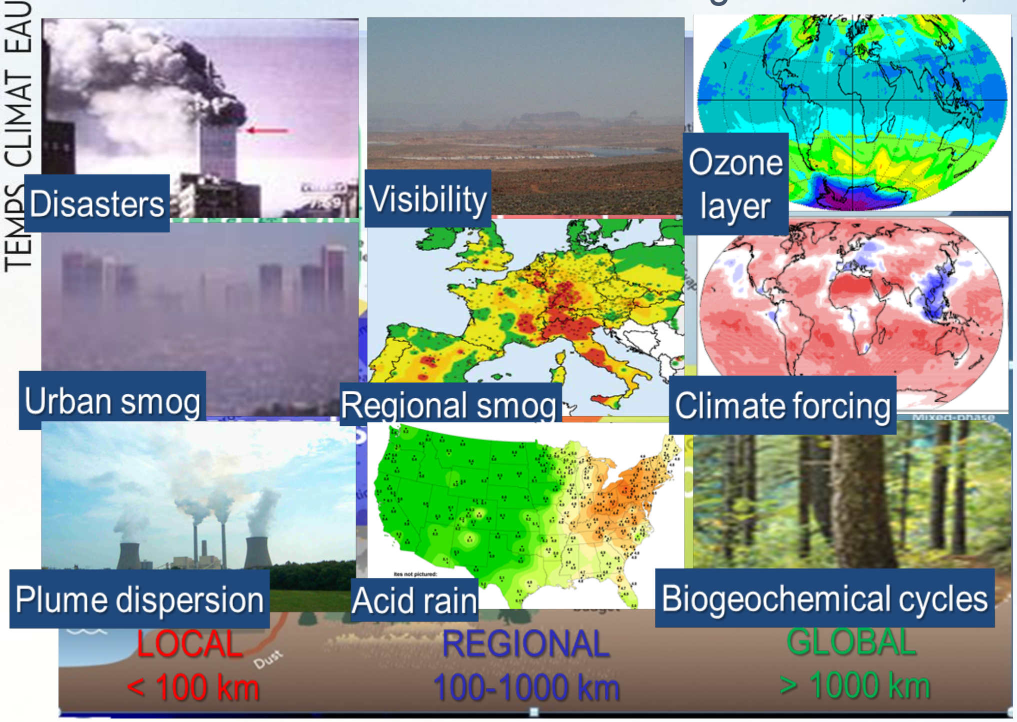
Advancing Atmospheric Composition Predictions and Related Services to Meet the Growing Societal Needs

Greg Carmichael, University of Iowa

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU



- ✓Trend toward closer linkages of weather, atmospheric composition, and climate related services
- ✓Information needed at higher resolution (and longer lead times) to address societal needs
- ✓Further improvements require advances in observing systems, models and assimilation systems

Atmospheric Composition Matters:
To Air Quality, Weather, Climate and More

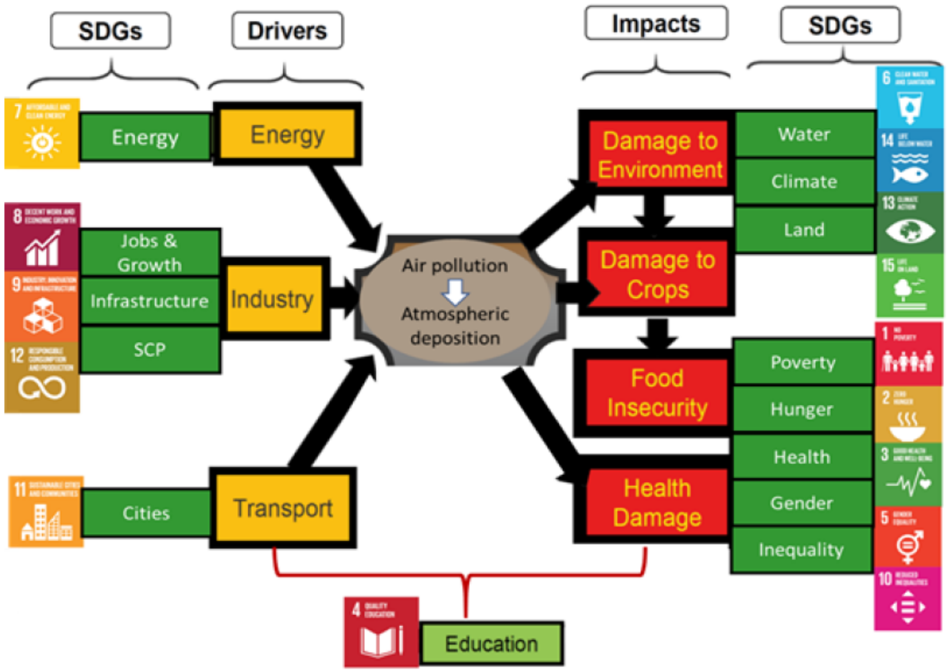


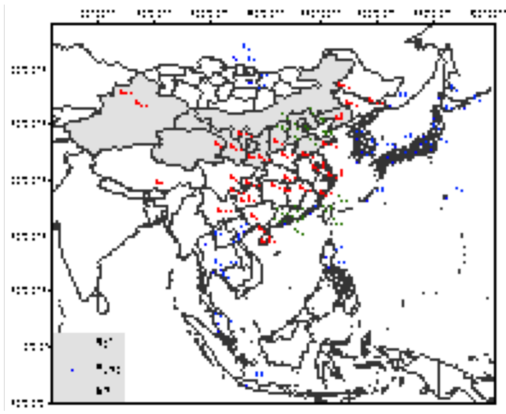
Figure 7. Relation of the United Nation's Sustainable Development Goals to air pollution drivers and atmospheric deposition impacts. Education is bridging knowledge on drivers and impacts (figure modified from Elder and Zusman, 2016).

