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Supporting local government public health and air quality decision-making with a sub-city scale air quality forecasting system from data fusion of models, satellite, in-situ measurements, and low-cost sensors

PI: K. Emma Knowland (NASA, Morgan State University)

Co-Is: Carl Malings (NASA, MSU), Christoph Keller (NASA, MSU), Stephen Cohn (NASA), Nathan Pavlovic (Sonoma Technology)

Collaborators: Sean Khan (UNEP), John White (US EPA), Dan Westervelt (LDEO), Sean Wihera (Clarity Movement Co.), Randall Martin (WUSTL)

Local End-Users: Ministry of Environment and Sustainable Development, Dakar, Senegal Instituto Pereira Passos, City Municipal Government, Rio de Janeiro, Brazil, US Cities

National/Global End-Users: UNEP & US EPA

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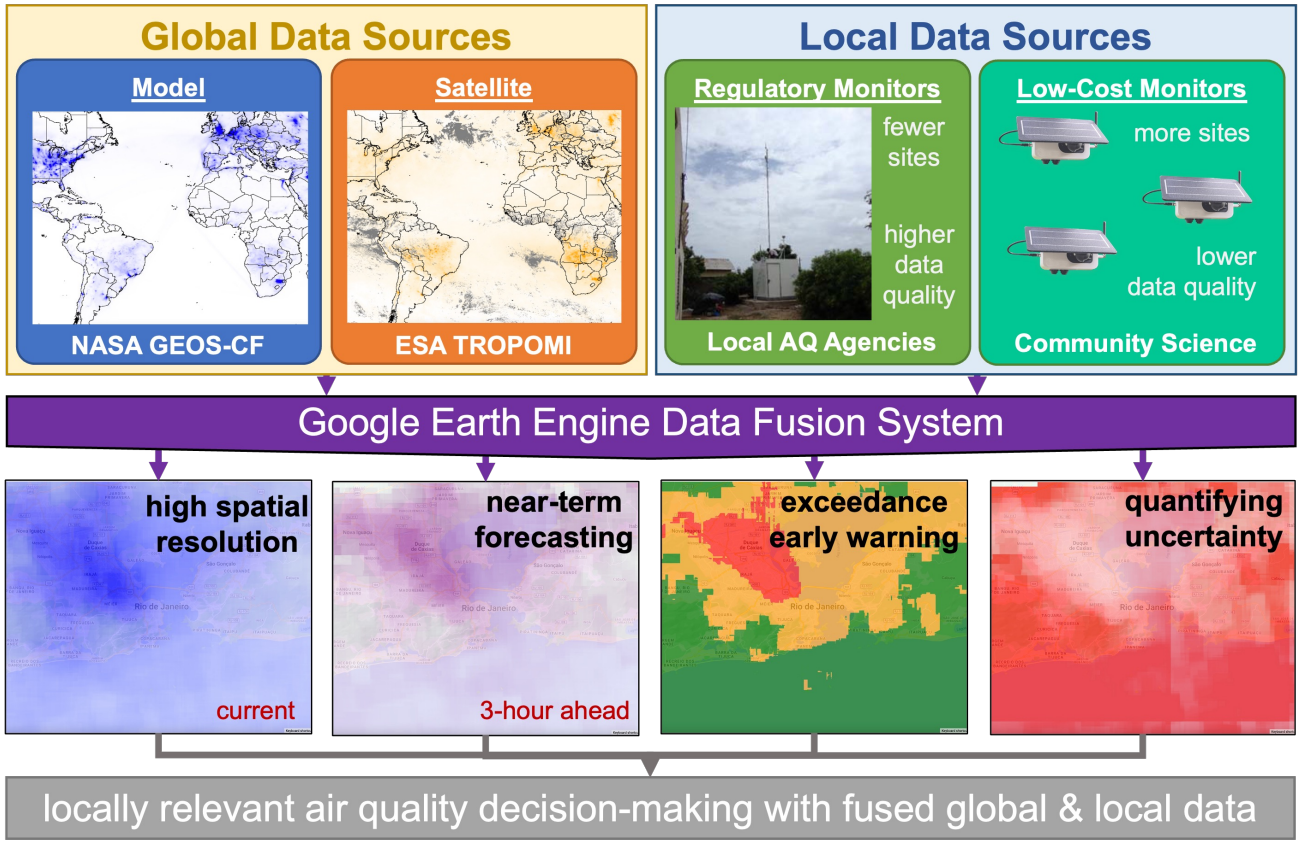
Our project's objective is to…

