National Aeronautics and Space Administration

Air Sensors as Input to an Air Quality Data Fusion System

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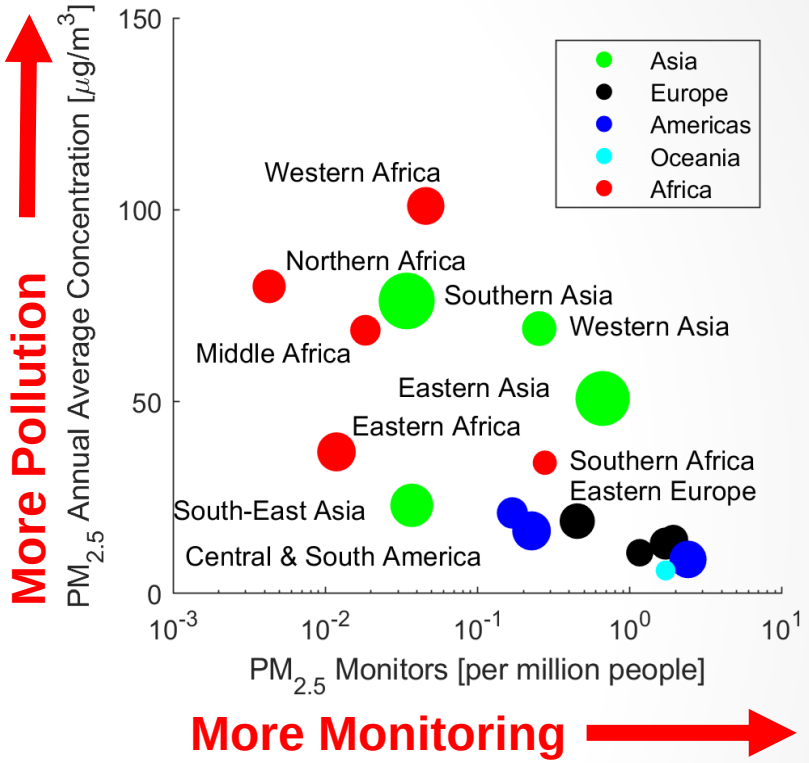
Regulatory & Reference Monitors

air quality monitoring trailer of the Houston Health Department



Pros

- Well established methods with known accuracy
- Trusted for science & regulatory applications

Cons

- Expensive to deploy and operate
- Relatively few monitors deployed
- Concerns about representativity of monitoring

Source: Malings et al. (2020) "Application of low-cost fine PM monitors to convert satellite AOD to surface concentrations in North America and Africa" *Atmos. Meas. Tech.*