More information needed

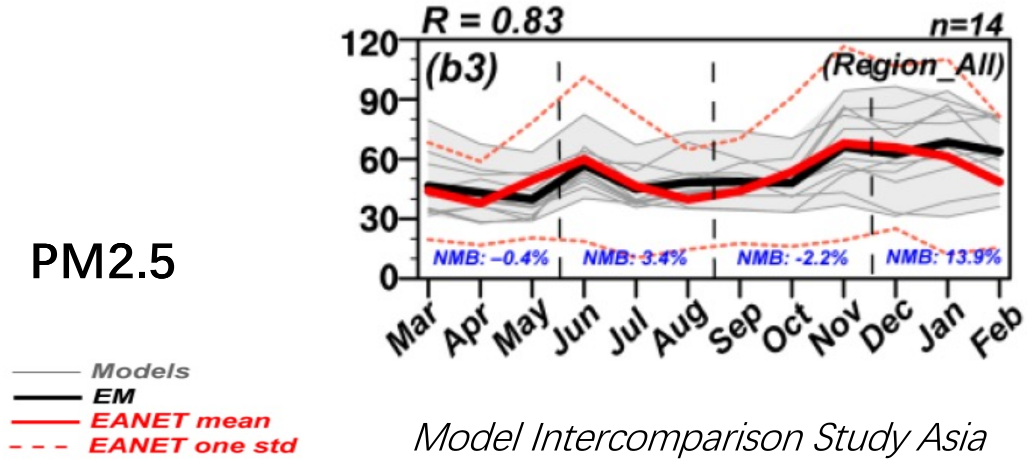
- ✓ Air pollution (anthropogenic, smoke, dust) predictions from weather – S2S and projection time scales at higher spatial resolution.
- ✓ Air pollution predictions/reanalysis with lower uncertainties of key components (including aerosol speciation) and by source/sectors to support impact estimates (health, crop yields, ecosystems) and air pollution management strategies.
- ✓ Rapid update of emissions from all sources, better estimates and constraints on fluxes, and improved surveillance (leaks, large emitters) and stocktaking.

The University of Iowa

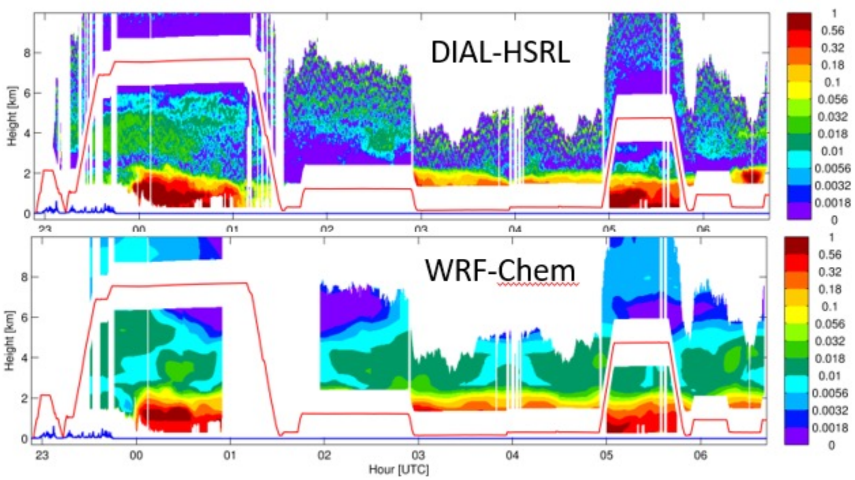
Current Air Quality Models have Appreciable Prediction Skill



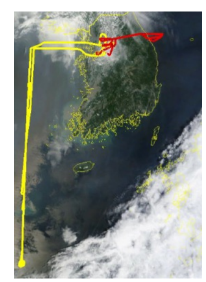
PM2.5



Model Intercomparison Study Asia (Itahashi et al., ACP, 2020)



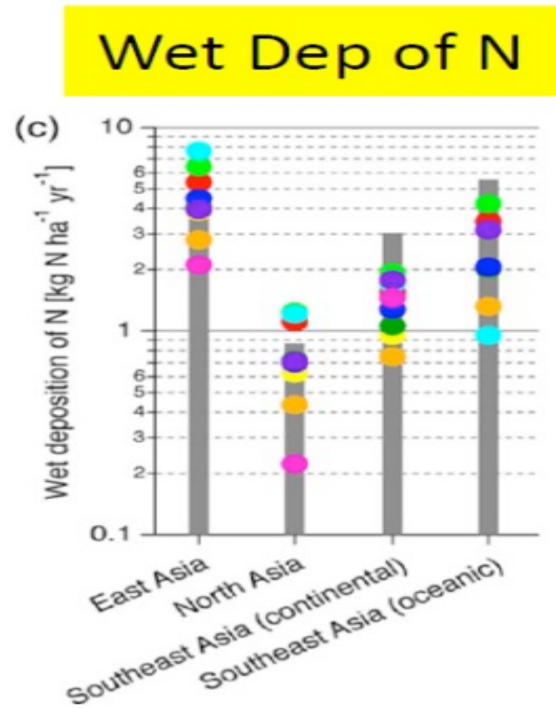
KORUS-AQ



Iowa/UCLA

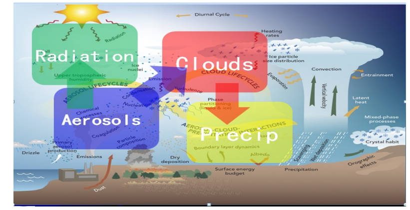
Major sources of uncertainty in AQ Models

- Emissions (anthropogenic and natural (e.g., biomass burning, wind blown dust)
- Meteorology
  - Clouds (photolysis rates, aqueous chemistry, redistribution)
  - Precipitation (removal by scavenging)
  - Planetary boundary layer height, local circulations
- Process understanding (chemistry, dry deposition, etc.)



