# The importance of atmospheric chemistry research in advancing understanding of weather, climate and air quality and enhancing associated societal services

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WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

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World Meteorological Organization
Organisation météorologique mondiale

GAW

# Reform of WMO

The eighteenth World Meteorological Congress (Cg-18, Geneva, 3–14 June 2019) adopted a historical reform of the WMO constituent bodies to embrace a more **comprehensive Earth system approach**, with a stronger focus on water resources and the ocean, **more coordinated climate activities** and a more concerted effort **to translate science into services for society**.

The Congress approved a new WMO strategic plan 2020-2023. **Long-term Goals and Strategic Objectives:**

**Goal 1:** Better serve societal needs: delivering, authoritative, accessible, user-oriented and fit-for-purpose information and services

**Goal 2:** Enhance Earth system observations and predictions: Strengthening the technical foundation for the future

**Goal 3:** Advance targeted research: Leveraging leadership in science to improve understanding of the Earth system for enhanced services

**Goal 4:** Close the capacity gap on weather, climate, hydrological and related environmental services: Enhancing service delivery capacity of developing countries to ensure availability of essential information and services needed by governments, economic sectors and citizens

**Goal 5:** Strategic realignment of WMO structure and programmes for effective policy- and decision-making and implementation.

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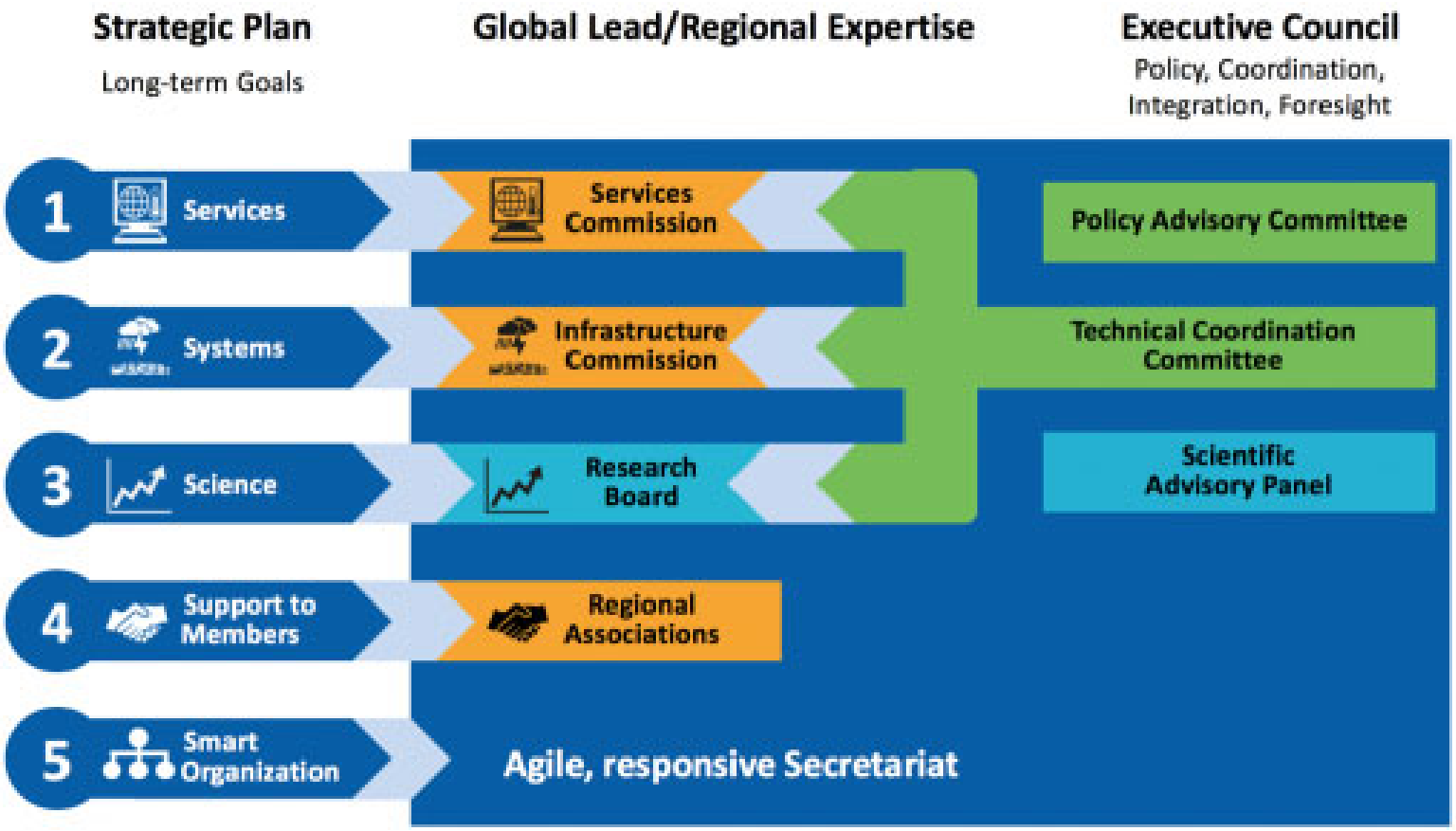
# Structure of WMO constituent bodies