…integrate diverse **global** and **local** air quality data sources…

…using the cloud computing platform of **Google Earth Engine**…

…to provide synthesized **estimates** and **forecasts** of air quality at a **local scale** but with a **global scope**…

…which will be freely accessible by air quality managers worldwide, facilitating their **decision-making** processes.



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Project Scheme and Partners

NASA GMAO: basic algorithm development & refinement

Clarity: low-cost sensor integration

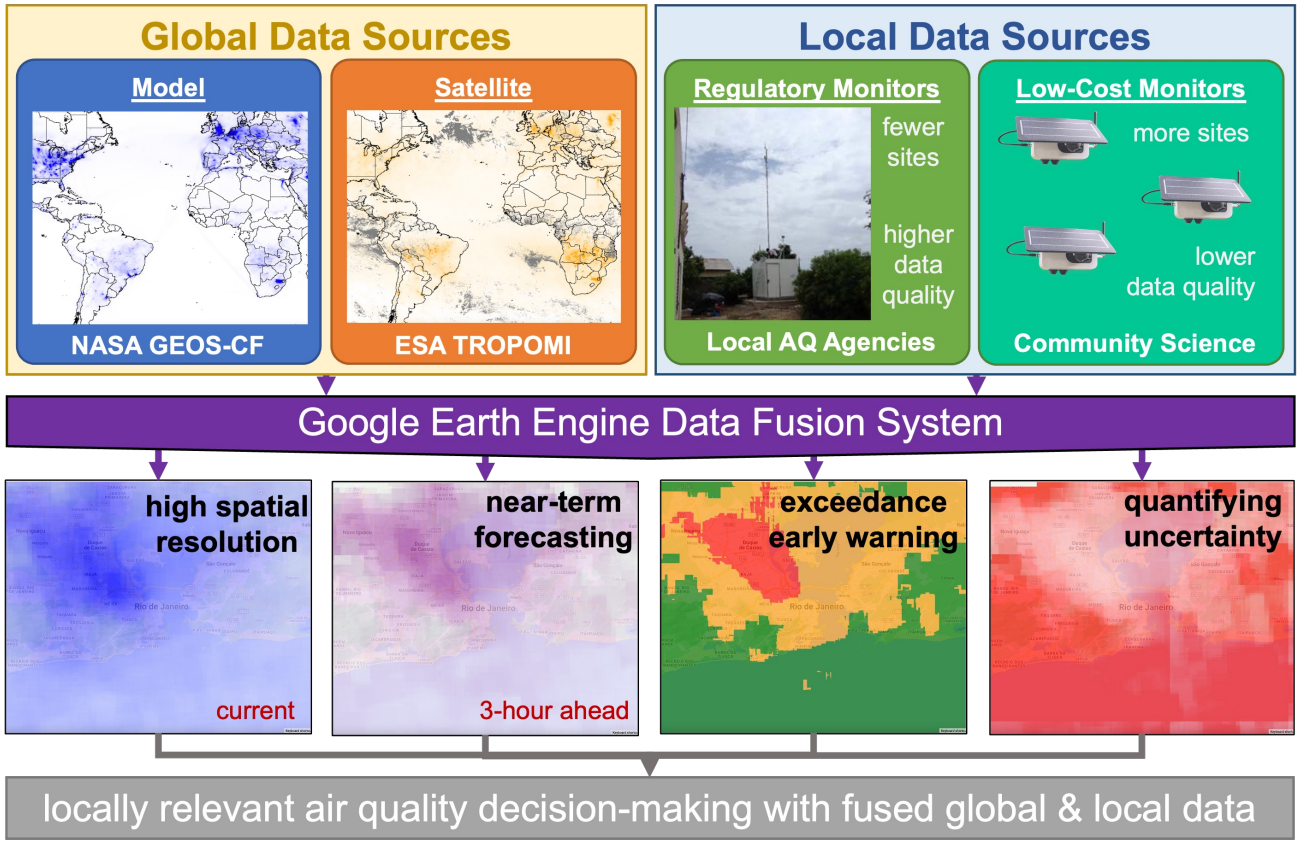
Sonoma Technologies: data fusion system implementation & user interface