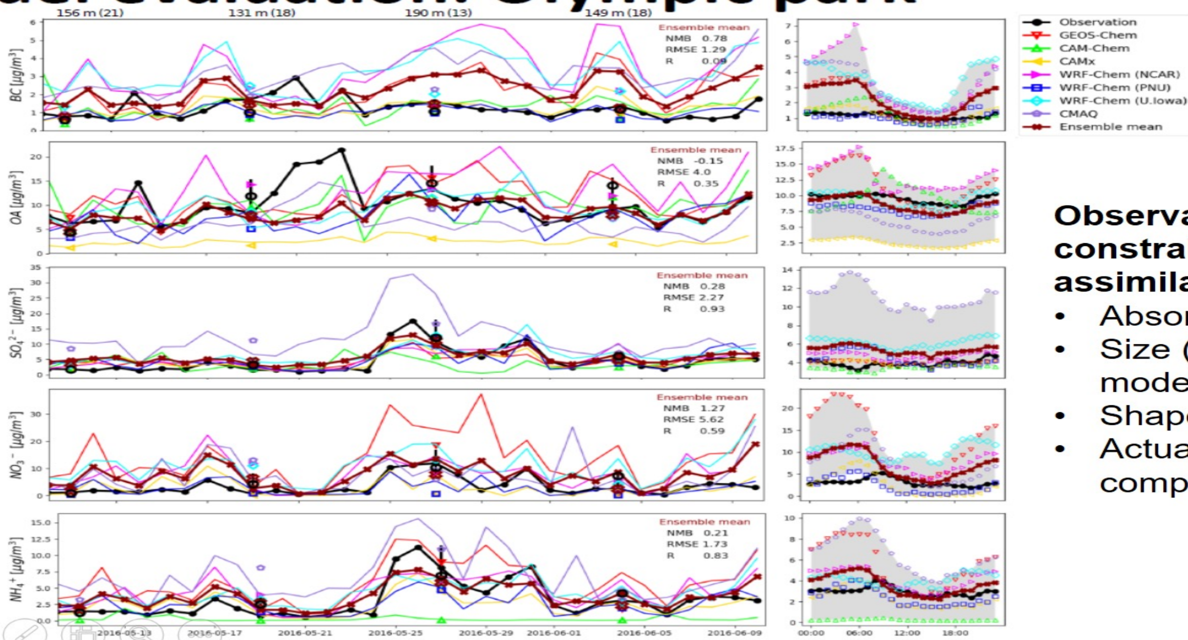
Itahashi et al., ACP, 2020

Air Pollutants Also Impact Weather & Climate -- *Aerosol Composition Matters*



There is also the issue of improving predictions of aerosol composition

Model evaluation: Olympic park



Observational constraints for assimilation:

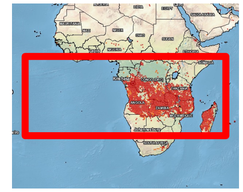
- Absorption
- Size (fine model)
- Shape
- Actual composition

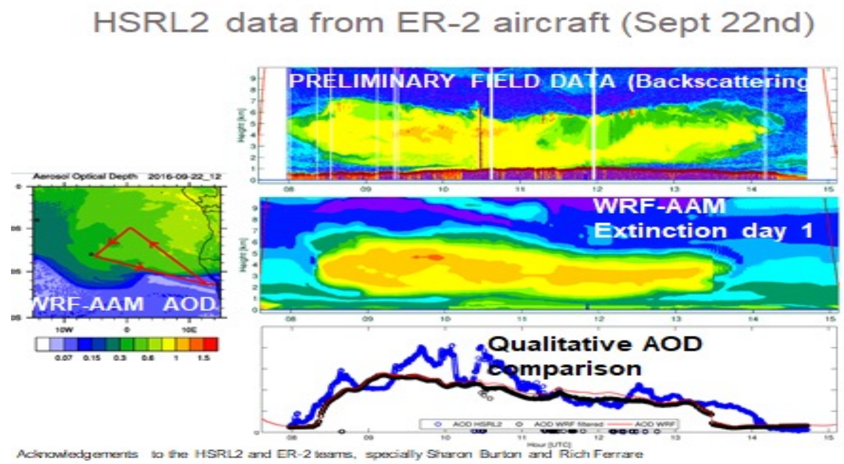
Park et al., Elementa, 2021

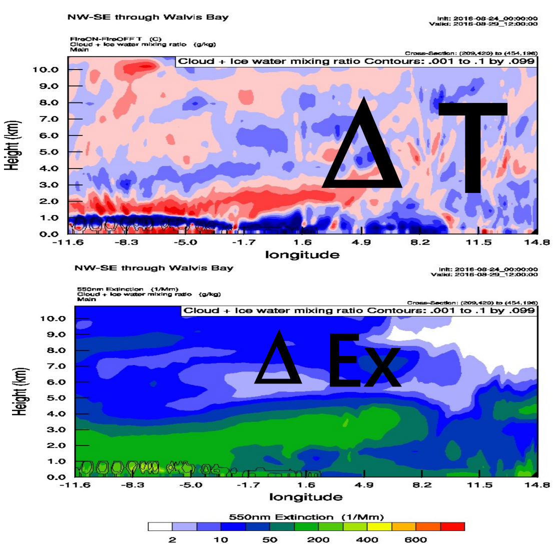
Models Constrained With Observations Play Increasing Important Roles In Research and Applications

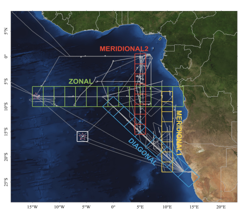
EXAMPLE: *Emission inversion and feedbacks (UCLA/IOWA)*