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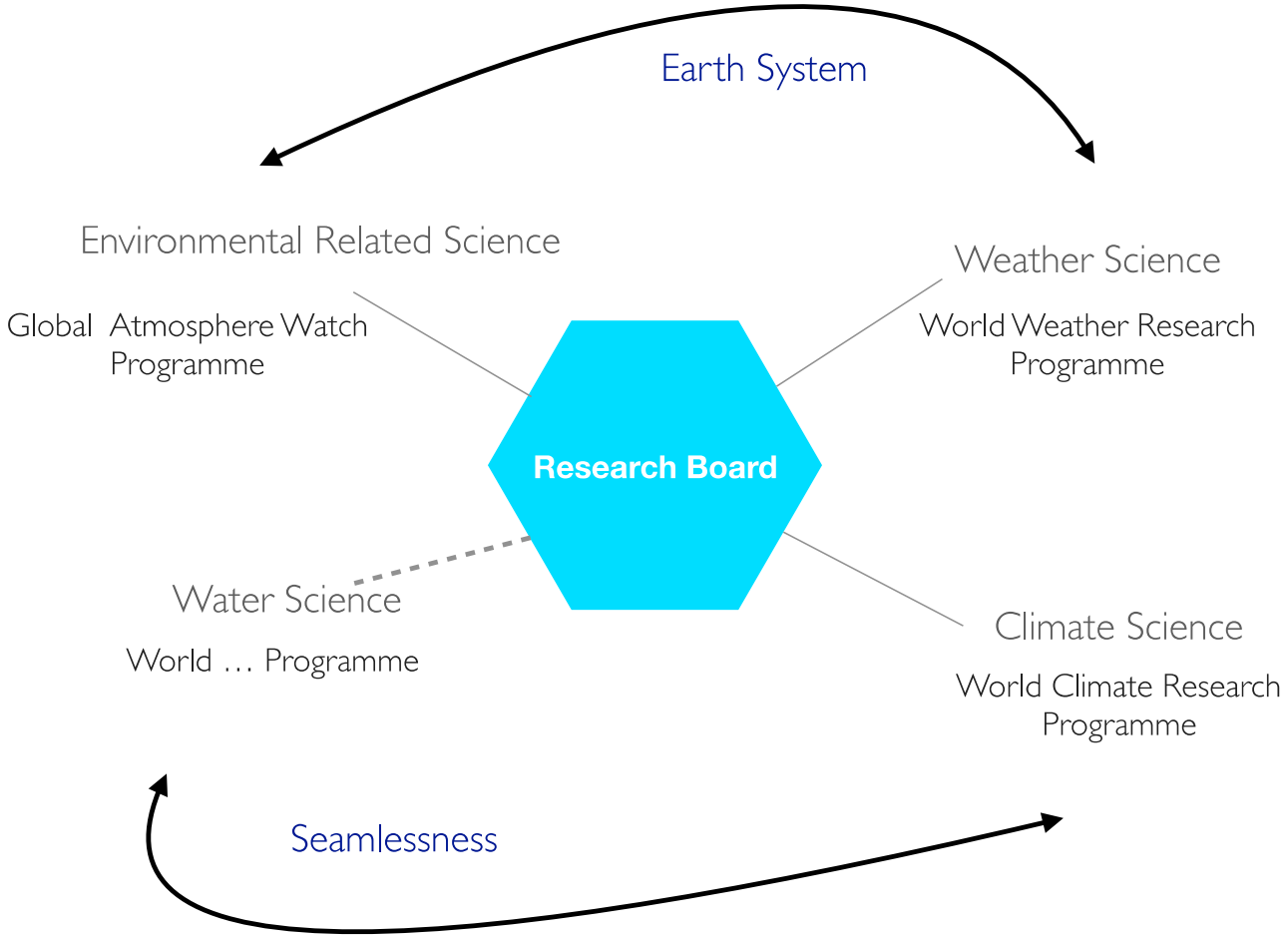
# Research Board