WUSTL: air quality data integration expertise (monthly/annual timescales)

Columbia LDEO: experience training end-users in AQ data interpretation

UNEP: integration with global end-users
Dakar, Senegal
Rio de Janeiro, Brazil

US EPA: integration with 4 US city partners



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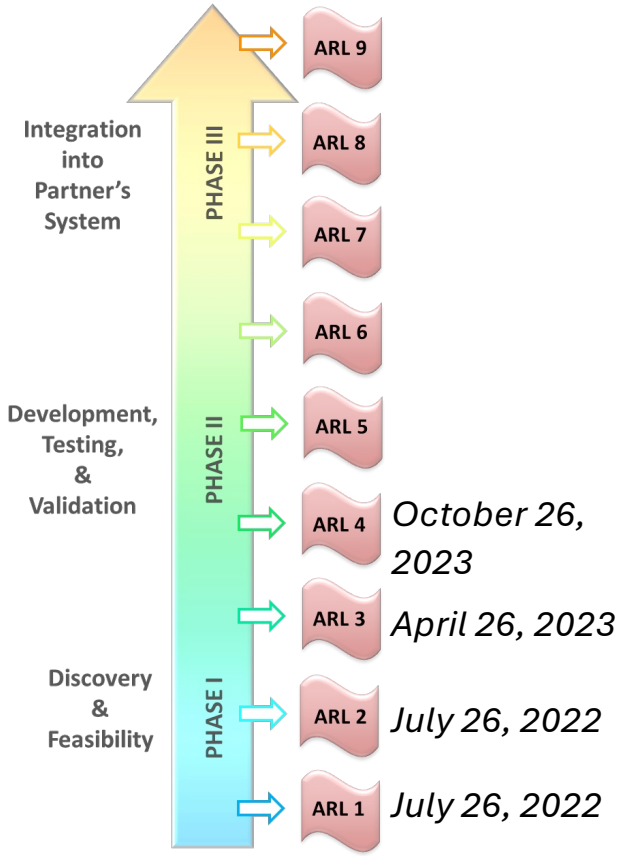

ARL Performance

- Start-of-Project ARL = 2 *(July 26, 2022)*
  - Fundamental data fusion methodology published in peer-reviewed journal: Malings et al. 2021: https://doi.org/10.1029/2021EA001743
  - Nathan Pavlovic (Sonoma Technologies, Inc.) had implemented a similar methodology in Google Earth Engine on behalf of end-user UNEP
- Goal ARL = 9
- Current ARL = 4 *(April 26, 2024)*
  - See subsequent slides

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Schedule & Milestones (Revised)

GMAO: Knowland : : Malings
Keller, Cohn

Sonoma Technology: Pavlovic, software engineers

US EPA (White) & UNEP (Khan) supporting end-users

* with LDEO (Westervelt) & Clarity (Wihera)
+ with WUSTL (Martin)

Objective & Tasks		Year 1		Year 2		Year 3	
1	a. Import new datasets to GEE, including GEOS-CF and RGM and LCS data						
	b. Merge existing GMAO and UNEP/Sonoma Technology data fusion methodologies						
	c. Refine data fusion system, including uncertainty quantification capabilities+						
	d. Incorporate LCS in the data fusion system, with uncertainty quantification*						
	e. Implement data fusion system into GEE tool, including interfaces						
	f. Refine GEE tool, especially input/output capability and interfaces						
2	a. Assess the status and identify key end-user needs for the GEE tool						
	b. Train end-users in the functionality and capabilities of the GEE tool*						
	c. Pilot deployment of GEE tool in end-user domains of interest						
3	a. Validate data fusion system in end-user domains of interest+						
	b. Integrate GEE tool into end-user decision-making processes						
	c. Evaluate the project's impact on decision-making outcomes						
	d. Integrate GEE tool with US EPA AirNow-Tech and UNEP GEMS Air systems						
	e. Transfer GEE tool to US EPA, UNEP, end-users for operational use						
Anticipated Application Readiness Level (ARL) metric		2	3	4	5	6,7	8,9