Low-Cost Sensors

PurpleAir: $PM_{2.5}$, T, RH

Clarity Node S: for $PM_{2.5}$, NOx, T, RH

SENSIT RAMP: $PM_{2.5}$, CO, NOx, O_3, SO_2, T, RH

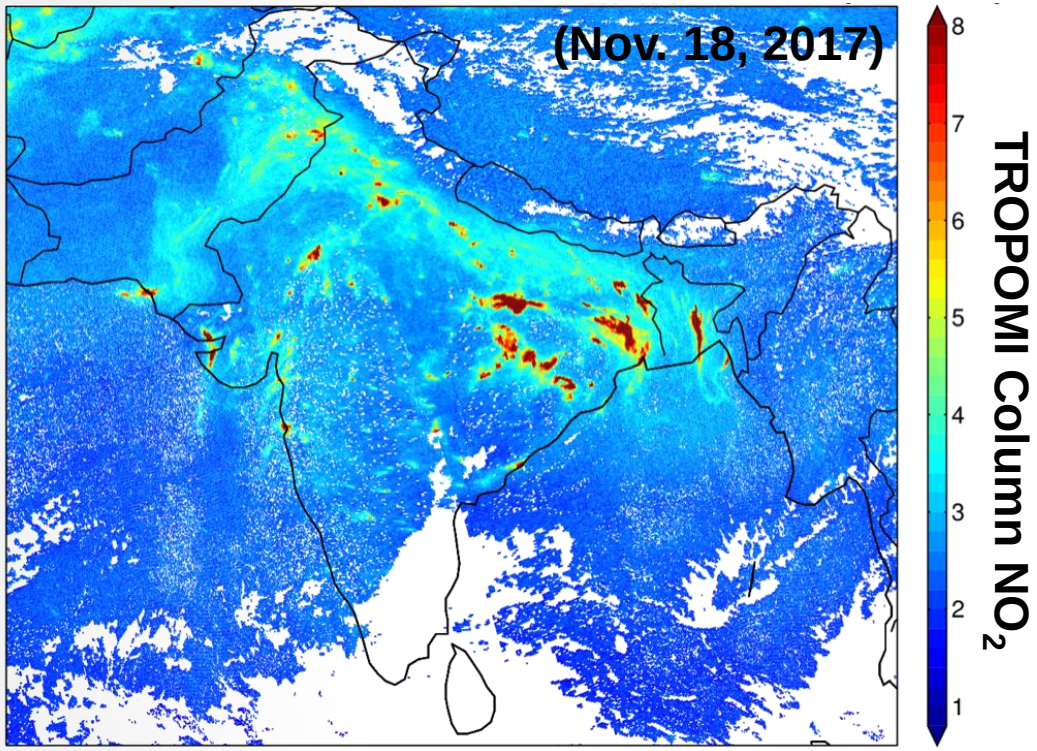
Pros

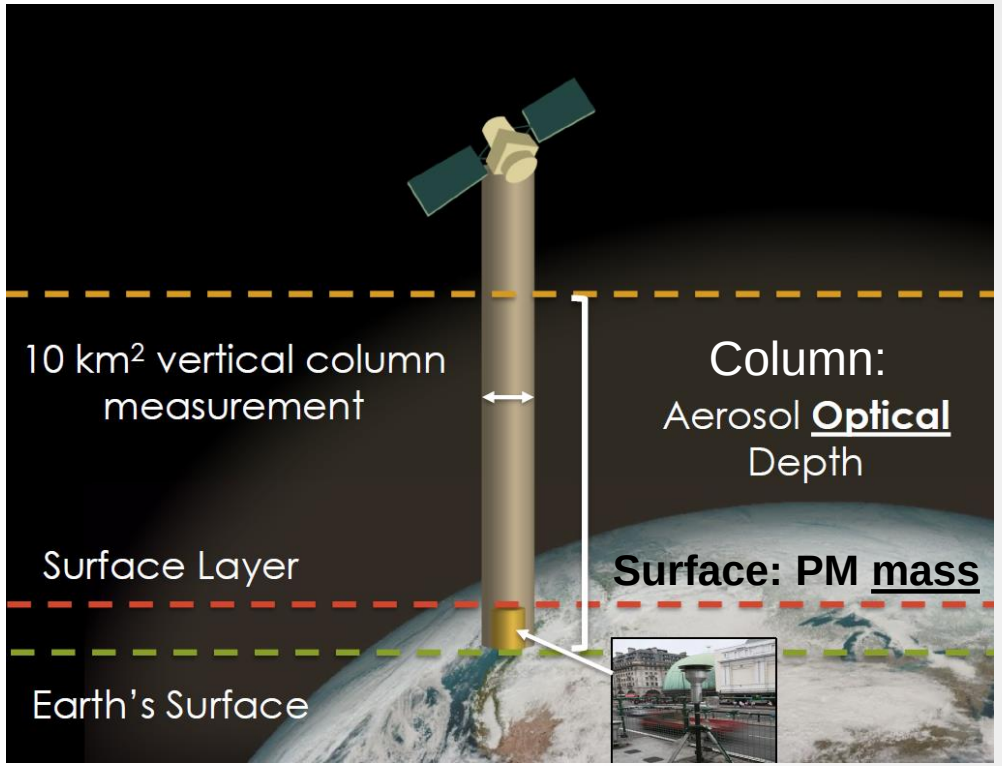
- Lower cost allows more monitor deployments
- Supplement existing regulatory monitors
- Explore previously unmonitored areas

Cons

- Poorer data quality (noise, cross-sensitivity, drift)
- Need for application-specific calibrations
- Not yet accepted for regulatory purposes

Satellites





Pros

- Stable instrument performance over many years
- Wide-area regional or global coverage
- Relatively high (and improving) spatial resolution

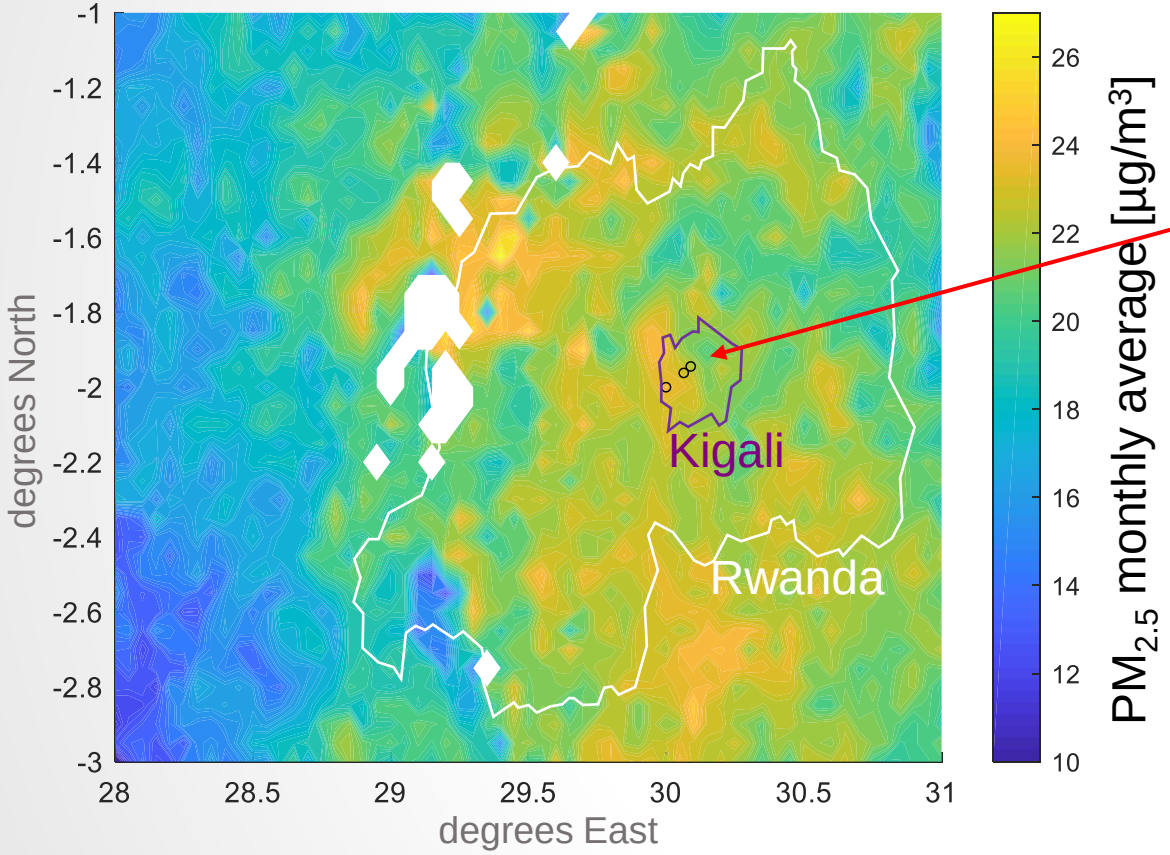
Cons

- Interference from clouds, dense smoke, nighttime
- Polar orbiters observe at the same time each day
- Observe column (rather than surface) quantities