1. Advance knowledge of the Earth System (fundamental knowledge development)
2. Advance policy relevant science (where some interaction with TCs happens)
3. Enhance connections between the science and the services through the value chain approach (where most of the interaction with other TCs will happen)

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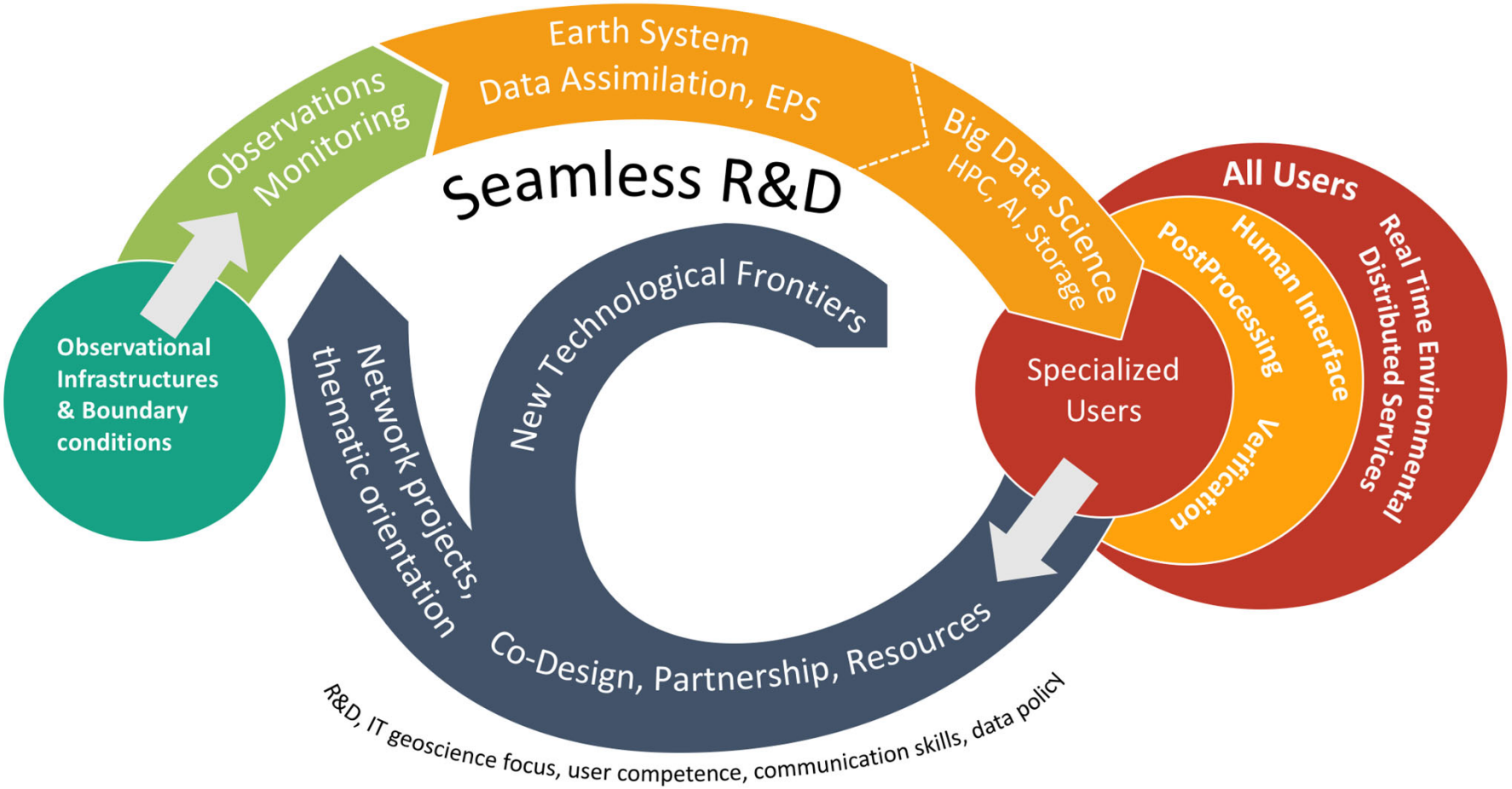
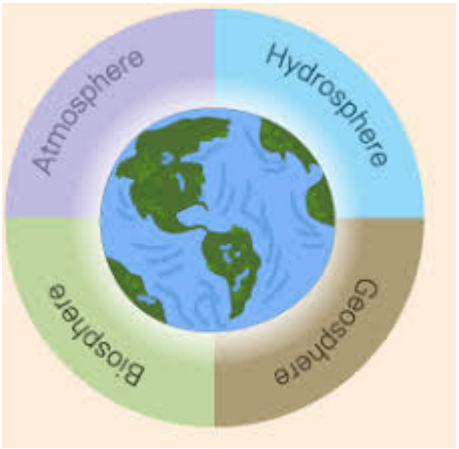
# SEAMLESS SCIENCE FOR SERVICES JOURNEY

