevant air quality analysis, including assessing levels of pollution, identifying sources, and producing forecasts.
- Previous WMO reports have dealt with LCS data quality on an individual ***unit level***, as in “An update on low-cost sensors for the measurement of atmospheric composition”, WMO-No. 1215, 2020.
- This report expands the scope, considering the use of LCS at a ***network level*** and ***integrated*** with other information sources to support various ***applications*** in air quality assessment and analysis.



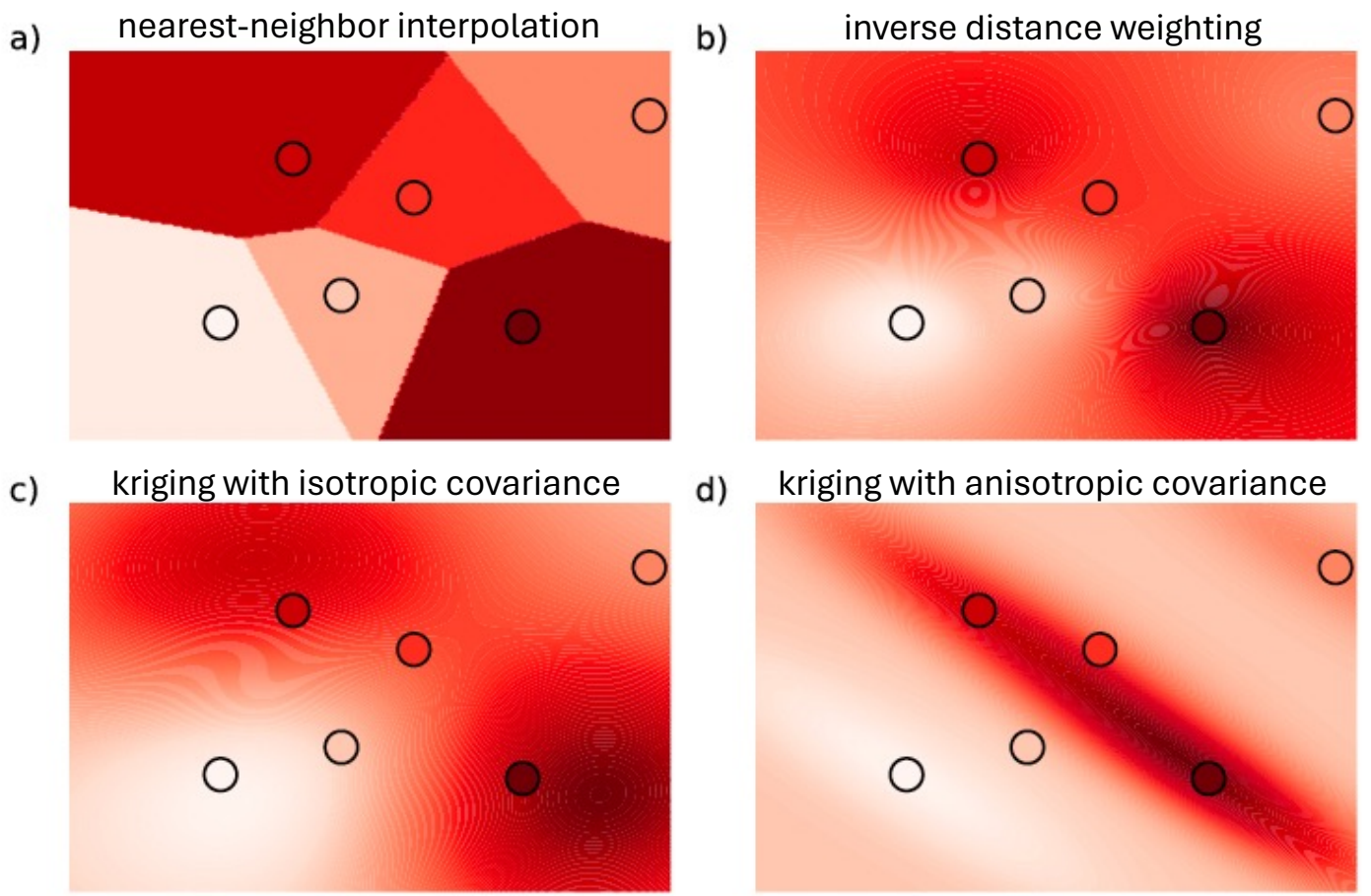
Chapter 2: Introduction

- LCS trade ***lower data quality*** and specificity for ***lower per-unit purchase cost***, allowing increased coverage.
- LCS occupy a ***niche*** within a larger system of air quality observation and modeling.
- Additional sources of air quality information include ***regulatory grade monitors*** (RGM), satellite ***remote sensing***, and local, regional, and global ***modeling***.