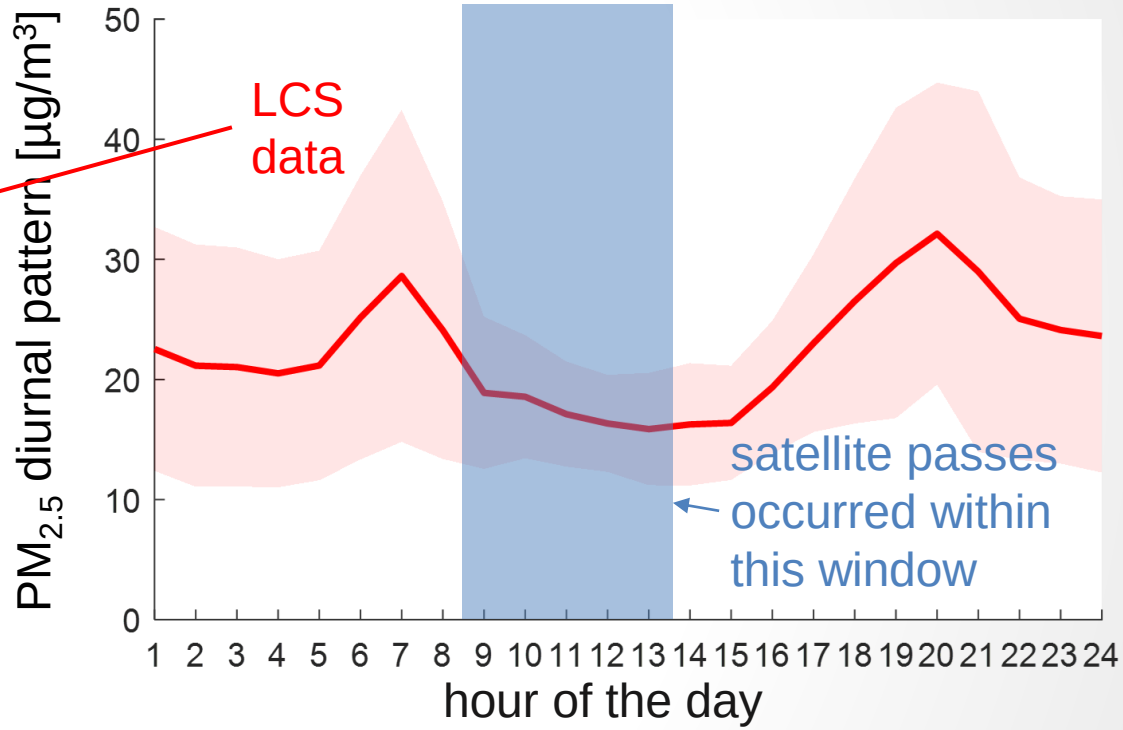
Source: Gupta, Follette-Cook, Strode, and Malings (2023) "Air Quality-Focused Remote Sensing for EPA Applications". NASA Applied Remote Sensing Training Program.

Satellites complementing Air Sensors

Spatial Coverage (satellite)