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Current activities for ARL 5

- 1c. Refine data fusion system, including uncertainty quantification capabilities
  - Malings et al. 2024, under review (DOI: 10.22541/essoar.171052565.52477494/v1)
- 2c. Pilot deployment of GEE tool in end-user domains of interest
  - NO_2 and $PM_{2.5}$ pilot deployment for Rio and Dakar
- 3a. Validate data fusion system in end-user domains of interest
  - Forecast skill analysis
- 3c. Evaluate the project's impact on decision-making outcomes
  - Project contributes to the 2021 City of Rio de Janeiro sustainable development plan

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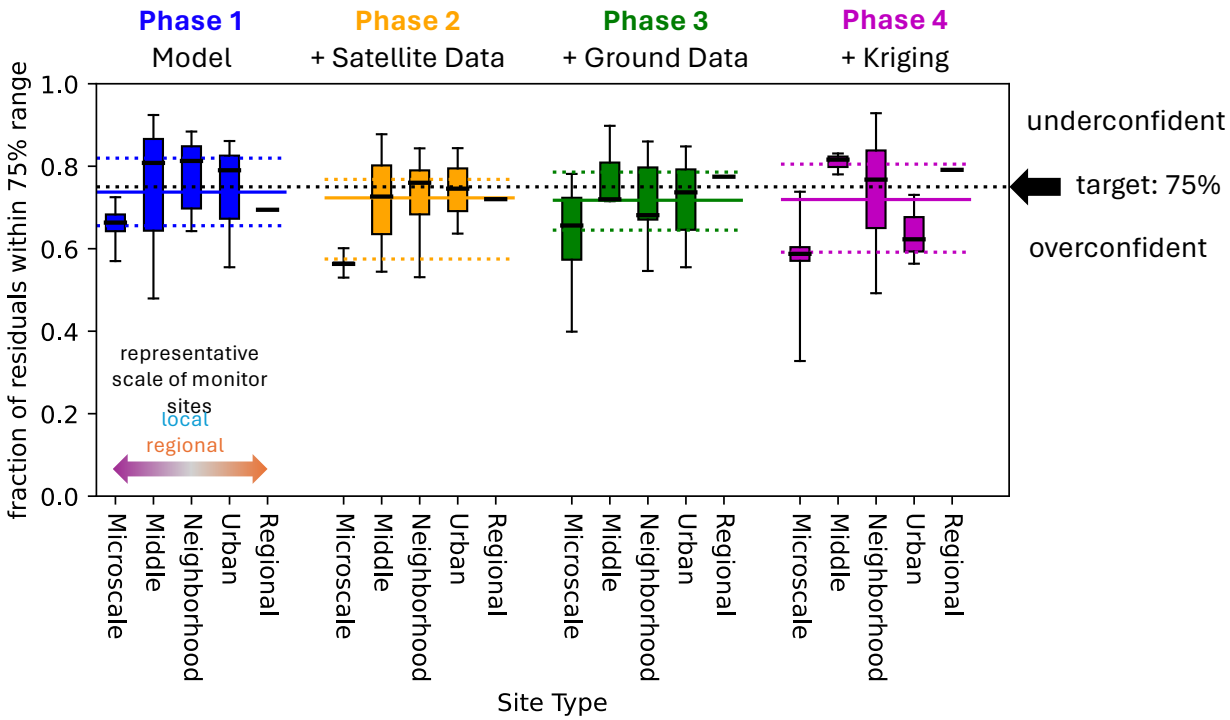
ARL 3, Milestone 1: Components of the application tested and validated independently

Task 1c: Refine data fusion system, including uncertainty quantification capabilities



Testing of the uncertainty quantification framework shows that most estimated confidence intervals across data fusion phases (1-4) and site types (different boxplots) capture the expected number of observations (75%, the "target" in the figure). The overconfidence observed for "microscale" sites is expected based on known limitations of the approach.