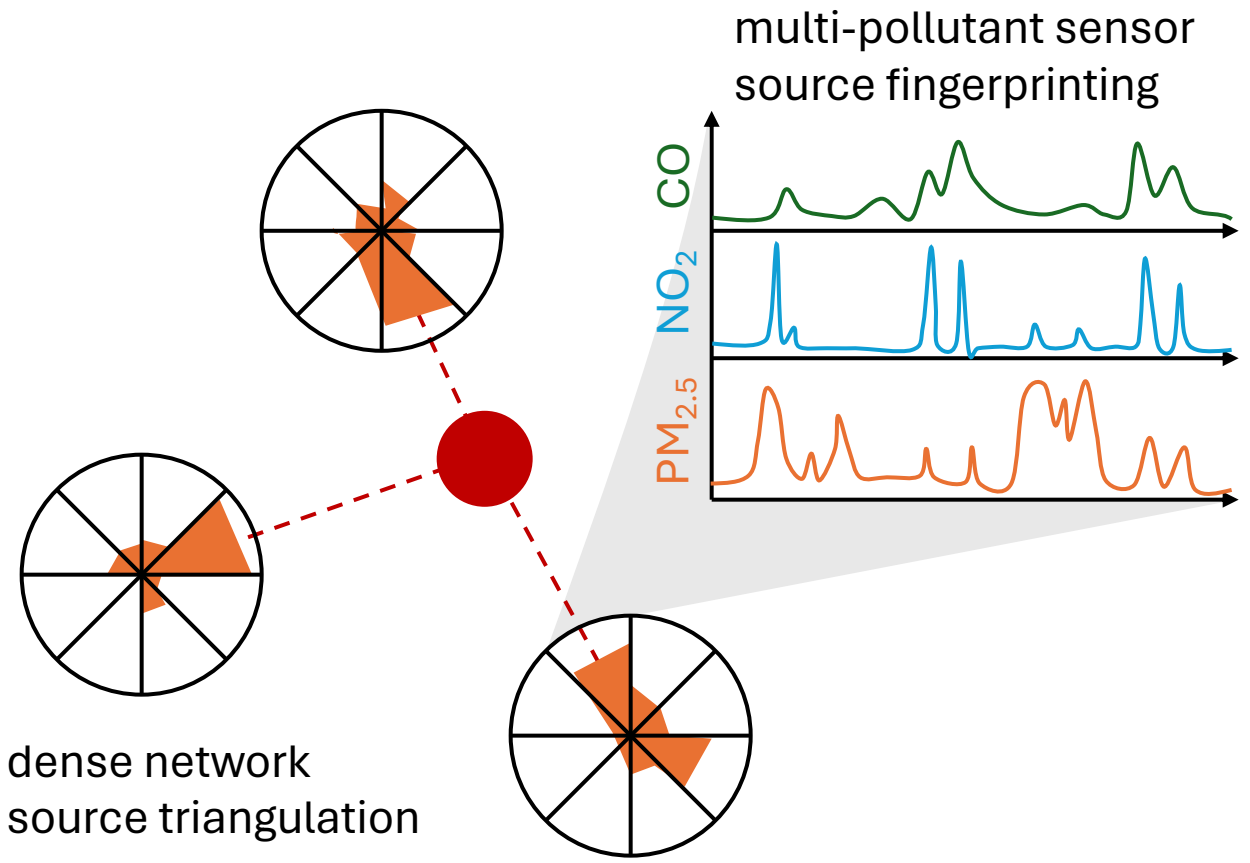
Chapter 3: Air Quality Reconstruction

- Simple ***interpolation*** techniques can be enhanced by the high spatial density facilitated by LCS.
- The power of ***statistical mapping*** via land use regression or fusion with satellite data can likewise be enhanced with more the diverse spatial coverage enabled by LCS.
- If LCS measurement uncertainties are accounted for, model ***bias correction*** and ***data assimilation*** are possible.