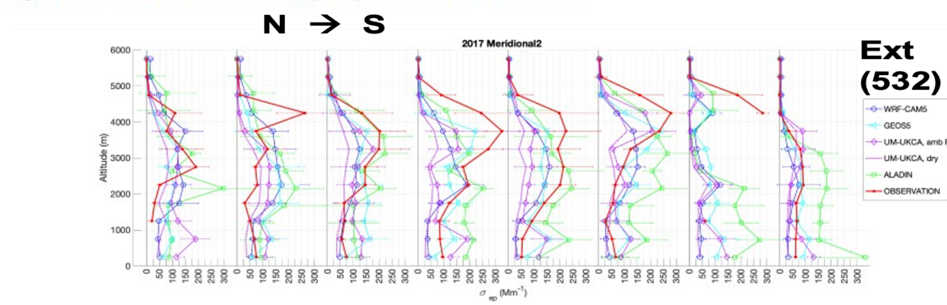
- WRF with aerosol-aware microphysics (AAM): **96 hrs**
  - Based on Thompson and Eidhammer (JAS, 2014) and Saide et al. (JGR, 2016), 12km resolution
  - Smoke emissions constrained in near-real time using Saide et al. (GRL 2015) over 6 regions for 8 hour intervals
  - Simulations turning on and off fires to assess aerosol-cloud-radiation interactions
  - Source identification
  - Full chemistry (gases and aerosol composition)





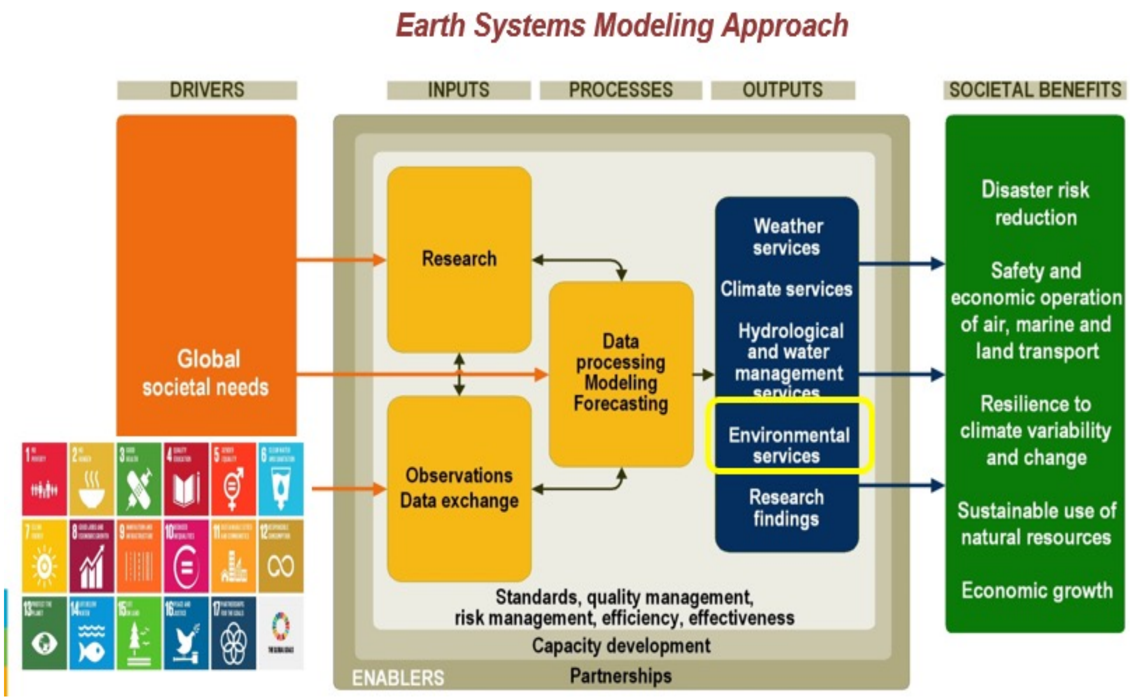






Vertical information is needed to test/improve predicted aerosol properties important to weather and climate

Overarching Objective - Improve Prediction Capabilities via Incorporating/Integrating Composition, Weather and Climate



Seamless Prediction *Across all Relevant Temporal and Spatial Scales (**GDPFS**) High Priority of WMO*

GLOBAL ATMOSPHERE WATCH

Provides international leadership in research and capacity development in **atmospheric composition** observations and analysis through:

- *maintaining and applying long-term systematic observations of the chemical composition and related physical characteristics of the atmosphere,*
- ***and delivering integrated products and services related to atmospheric composition of relevance to society.***

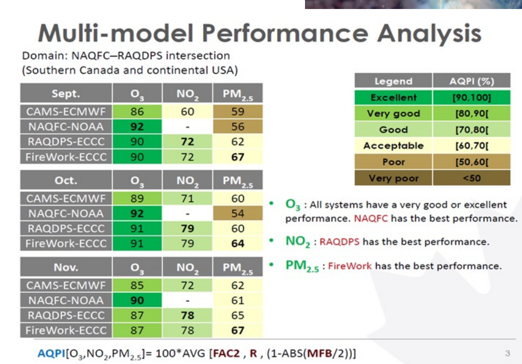
Global Air Quality Forecasting and Information system (GAFIS)

“… to enable air quality forecasting and information services in a globally harmonized and standardized way tailored to the needs of society …“

… help the transition of science to services …

… focus on **operational** AQ (forecast) services …

GLOBAL ATMOSPHERE WATCH



Multi-model Performance Analysis

Domain: NAQFC–RAQDPS intersection
(Southern Canada and continental USA)

Sept.	O_3	NO_2	$PM_{2.5}$
CAMS-ECMWF	86	60	59
NAQFC-NOAA	**92**	-	56
RAQDPS-ECCC	90	**72**	62
FireWork-ECCC	90	72	**67**

Oct.	O_3	NO_2	$PM_{2.5}$
CAMS-ECMWF	89	71	60
NAQFC-NOAA	**92**	-	54
RAQDPS-ECCC	91	**79**	60
FireWork-ECCC	91	79	**64**

Nov.	O_3	NO_2	$PM_{2.5}$
CAMS-ECMWF	85	72	62
NAQFC-NOAA	**90**	-	61
RAQDPS-ECCC	87	**78**	65
FireWork-ECCC	87	78	**67**

Legend	AQPI (%)
Excellent	[90,100]
Very good	[80,90[
Good	[70,80[
Acceptable	[60,70[
Poor	[50,60[
Very poor	<50

- O_3 : All systems have a very good or excellent performance. NAQFC has the best performance.
- NO_2 : RAQDPS has the best performance.
- $PM_{2.5}$: FireWork has the best performance.