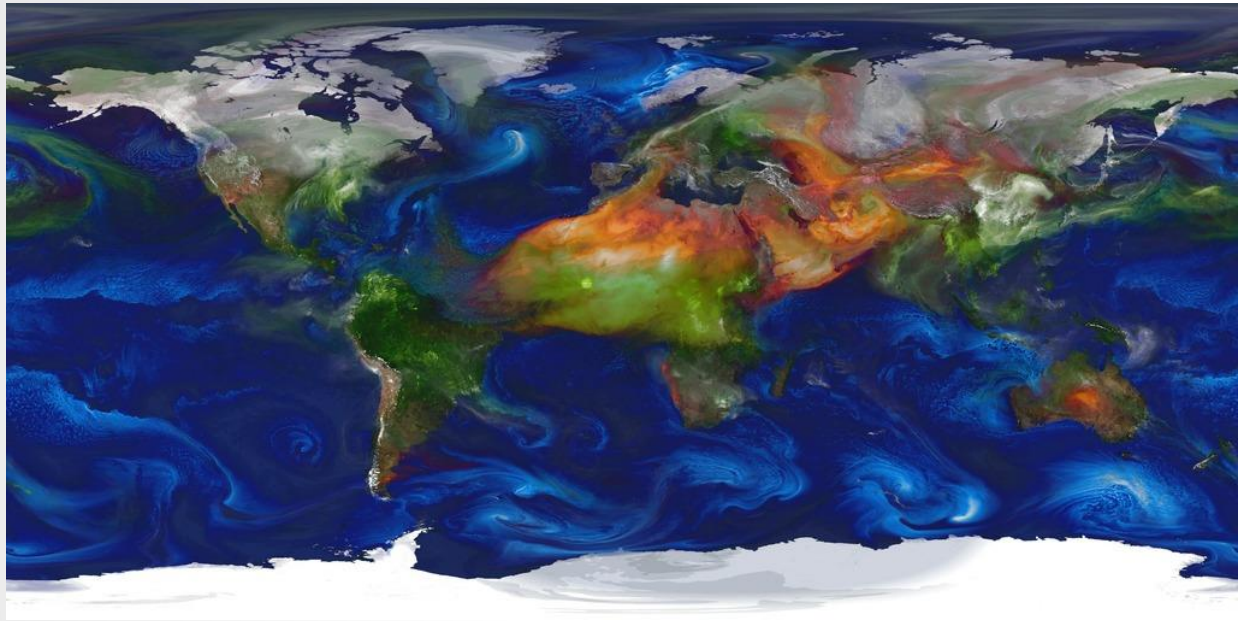


Temporal Coverage (Air Sensors)

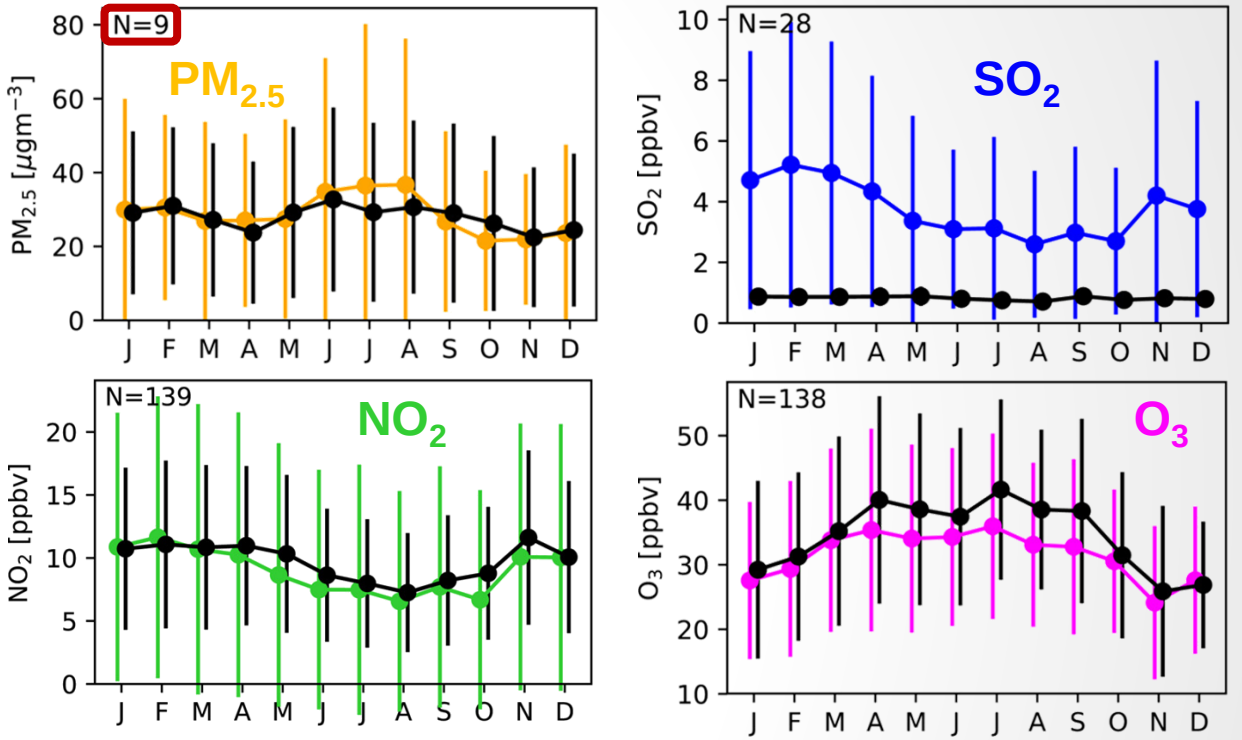


Source: Malings et al. (2020) "Application of low-cost fine PM monitors to convert satellite AOD to surface concentrations in North America and Africa" *Atmos. Meas. Tech.*

Models



Monthly average concentrations at sites in Africa



GEOS ground data

Pros

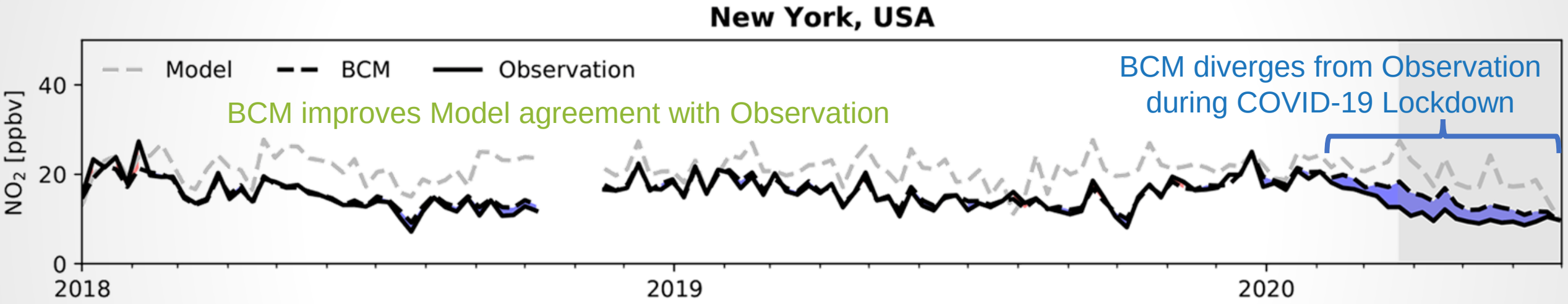
- Complete data coverage in space and time
- Forecasting of future air quality