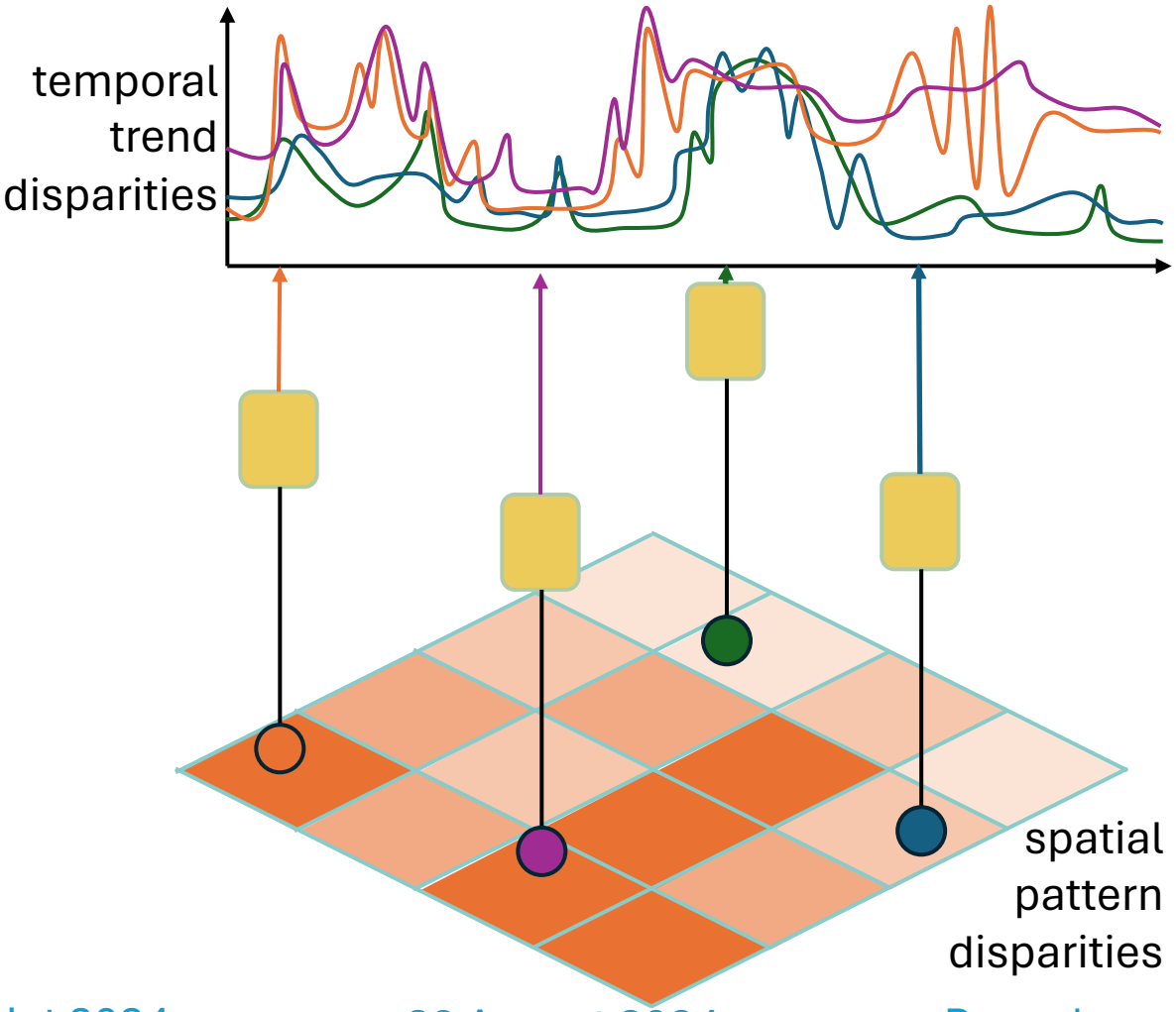
Chapter 4: Source Identification and Attribution

- Dense networks of LCS allow for source triangulation, especially when combined with wind data, and allow for detection of more ***local sources***.
- ***Multi-pollutant*** LCS can isolate the "fingerprints" of many sources; even qualitative data have been used to produce robust source attributions.
- LCS networks can cost-effectively ***track*** the outcomes of ***mitigation activities*** and pollution control policies at local scales.