$AQPI[O_3,NO_2,PM_{2.5}]$= 100*AVG [FAC2 , R , (1-ABS(MFB/2))]

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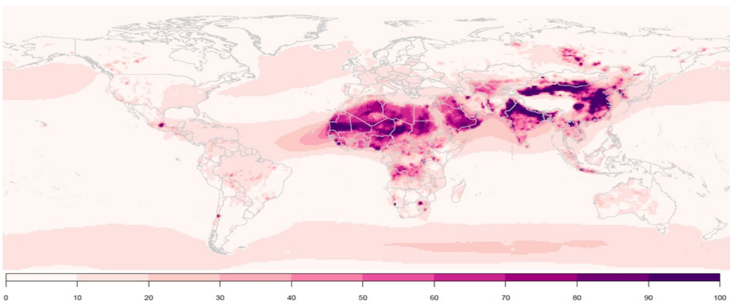
Collectively Building a Network of Air Quality Service Providers and Users

Example of the applications in GAW

Support of assessments of human health impacts

- Joint work with WHO on development of the Platform for Global Burden of Disease

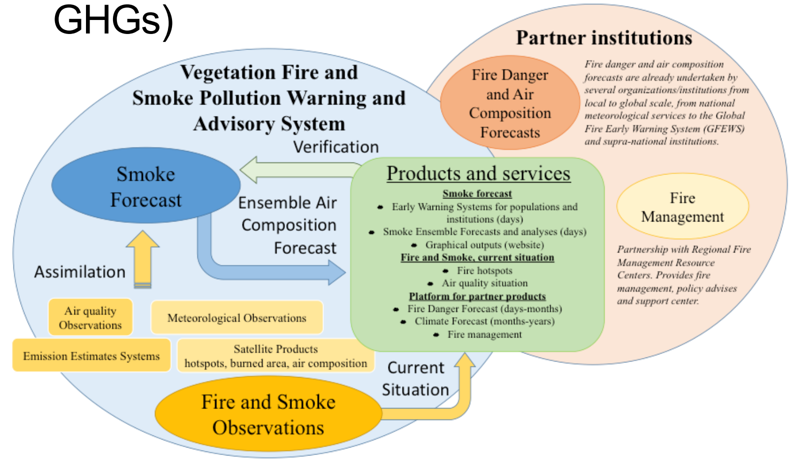


<u>+ Global reanalysis</u>: global distribution of PM2.5 in CAMS reanalysis, recent work on ozone constraints

<u>+ Source Attribution</u> (sector/region/anthropogenic) is Becoming an Important Component of Air Quality Predictions and management (also for GHGs)

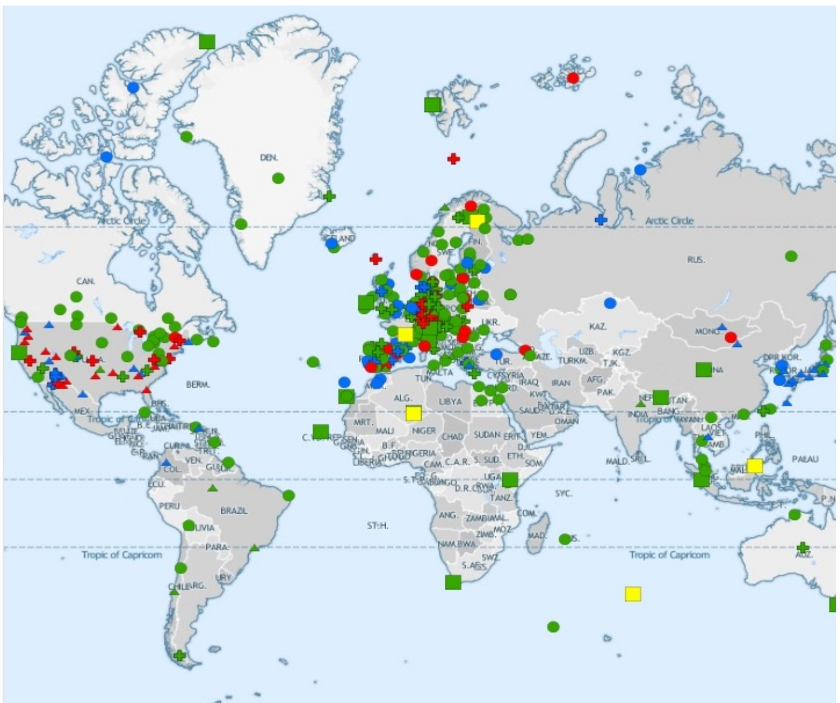
- Aerosol impacts on Seasonal to sub-seasonal (S2S) predictions (GAW/WGNE project on going)