Cons

- Coarse resolution compared to point measurements
- Incomplete or outdated emissions inventories
- Validation only possible where other data exist

Sources: "GEOS-5 Aerosols Simulation for SC 2014", Scientific Visualization Studio, NASA GSFC.
Keller et al. (2021) "Description of the NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0". *Journal of Advances in Modeling Earth Systems*

Surface Observations Complementing Models

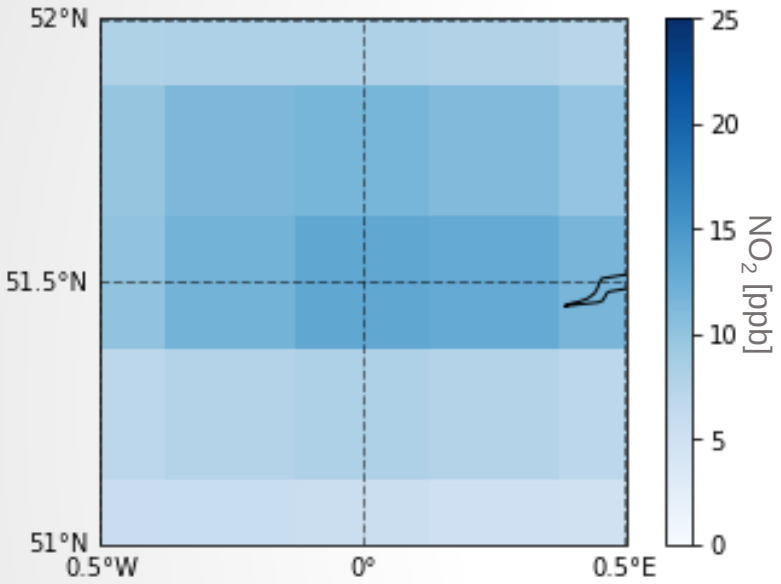


- Ground-truth data allow for bias-correction of models
- Divergence of surface observation and bias-corrected model
- Model bias-correction can be applied with trusted low-cost sensor data
  - Efforts underway using AirQo sensors in Uganda, part of the WRI CanAIRy Alert project

Source: Keller et al. (2021) "Global impact of COVID-19 restrictions on the surface concentrations of nitrogen dioxide and ozone". *Atmospheric Chemistry and Physics*

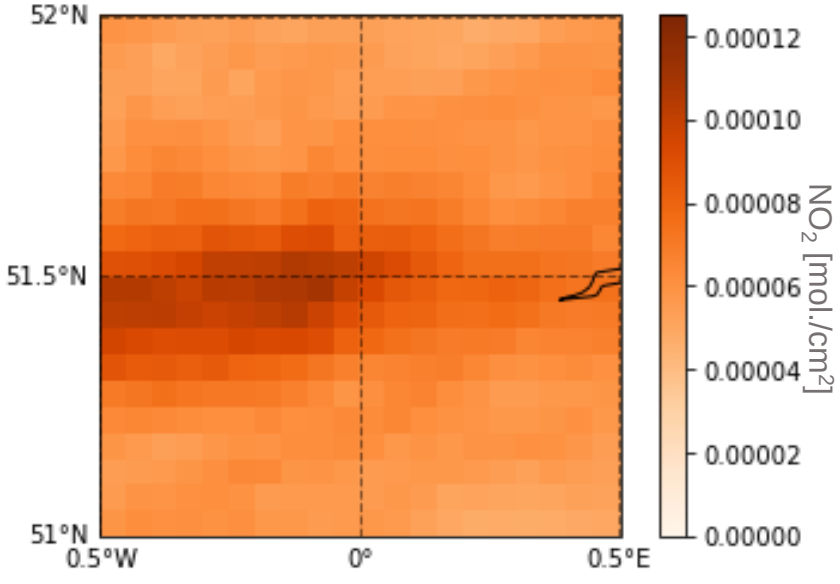
Case Study: Surface NO_2 Forecasting in London