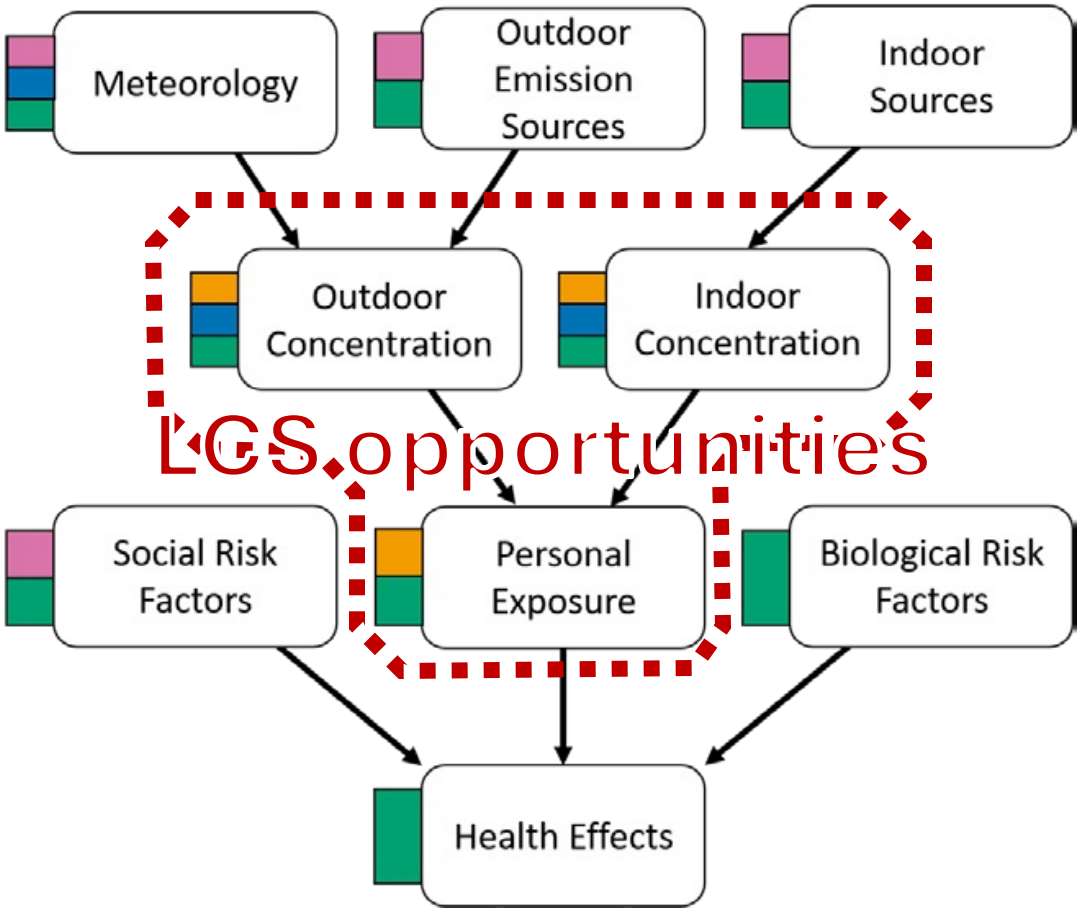
Chapter 5: Air Quality Patterns & Trends for Environmental Justice

- LCS can ***identify disparities*** in air pollutant exposure within and between communities, enabling environmental justice advocacy.
- This requires first demonstrating that the LCS have ***high inter-unit consistency*** (i.e., precision).
- ***Independent data sources*** (e.g., satellites) can corroborate disparities identified by LCS.
- ***Community involvement*** in LCS network design, deployment, data collection, and analysis can also support mitigation activities based on the data collected.