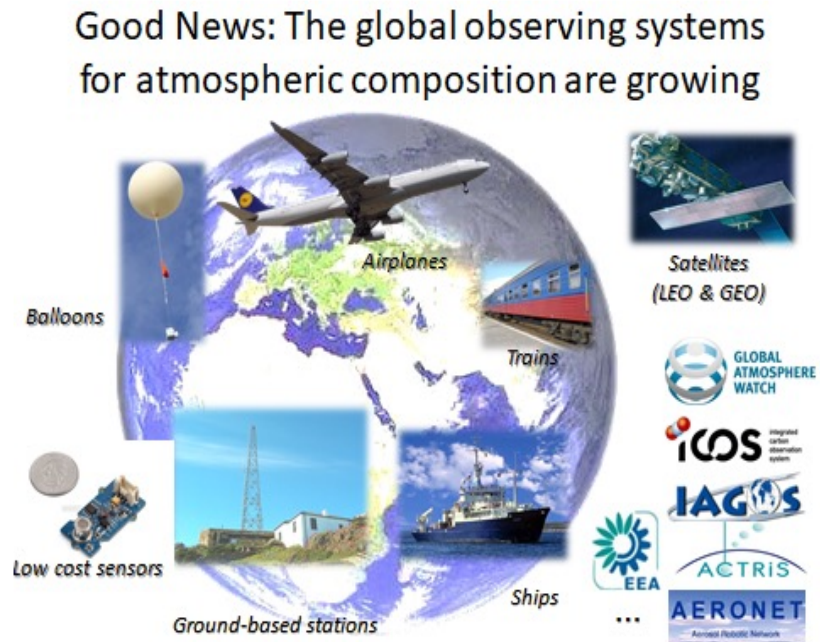
- Vegetation Fire and Smoke Pollution Warning and Advisory System



Overview of a Vegetation Fire and Smoke Pollution Warning and Advisory System

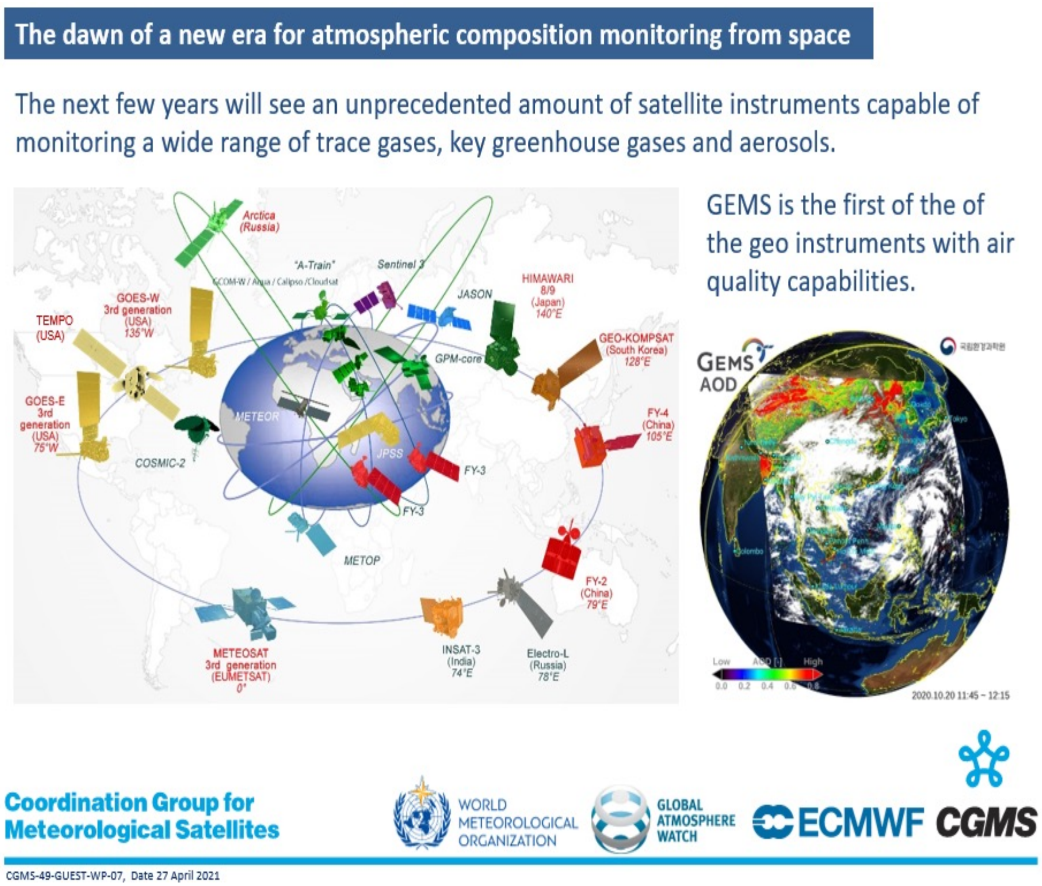
Scarcity of data -- *common need to enhance observing system*



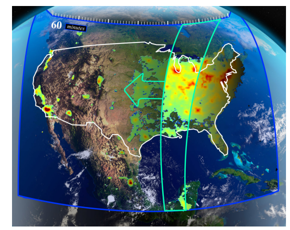


New **WMO Unified Data Policy :** Open, and the new Global Basic Observing Network (**GBON**) includes requirements for atmospheric composition

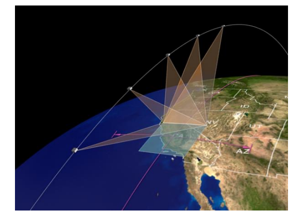
Major advances from space



TEMPO



MAIA



But ….