MODEL



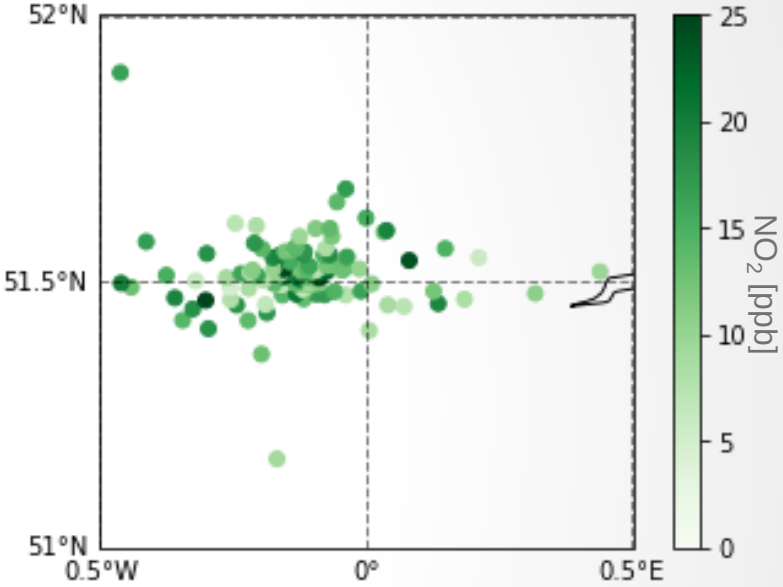
GEOS-CF

SATELLITE



TROPOMI

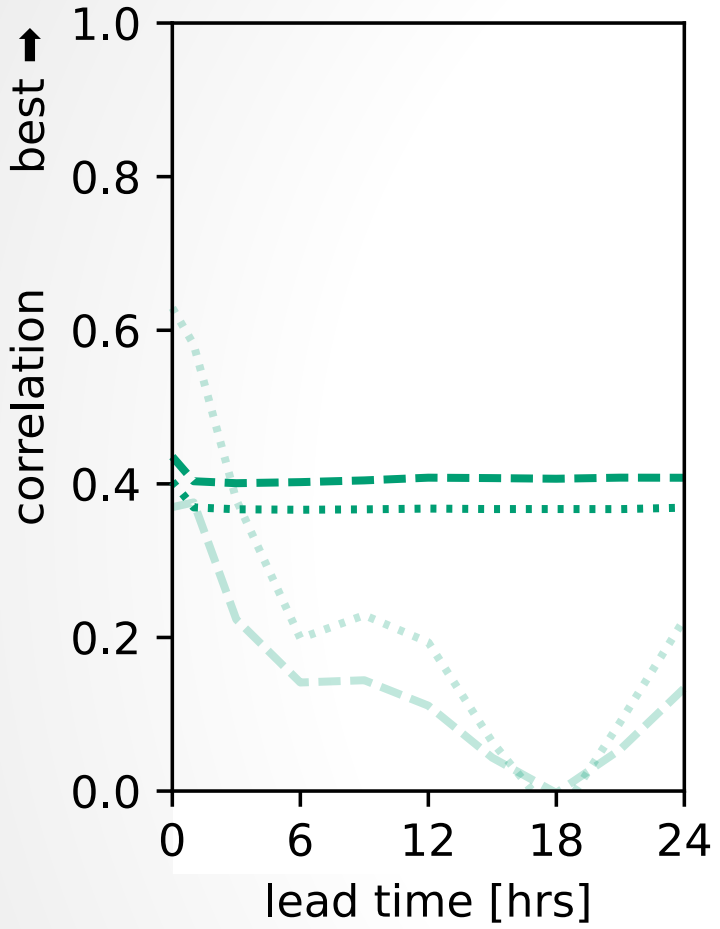
GROUND MEASURES

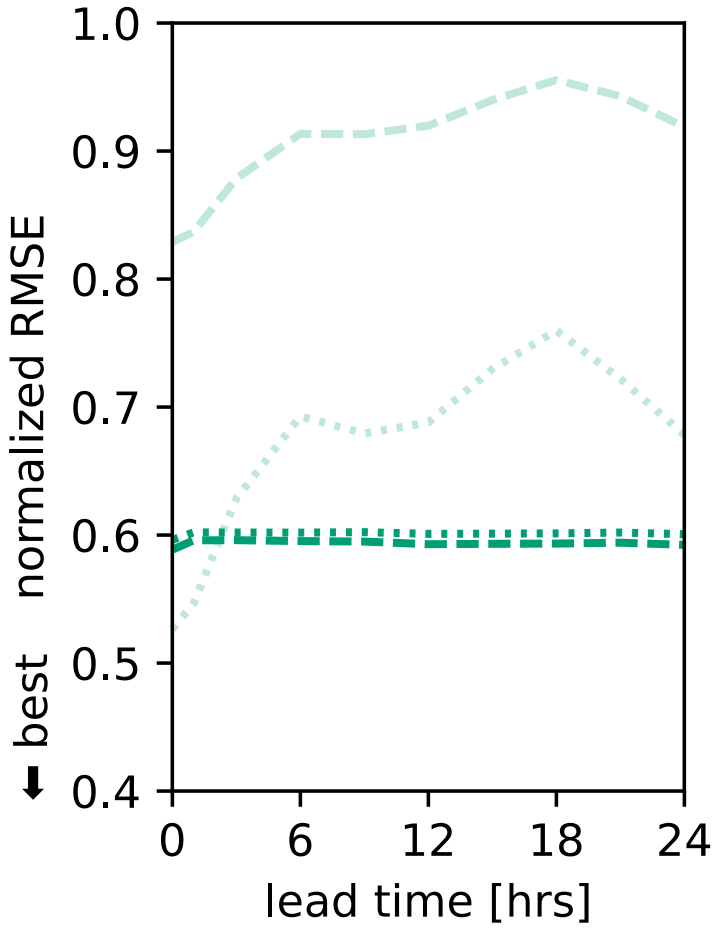


London Air Quality Network +
Breathe London Network (sensors)