Chapter 6: Health Studies and Personal Exposure Monitoring

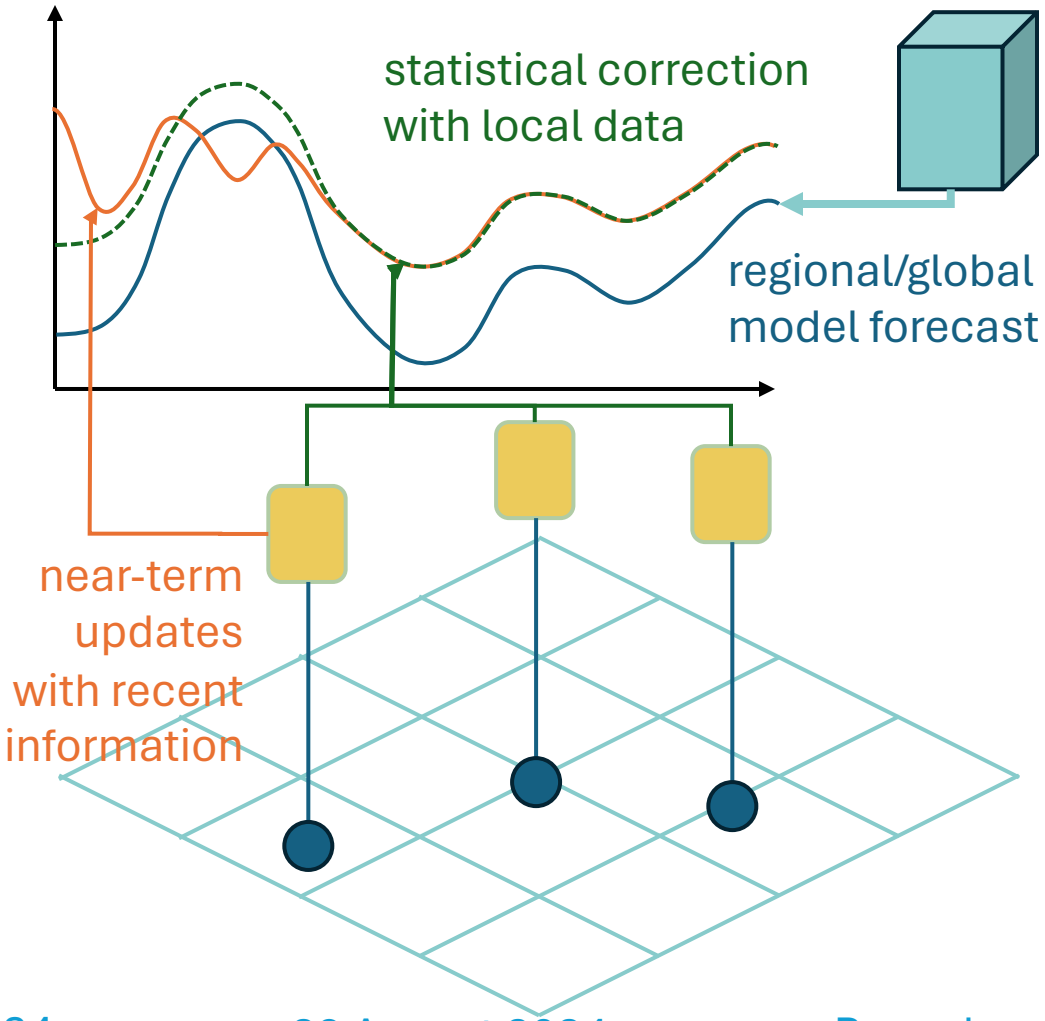
- ***Lack of in-situ data*** for epidemiological studies is a critical issue for low- and middle-income countries which LCS can begin to address.
- Quality-controlled LCS data combined with other information may support more spatially ***focused, short-term*** health studies.
- Qualitative insights from portable and wearable ***LCS can help individuals take action*** to reduce their personal exposure and risks.
- Ensuring the ***privacy*** of personally identifiable health data is needed in such applications.