A manuscript describing the approach with case studies performed in San Francisco and New York City is under review in the *Journal of Geophysical Research - Machine Learning and Computation* (preprint; March 2024).

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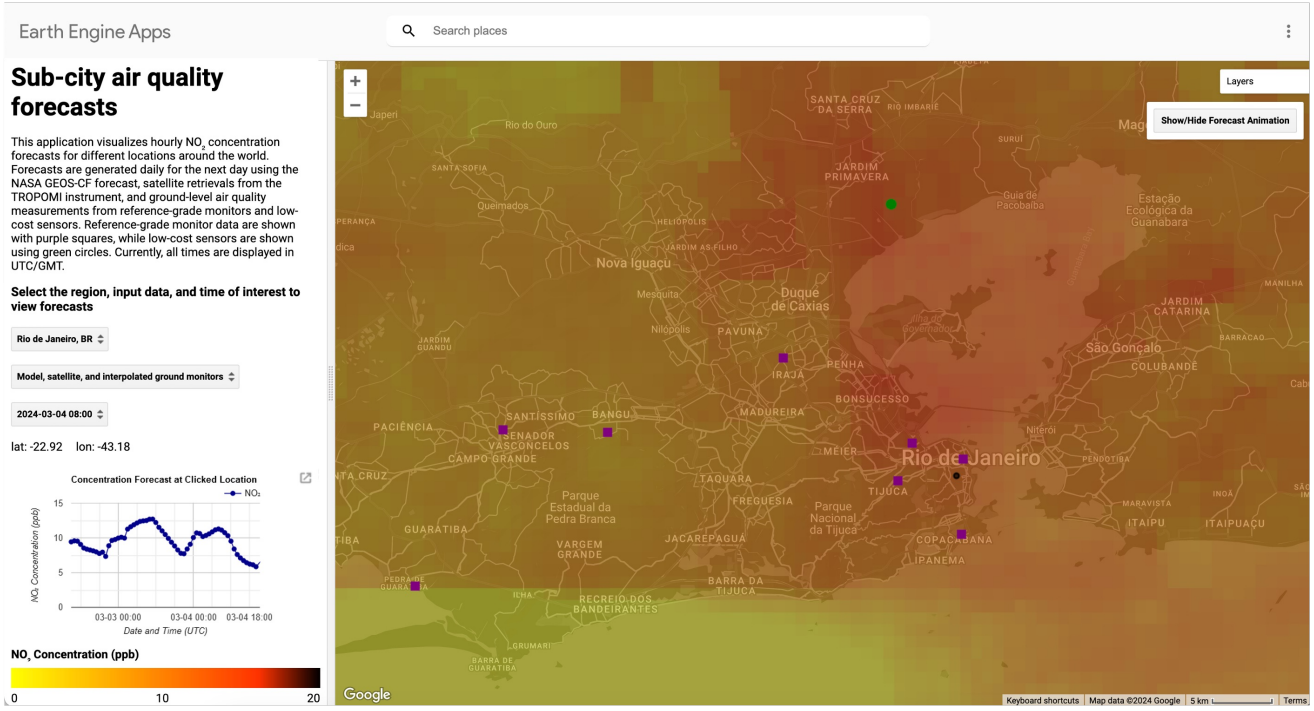
ARL 5, Milestone 1: Application components have been integrated into a functioning protype application system with realistic supporting elements

Task 2c. Pilot deployment of GEE tool in end-user domains of interest



A functional integrated prototype has been created, incorporating ground-based monitoring data, GEOS-CF forecasts, and TROPOMI satellite data. Results are presented via an interactive online dashboard (screenshot at left).