Fused Estimates & Forecasts of Surface NO_2 Concentrations

Case Study: local data only





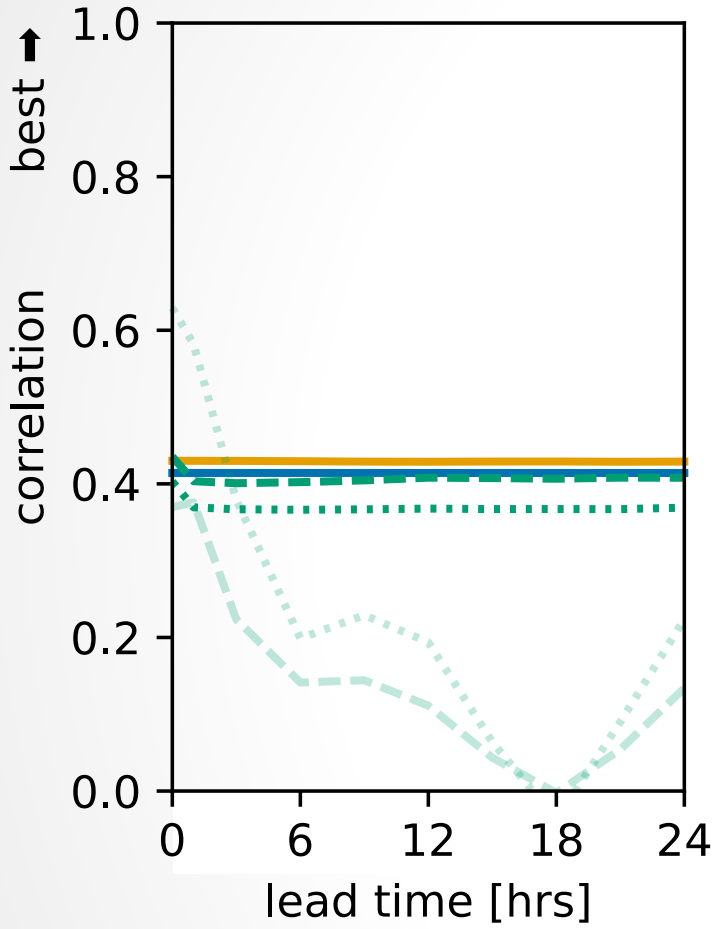
Monitors (persistence forecast)
Monitors (climatology forecast)
Sensors (persistence forecast)
Sensors (climatology forecast)

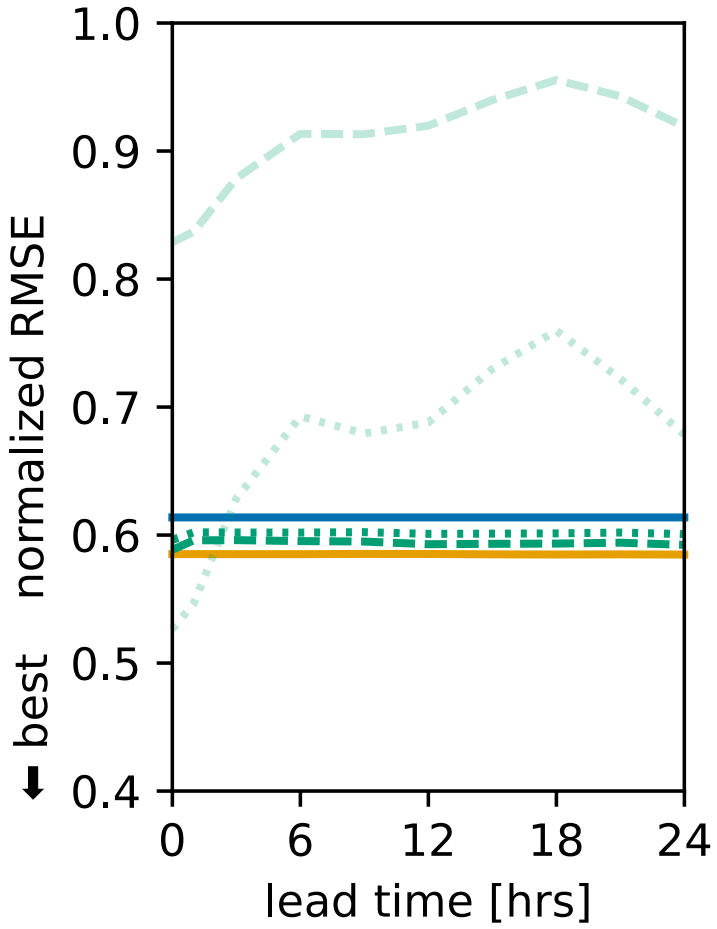
Dense air sensor networks provide better short-term forecasts via the persistence method

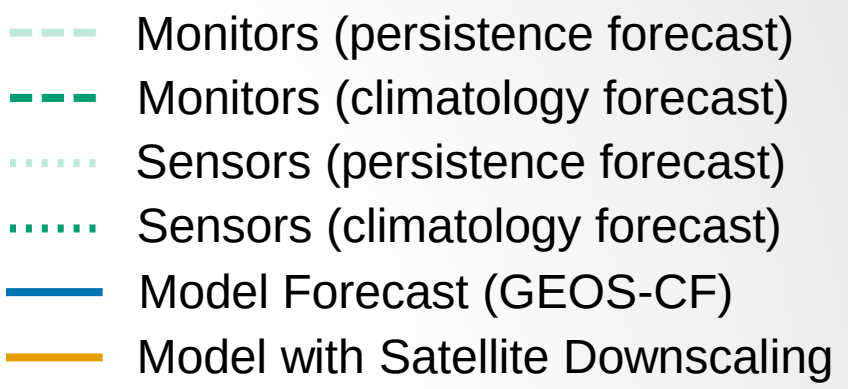
Climatology forecasts provide consistent long-term forecasts with either regulatory monitor or low-cost sensor data

forecasting results for ***London, October & November 2019***
cross-validation: leave-one-site-out, considering only regulatory sites
plotted results represent ***average metrics*** across validation sites