Gardner-Frolick et al. (2022)

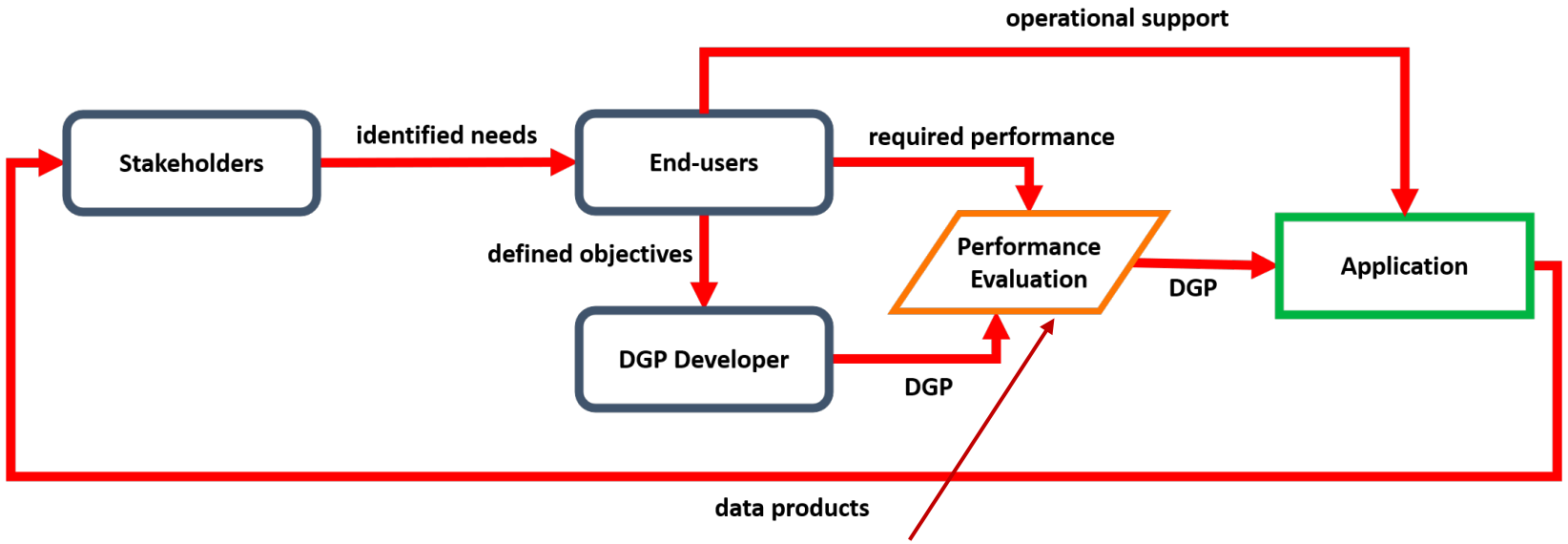
Chapter 7: Air Quality Forecasting

- LCS networks can improve ***short-term***, ***localized forecasting*** from regional or global air quality models, supporting advisories and warnings.
- Characterizing ***uncertainties*** in LCS data, including connections to meteorological factors, are key to their use in forecasting.
- LCS can provide data for ***evaluating model forecasts*** where RGM networks lack coverage.
- Latency, quality (i.e., accuracy and uncertainty) and ***spatial representativity*** of the LCS data are key factors for long-term performance forecast evaluations or near-real time validation.