Next Steps:

- Quantitative evaluation of outputs in target regions.
- Verify uncertainty quantification, as outlined in a manuscript currently under review (preprint; March 2024).
- Modify prototype as needed to present PM2.5 and Ozone data.

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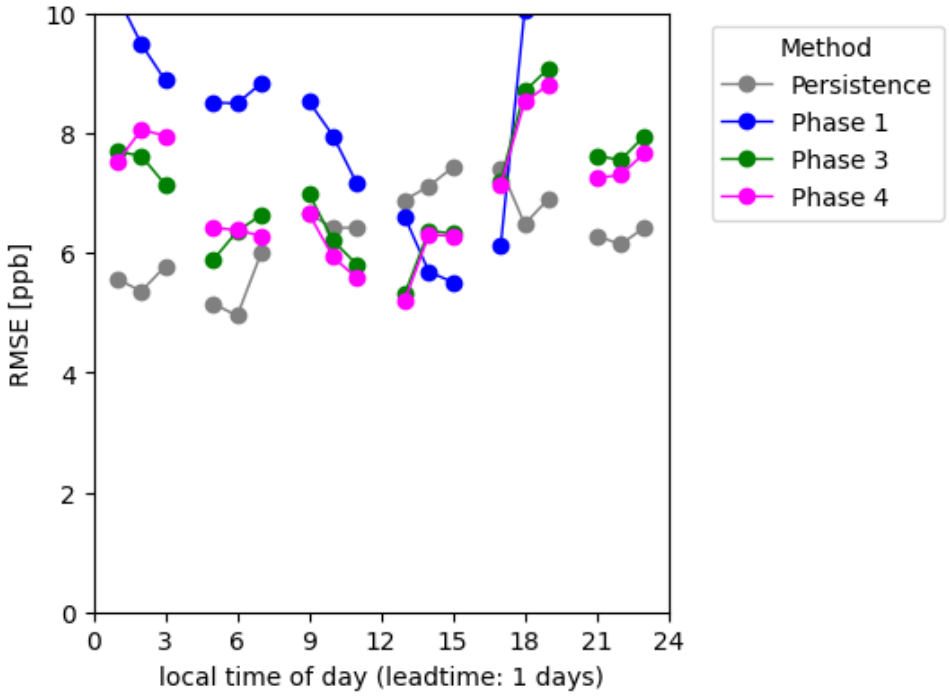
ARL 5, Milestone 2: The application systems potential to improve the decision-making activities has been determined and articulated

Task 3a. Validate data fusion system in end-user domains of interest



Based on the application prototype, which has been running for Rio since November 2023, a preliminary analysis of the data fusion forecasting performance was conducted. Analysis results for January 2024 (figure at left) suggest that proceeding from Phase 1 (using model forecasts alone) through to Phases 3 and 4 of the data fusion process tends to reduce forecasting error (RMSE, vertical axis) across different times of day (horizontal axis). Performance is comparable with persistence forecasting; further improvement is expected as parameters are locally refined for Rio.

Next Steps:

- evaluate other pollutants (PM2.5, Ozone)
- expand evaluation to other application areas.

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ARL 5, Milestone 2: The application systems potential to improve the decision-making activities has been determined and articulated

Task 3c. Evaluate the project's impact on decision-making outcomes

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Aspiração | MCR3 **Cidade Neutra em Carbono**

Estratégia 1 - Fomento a Tecnologias Limpas
Estabelecer baixa emissão de carbono no setor de transporte, iluminação pública e edificações como forma de mitigar emissão de GEE.