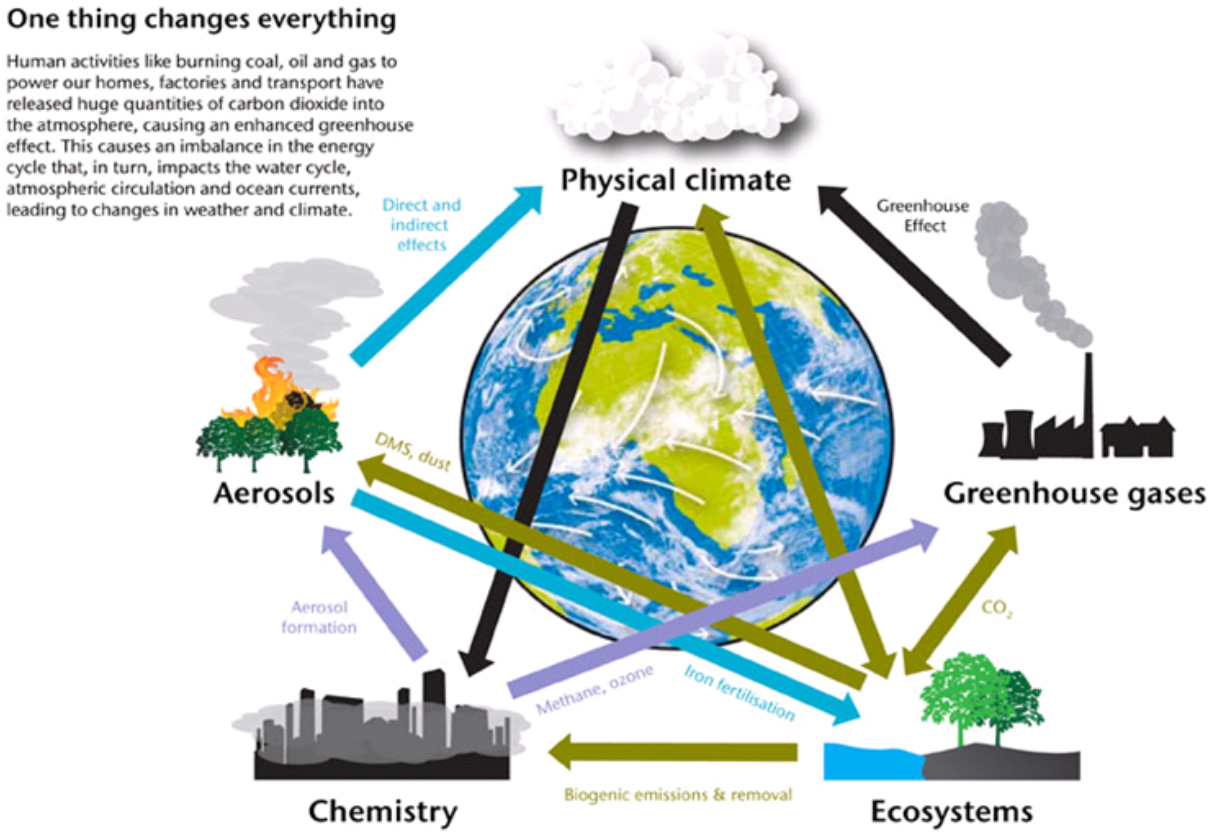
- Quality, Relevance and Impact:
- User Interactions forces exploration of “What works”
- Seamless Earth system modelling across weather, water, environment, ocean, climate; interoperable observation systems of ES components