Chapter 8: Data Quality and Disclosure

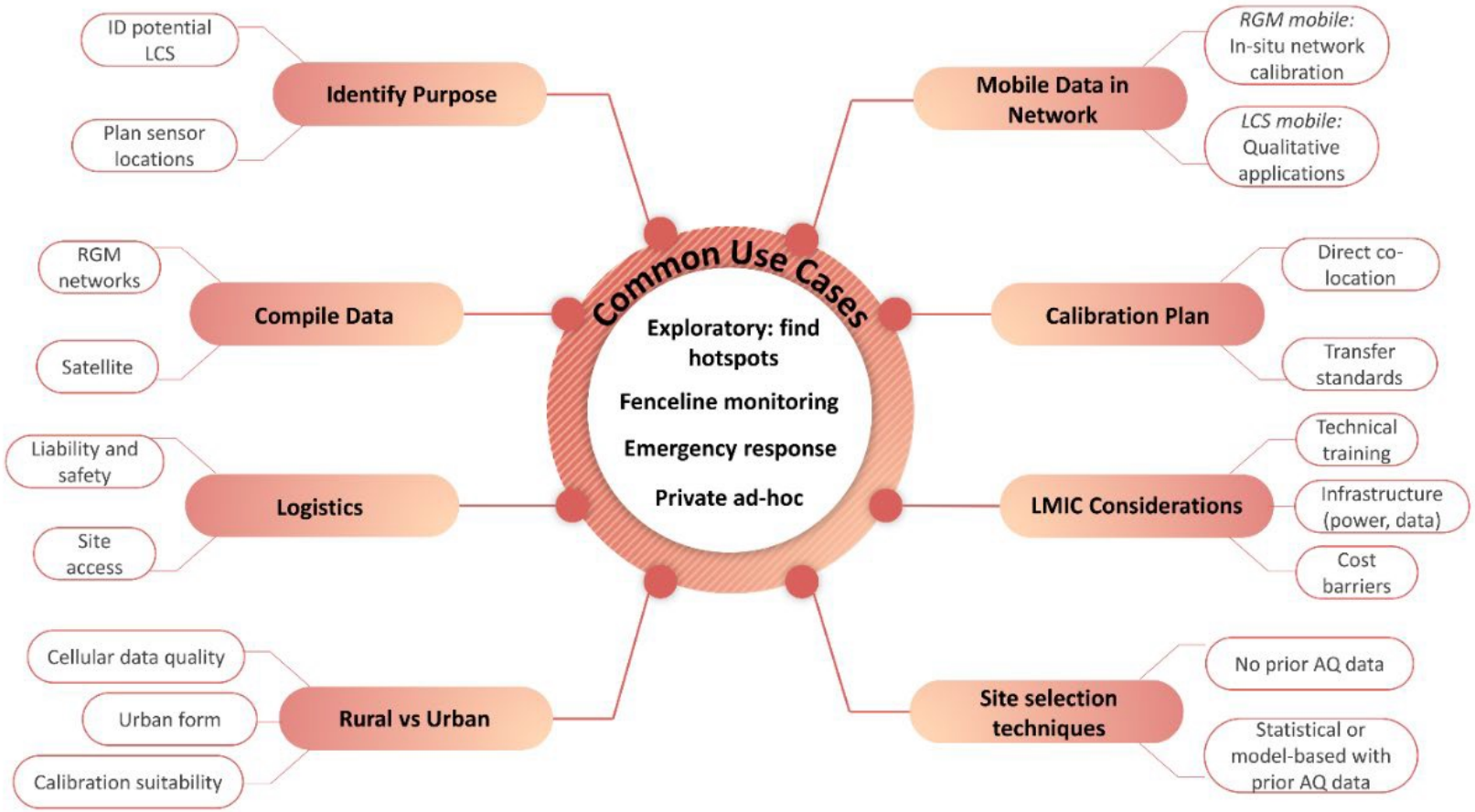
- LCS data should contribute to a data-generating process (DGP) that provides information for stakeholders to ***make air quality management decisions***.
- LCS data and DGP output evaluations should ***mimic the intended use case*** as closely as possible.
- ***Well-defined***, ***transparently reported*** methods and metrics should be applied for data quality evaluation.



LCS performance should be evaluated for its intended use-case, compared to baseline methods for the use-case not using the LCS data