- **High-quality global atmospheric composition observations are of critical importance to society** and are needed to estimate exposure for health assessments, document trends in greenhouse gas emissions, and monitor compliance to conventions and protocols (e.g., those related to ozone depleting chemicals (ODCs)), among others.
- Unfortunately**, the current observing networks for atmospheric composition are fundamentally inadequate** to support the increasing number of the environmental regulations and societal applications as most recently highlighted in the commentary *Huge gaps in detecting networks plague emissions monitoring* (ref). Weiss, R.F., A.R. Ravishankara and P.A. Newman (2021) Nature 595, 491-493.
- **The environmental problems facing society caused by air pollution are interlinked**, however. Atmospheric chemical components can play many roles. For example, tropospheric ozone is both an important air pollutant and greenhouse gas. ODCs impact the stratospheric ozone layer and can be powerful warming agents. In the discovery phase, the research networks mostly have been addressing a single issue, like inadvertent ozone depletion by the ODCs.
- Optimal approach is to i**nvest in an observational network that covers a comprehensive suite of parameters (greenhouse gases, air pollutants, ODCs)** to support policies aimed at reducing their collective societal environmental impacts was proposed by Kulmala in 2018 acting on concepts laid out in the IGACO assessment report (IGACO 2004).
- We support this idea and recommend the implementation of the value cycle approach mentioned above where the observational data flow is coupled to operational and research mode Earth system modelling, so that the operational and the research infrastructure is bound together. This will help in realizing the vision for the global Earth observatory because it will mostly reside in the long term operational domain which has the responsibility – and the funding - to monitor compliance and to forecast pollution loads related e.g. to human health, agriculture, water quality, UV radiation, climate change etc.

But .....

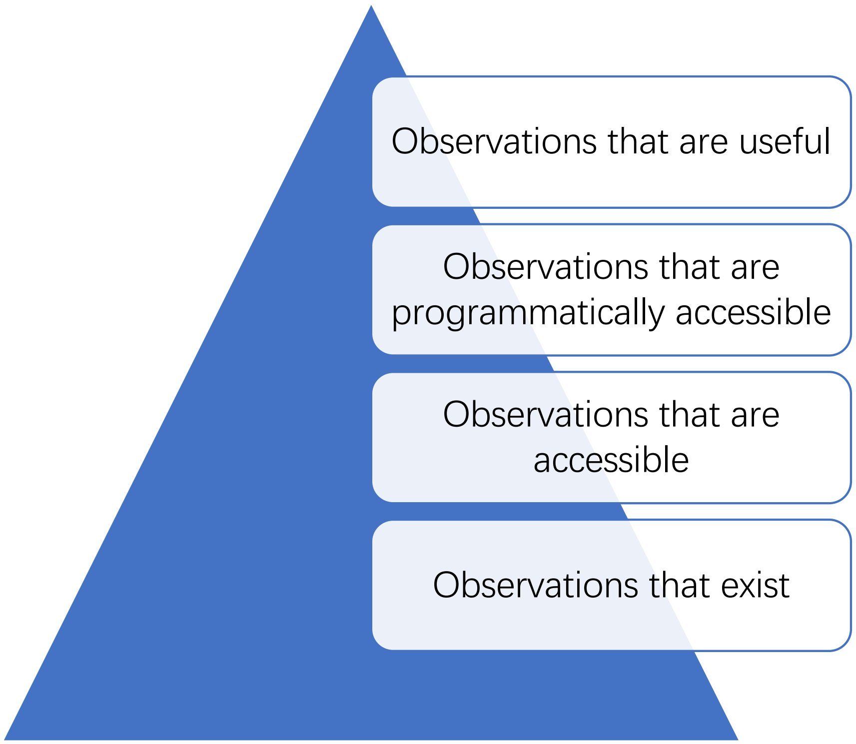
- We need to **make further investments in high-quality global atmospheric composition observations** to support societal needs to address the pressing environmental problems that surround changes in atmospheric composition.
- We recommend the implementation of the **value cycle approach** where the **observational data flow is coupled to operational and research mode Earth system modelling**, so that the operational and the research infrastructure is bound together.
- We can meet this challenge to enhance the observing system through **focused science for service applications** and embracing interoperable observation systems and standardized metadata leading to data that are findable, accessible, interoperable and retrievable (FAIR).
- The **coupling of the observational data flow with earth system models in operational as well as research modes** will promote a more diverse and inclusive atmospheric composition research and application/user community where use experience feeds into the research part, and where mature research results are translated into the operational applications.
- This will lead to faster exploration and exploitation of atmospheric composition information, and **more impactful applications for science and society.**

Build a global Earth observatory

Markku Kulmala calls for continuous, comprehensive monitoring of interactions between the planet's surface and atmosphere.

Markku Kulmala

We are not using what we know



Some of the data have metadata that allows users to assess quality and handle accordingly.

Some of the in-principle accessible data are aggregated, downloadable, machine-readable through generalizable queries.

Some of are made "open" in some format or purchasable through a well-defined process. With a little work, one can find them and build a dataset

Increasing investment in measurements of atmospheric composition, particularly at ground level, from public, private, academic and even communities.

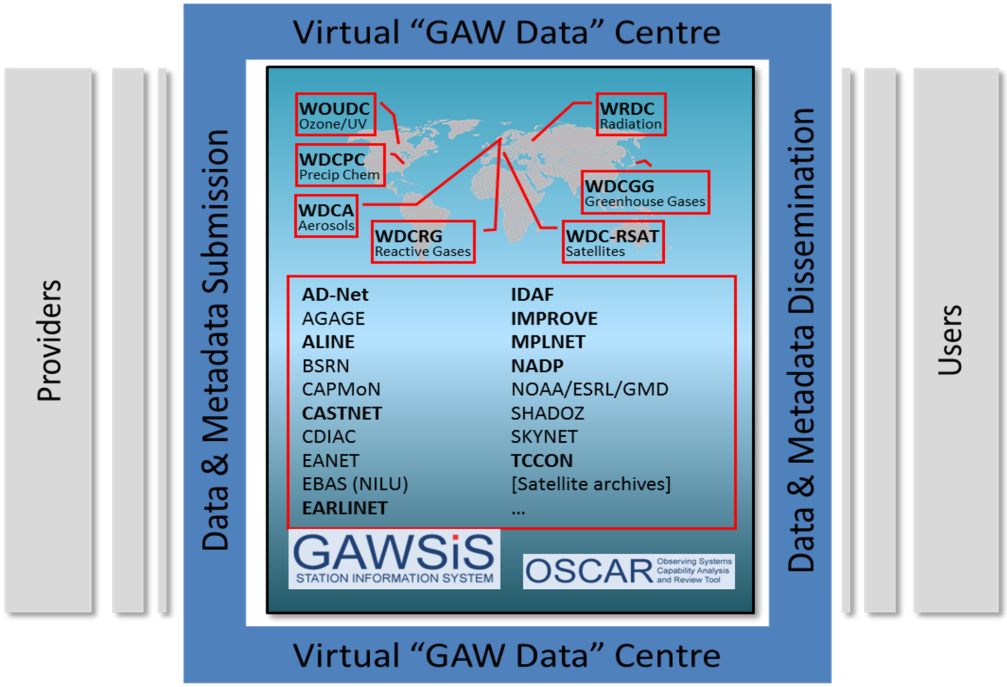
How to make sure we have consistent labeling to enable users to separate signal from noise?