Indicador: **Padrão de Qualidade do Ar Intermediário (PI-3), equivalente a Material Particulado - MP10**

Valor de Referência (2019): **35,54 microgramas de material particulado/m³**

Resultado a ser alcançado (2030): **30**

Fonte: **SMAC**

Ação Climática

META:
MCR3.4 - Alcançar o padrão de qualidade do ar equivalente a 30 microgramas por metro cúbico para médias anuais de material particulado na cidade do Rio de Janeiro[1]

ODS Principal: **9.4, 12.4 - 12.6, 17.14 - 17.16**

ODS Secundário: **3.9, 11.6**

Ações Estruturantes	Marcos temporais
MCR3.4.1 Elaborar um plano municipal para redução das emissões de poluentes atmosféricos de fontes fixas;	Até 2022
MCR3.4.2 Implementar um programa de treinamento para que servidores municipais atuem como multiplicadores na comunicação de problemas relacionados à poluição atmosférica;	Até 2022
MCR3.4.3 Criar um Comitê Técnico voltado ao combate à poluição atmosférica, estabelecendo parcerias com outras instituições públicas e acadêmicas e representantes da sociedade civil;	Até 2022
MCR3.4.4 Estabelecer repositório de artigos científicos sobre qualidade do ar na Cidade do Rio de Janeiro e na Região Metropolitana e montar um workshop sobre o tema;	Até 2022
MCR3.4.5 Implementar regulamento que estabeleça o registro obrigatório de emissões de poluentes atmosféricos junto ao Cadastro Técnico Federal do IBAMA, para as atividades elegíveis, como condicionante para o licenciamento ambiental municipal;	Até 2022
MCR3.4.6 Elaborar periodicamente o Inventário de Emissões de Fontes Fixas e Veiculares da Cidade do Rio de Janeiro;	Até 2026
MCR3.4.7 Implementar um modelo de previsão de qualidade do ar para o Cidade do Rio de Janeiro;	Até 2026
MCR3.4.8 Estabelecer parcerias com cidades da Região Metropolitana e com o Governo do Estado do Rio de Janeiro para buscar um planejamento de ações integradas relativas à melhoria da qualidade do ar;	Até 2026
MCR3.4.9 Quantificar periodicamente a redução de emissões de poluentes atmosféricos devido à mudança da frota para veículos não-emissores ou pouco-emissores;	Até 2026
MCR3.4.10 Ampliar a capacidade de coleta de dados da Rede Municipal de Monitoramento da Qualidade do Ar, por meio da instalação de monitores de PM2,5, COV's e NOx;	Até 2029

Ação Climática
Projetos Sustentáveis
Ação Climática Prioritária

https://doweb.rio.rj.gov.br/portal/visualizacoes/pdf/4975#/p:322/e:4975

This project contributes to the 2021 City of Rio de Janeiro sustainable development plan in two ways:

Implementing an air quality forecasting model for Rio de Janeiro (to be implemented by 2026)

- This project's air quality forecasting tool can provide this capability.

Expand the existing air quality monitoring network in Rio de Janeiro, including new monitoring stations for $PM_{2.5}$ and NO_x (to be completed by 2029)

- The uncertainty analysis capabilities of the data fusion tool being implemented can support the identification of informative monitoring locations.
- This is beyond the scope of this funded grant work but requested by Rio partners since the onset of the project.

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ARL 5, Milestone 2: The application systems potential to improve the decision-making activities has been determined and articulated

Task 3c. Evaluate the project's impact on decision-making outcomes

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Diário Oficial do Município do Rio de Janeiro