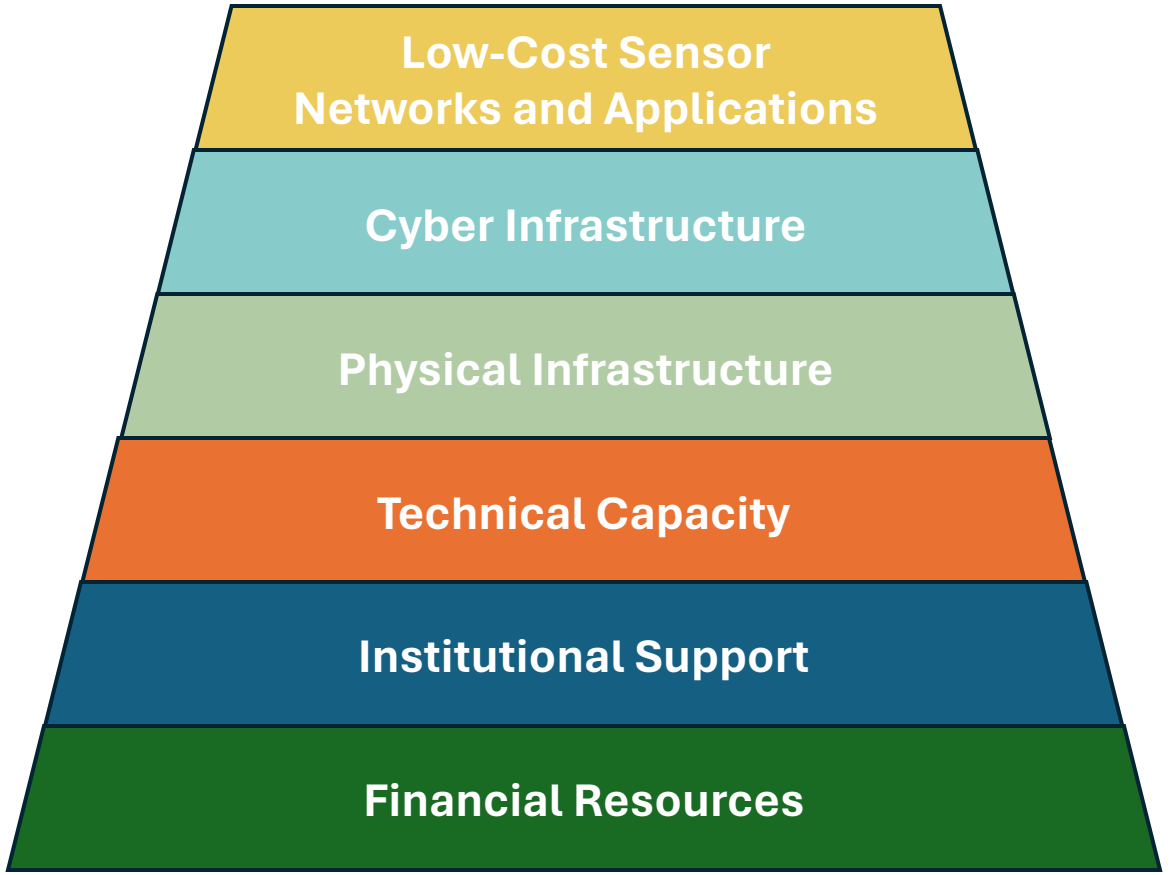
Chapter 9: Air Quality Monitoring Network Design

- Air quality monitoring network design should be guided by the ***intended use*** of the data and its role in making air quality management decisions.
- LCS can support ***exploratory*** analysis, network ***expansion*** planning, ***supplemental*** monitoring, and ***emergency*** response deployments.
- LCS are ***one of many tools*** which can contribute to a monitoring network strategy.



Chapter 10: AQ Monitoring Network Operations: Infrastructure Needs

- **Physical Infrastructure**
  - Equipment and spare parts
  - Suitable siting for sensors
  - Power and communications
- **Cyber Infrastructure**
  - Data storage and processing
  - Common formats and standards
  - Accessibility and interoperability
- **Technical Capacity**
  - LCS operator and network manager training
  - Sharing of best practices and guidance
  - Public outreach and awareness
- **Financial and Institutional Support**
  - Sustained funding sources
  - Community involvement
  - A pathway from data to action



Chapter 11: Best Practices for Integrating Low-Cost Sensor Systems

- LCS can be useful tools for acquiring air quality pattern and trend information.
- In regions lacking air quality RGM, LCS can provide the first insight into local air quality, guiding further investigations and prioritizing mitigation strategies.
- In regions with existing RGM, LCS can supplement these with local near-real time data.
- Assessing LCS performance in the target environment via RGM co-location is recommended wherever possible to better support quantitative applications of LCS data.
- When this performance is appropriately accounted for, LCS networks have tremendous potential to enhance air quality reconstruction, forecasting, source identification, and health and environmental justice applications.
- Sustained and attainable funding is needed to support LCS network design, deployment, management, data storage and analysis, and translating LCS data into insight and action.

S A 1 2 3 4 5 6 7 8 9 10 11 C

Thank you!

Questions?

carl.a.malings@nasa.gov

We would like to acknowledge the expertise and efforts of the many authors, editors, and contributors who made this report possible.

Read the Report:

https://library.wmo.int/idurl/4/68924

WORLD METEOROLOGICAL ORGANIZATION

UN environment programme

IGAC INTERNATIONAL GLOBAL ATMOSPHERIC CHEMISTRY