# Earth System approach




The term “Earth system" refers to Earth´s interacting physical, chemical, and biological processes. The system consists of the land, oceans, atmosphere and poles. It includes the planet's natural cycles — the carbon, water, nitrogen, phosphorus, sulphur and other cycles — and deep Earth processes.

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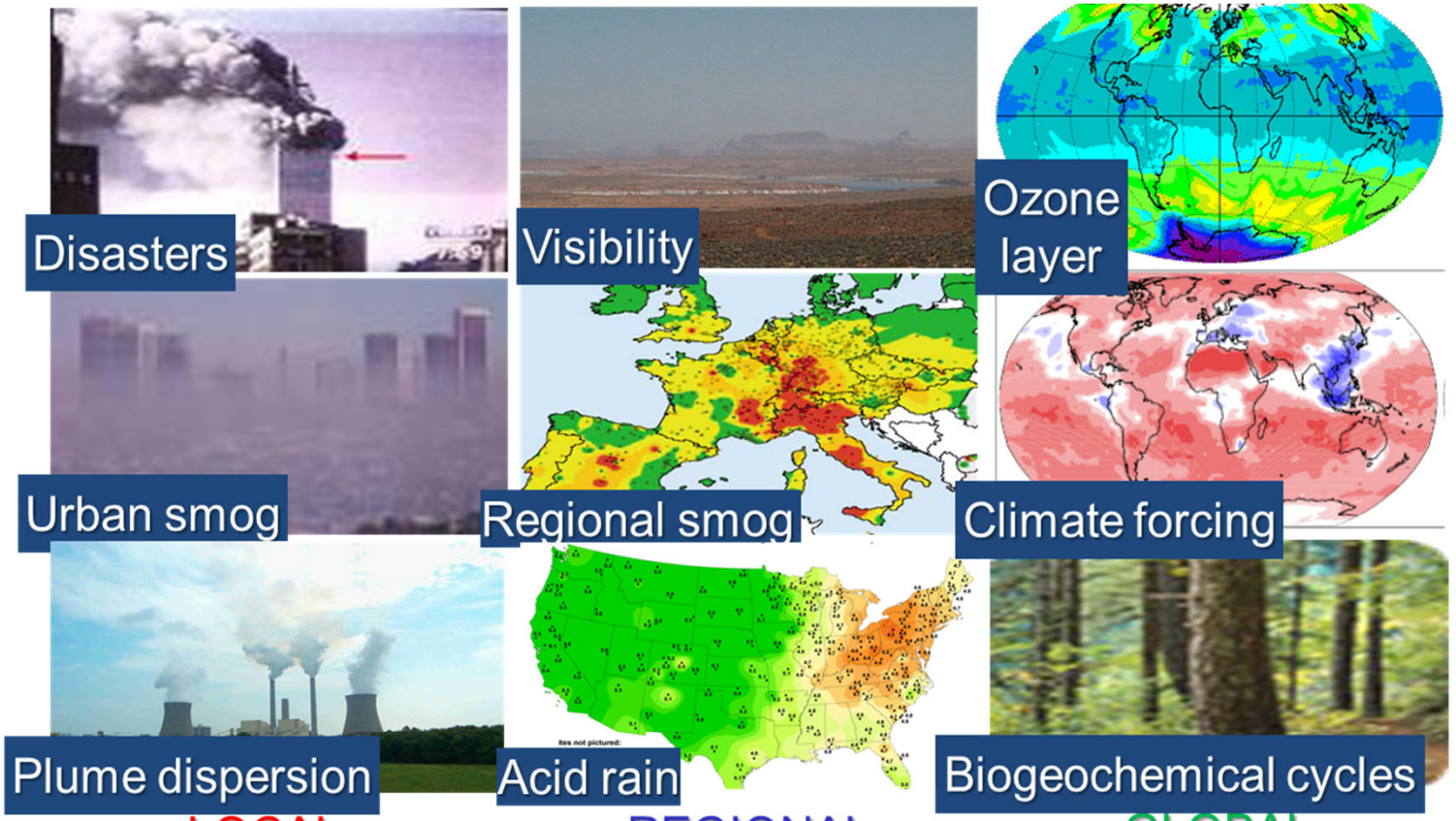
# Atmospheric Composition Matters: To Air Quality, Weather, Climate and More