IPP

Nº	E/C	Descrição	Fonte	Unidade de Medida	Valor de Referência	Data de Referência	Meta 2024	Regras
1	E	Garantir que pelo menos 85% das famílias mais vulneráveis da cidade saiam da sua situação de risco social, por meio de ações do Programa Territórios Sociais, até 2024.	IPP	%	83,8%	2023	85%	
2	E	Desenvolver o primeiro modelo de previsão da qualidade do ar em escala local para o Rio de Janeiro, em parceria com a NASA, em apoio às ações de monitoramento e vigilância ambiental e da saúde em 2024.	IPP	Entrega	N/A	N/A	Modelo concluído e disponível em plataforma online	Nº de Metas → Nota - % Bônus 1 → 7 (20%) 2 → 8 (60%) 3 → 8,6 (72%)
3	E	Revisar e atualizar, em 2024, o Índice de Desenvolvimento Social - IDS e o Índice de Progresso Social - IPS para subsidiar a revisão do PDS em 2025 e o novo Plano Estratégico da Cidade 2025-2028.	IPP	Entrega	N/A	N/A	Índices revisados e atualizados	
Se atingir 50% ou mais das metas estratégicas, considerar metas abaixo:								
4	C	Realizar o mapeamento do crescimento vertical das edificações de toda a Cidade do Rio de Janeiro e publicar os resultados no ano de 2024.	IPP	Entrega	N/A	N/A	Mapeamento realizado e publicado no SIURB	Nº de Metas → Ponto adicional - % Bônus adicional 2 → 0,3 (6%) 3 → 0,4 (8%)
5	C	Lançar 5 novas publicações de divulgação da Cidade em 2024.	IPP	Unidade	5	2023	5	
6	C	Realizar Seminário Internacional "Territórios Sociais" sobre políticas públicas de superação de vulnerabilidades sociais em 2024.	IPP	Entrega	N/A	N/A	Seminario Realizado	
Se atingir 50% ou mais das metas estratégicas, considerar meta abaixo:								
7	P	Meta de Performance	SMFP	Itens a cumprir	-	-	Itens cumpridos	Ponto Adicional – % Bônus Adicional 1 (20%)

https://doweb.rio.rj.gov.br/portal/visualizacoes/pdf/6520#/p:43/e:6520

Developing an air quality forecasting model for Rio de Janeiro in collaboration with NASA has been identified as a key target for the Instituto Pereira Passos (IPP) for 2024 by the Rio de Janeiro Mayor's office.

This indicates the value placed on the potential impact of such a tool by the local government and policy-makers.

To be successful, we need to provide the online tool for NO_2 and $PM_{2.5}$ to Rio by end of 2024. This is 2-years ahead of schedule proposed in the 2021 sustainable development plan

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Emma Knowland visited Rio de Janeiro in November 2023, presenting “Data Fusion for Urban Air Quality and Health Assessment & Forecasting for the city of Rio de Janeiro”, engaging in extended discussions with stakeholders, and visiting the Rio Operations Center which will ultimately make use of the GEE data fusion system.

During the visit, Emma Knowland conducted an interview discussion the NASA-Rio partnership agreement and this project which was also posted to the Instituto Pereira Passos Instagram page.

Photograph taken during PI Knowland’s visit to the Rio Operations Center.
Credit: LinkedIn, Marcus Belchior

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Challenges and Risks

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Rank	Type*	Risk	Mitigation Action	Date first noted/Date resolved (if applicable)
1	T	Lack of ground-based monitor data (especially in Dakar)	Use historical datasets (2010-2019) for validation; design the GEE tool to be robust to missing data	2/28/2023
2	T	NASA EOS satellites approaching end of life	Need to test alternative satellite products than MODIS	Start of project
3	T	IT problems with SonomaTech, Inc servers	Timeline for transition of data pre-processing to cloud services (part of Task 3e) has been accelerated	3/13/2024
4	T	Google Earth Engine service changes and availability	Work with Google team and collaborators to understand and adapt to service changes	Start of Project
5	B	Low Cost Sensor data from PurpleAir no longer freely available	Coordinate with EPA AirNow partners regarding LCS data for US. Work with Clarity collaborator for LCS data access in other end-user locations.	2/1/2024
6	ES	Changes in end-user priorities	Can be adjusted for so long as requirements remain within project scope	Start of project
7	T	Changes to collaborator systems and development timelines	Coordinate with collaborating entities to adjust plans within scope	2/28/2023

* Please designate risk type as: Technical (T), Budget (B), End-User/Stakeholder (ES), or Project Management (PM)

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Challenges and Risks

National Aeronautics and Space Administration

Rank	Type*	Risk	Mitigation Action	Date first noted/Date resolved (if applicable)
8	PM	SonomaTech, Inc personnel changes	Training of new staff was already in progress; timeline for transitioning tasks to new staff has been accelerated	3/26/2024
9	PM	Stakeholder personnel changes	Good communication with contacts to manage handover of project to new employee	1/15/2023
10	T	Air Quality Model updates may impact their availability in GEE	Coordinate with GEE to ensure minimum disruption in data availability	Start of project

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