Case Study: global data from models & satellites







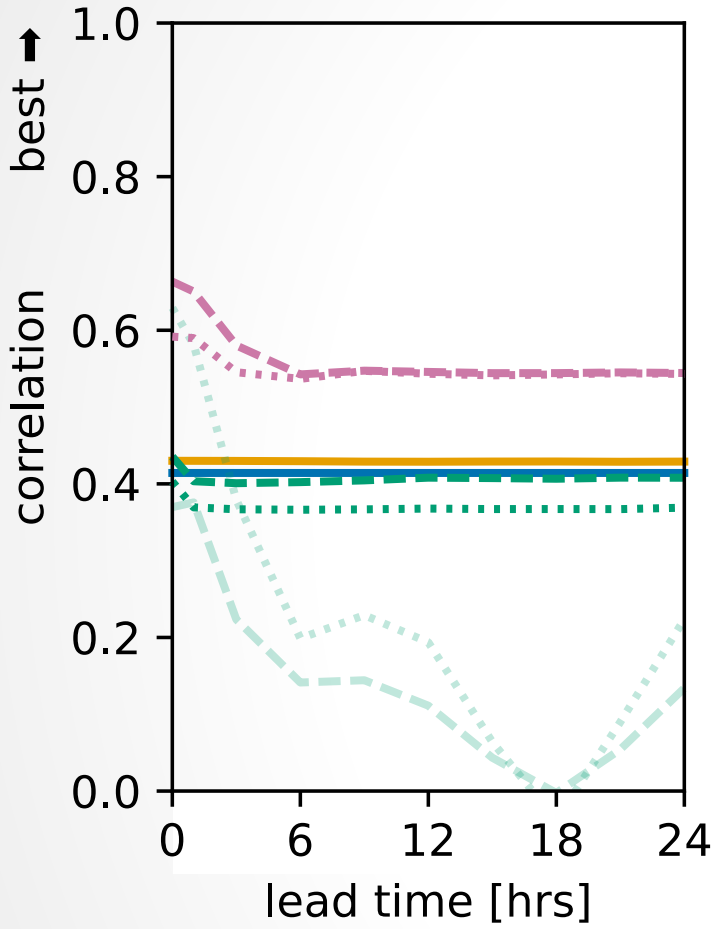
forecasting results for ***London, October & November 2019***
cross-validation: leave-one-site-out, considering only regulatory sites
plotted results represent ***average metrics*** across validation sites

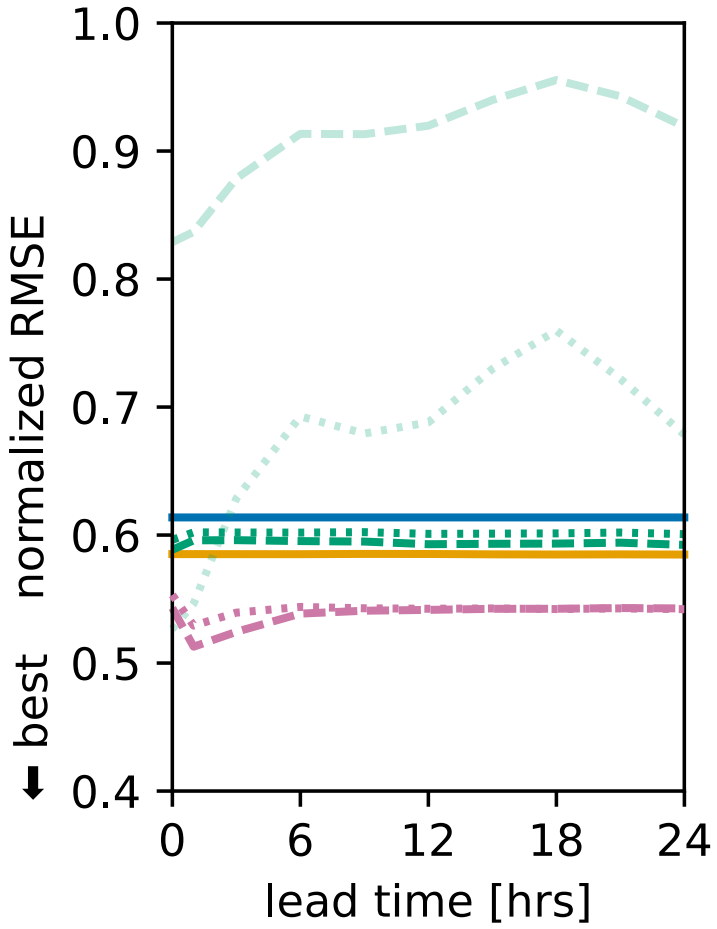
Global model (GEOS-CF) forecast performance is comparable to climatology forecasts with local data

This may be specific to areas like London with accurate & up-to-date emissions inventories

Downscaling model outputs with satellite data slightly improves performance overall

Case Study: bringing everything together





- Monitors (persistence forecast)
- Monitors (climatology forecast)
- Sensors (persistence forecast)
- Sensors (climatology forecast)
- Model Forecast (GEOS-CF)
- Model with Satellite Downscaling
- Model + Satellite + Monitors
- Model + Satellite + Sensors

Combining all data sources together yields the best forecasts both long- and short-term

Accurate regulatory monitor data improves short-term forecasts most, but long-term performance is comparable using low-cost sensors

forecasting results for ***London, October & November 2019***

cross-validation: leave-one-site-out, considering only regulatory sites

plotted results represent ***average metrics*** across validation sites

Summary

Regulatory Monitors, Air Sensors, Models, and Satellites can provide complimentary information for air quality assessment and forecasting

Data Fusion of all available information is a promising approach

Advantages & Limitations of different data sources should be respected, including quantification and propagation of uncertainties