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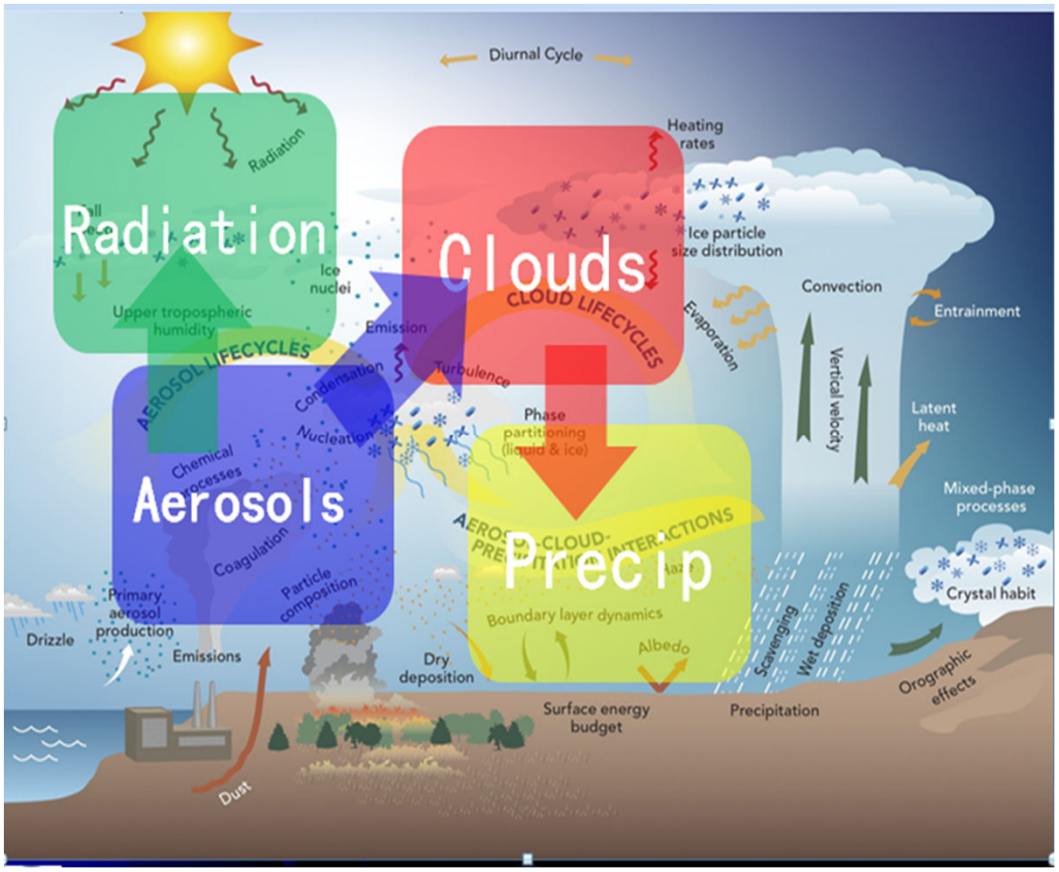
The University of Iowa