How to ensure that what's "open" is actually retrievable – and that this arrangement is sustainable.

How to increase incentives for opening data – if not real time, then with a lag?

Jessica Seddon, PhD
Global Lead, Air Quality
World Resources Institute

Critical Need: Enhance data management architectures to facilitate improved metadata exchange and interoperability, data discovery and analysis, and to promote and facilitate the near-real time delivery of data.



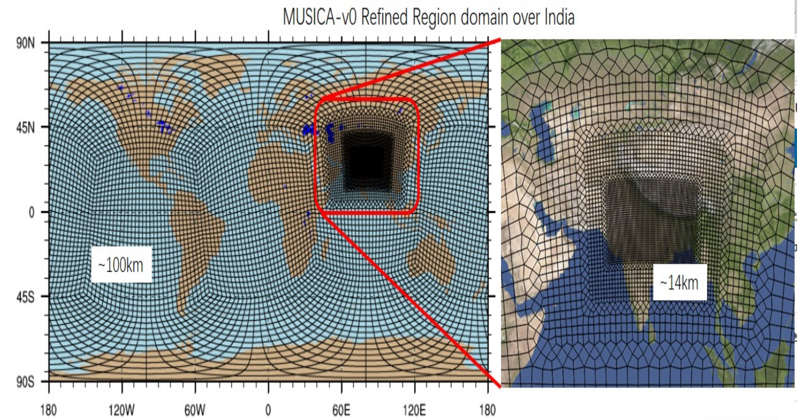
Implementation of the WIGOS metadata standard

GAW Data Management

Confronting Future Models with Future Satellite Observations of Clouds and Aerosols: 2020 ACCP Modeling and Assimilation Virtual Workshop ***… looking out a decade (BAMS 2021)***

Nov 10,12th 2020

A. Gettelman[1], G. R. Carmichael[2], G. Feingold[3], A. M. Da Silva[4], S. C. Van Den Heever[5]

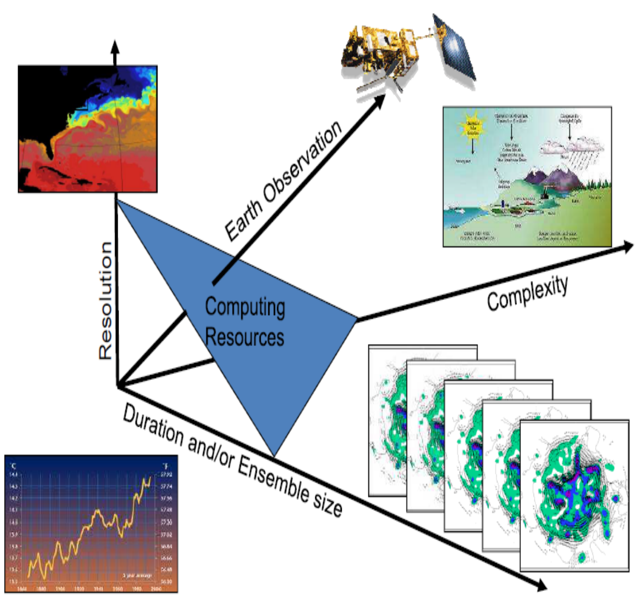


- Models of the future will be higher resolution, often refined resolution over a region of interest, and coupled with applications from air quality and human health to hydrology and runoff. These models will be integrated across scales in space and time (from regional to global, from weather to climate) and also across applications (including NWP and air quality forecasting).
- Future observations will be refined and expanded. Satellite observations will provide targeted observations with higher quality, higher spatial resolution and more, coincident variables. But there will also be significant additional observations of different variables from a myriad of sensor networks such as geostationary satellites, swarms of small satellites, suborbital and surface platforms. All these observations will need to be integrated (with models) into observing and modeling systems.
- This future requires comprehensive model-data synthesis capabilities. The boundary between observations, retrieval, model and observation simulators will blur.
- This new paradigm will also accelerate the blurring of disciplinary boundaries and create a new generation of interdisciplinary scientists using a fusion of data and models.

Overarching Goal:

Advancing Atmospheric Composition Predictions and Related Services to Meet the Growing Societal Needs

Improving predictive skill



- ✓ High-quality atmospheric composition infrastructure (ACF) (obs, models, data management & people) that provides long-term comprehensive measurements and products is of critical importance to society (e.g., COVID impacts, CH_4 leaks, Global Burden of Disease). ***The need for, and uses of, ACF are expanding.***
- ✓ **Challenges:** expanding/maintaining the ACF (observations and Earth System Modeling); increasing impact by direct and timely engagement of end-users (health, urban resilience, policy makers), and strengthening collaborations and capacity across regions and organizations.
- ✓ **Opportunities**: meet the challenges through enhanced/focused science for service applications of ACF and embracing holistic *Open Science* to achieve a better integrated observing system (including low-cost sensors, space-based, vertically-resolved elements), enhanced and more seamless data discovery and use, better access to models and products, and a more diverse and inclusive atmospheric composition community.
- ✓ This will lead to faster exploration and exploitation of atmospheric composition information, and **more impactful applications for science and society.**