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




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

***Observations and models are essential components for effective environmental management***

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# Global Atmosphere Watch Programme

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,*
- *emphasizing quality assurance and quality control,*
- *delivering integrated products and services related to atmospheric composition of relevance to users.*

**GAW builds on partnerships involving contributors from 100 countries (*including many contributions from research community*)**




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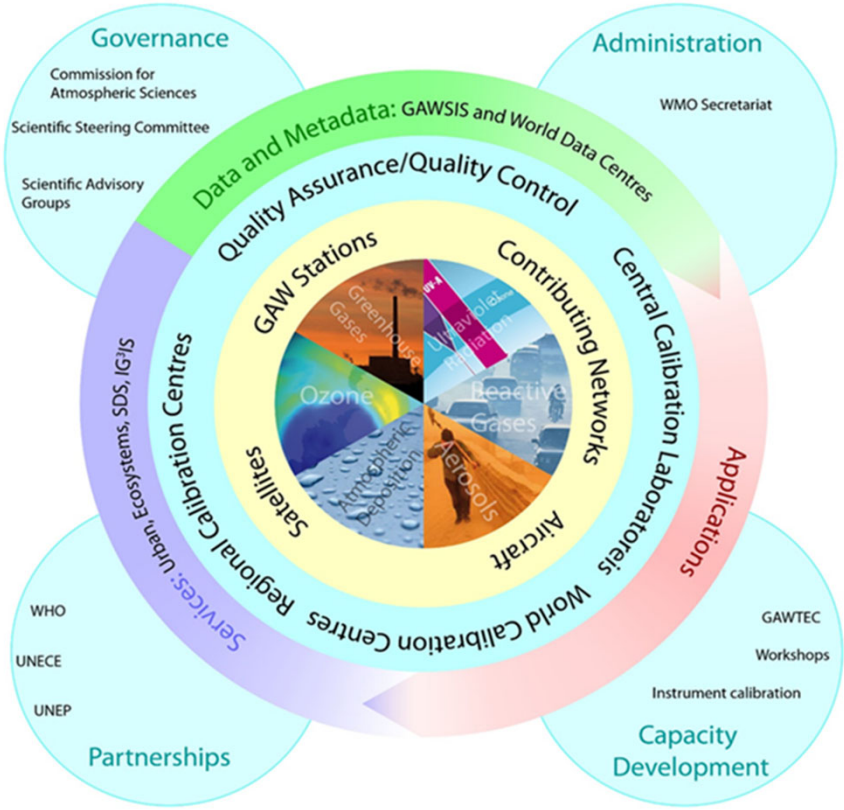
# Elements integrated in GAW

- Observations
- Quality assurance
- Data management
- Modeling and analysis
- Joint research
- Capacity building
- Outreach and communications




***Promote a "value chain" from observations to services***

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# Observational infrastructure

**GAW Station Information System (GAWSIS)**

World Meteorological Organization

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

| | | | |
|---|---|---|---|
| Global | ■ | Reporting | ● |
| Regional | ● | Partly Reporting | ● |
| Contributing | ▲ | Non-reporting | ● |
| Local | ★ | Closed | ● |
| | | Planned | ● |
| | | Pre-operational | ● |

1) GAW stations are often comprised of a rather complicated “research” infrastructure
2) Many stations are operated by the other agencies than NMHSs
3) GAW collaborates with the regional networks and networks operated for national regulations and conventions

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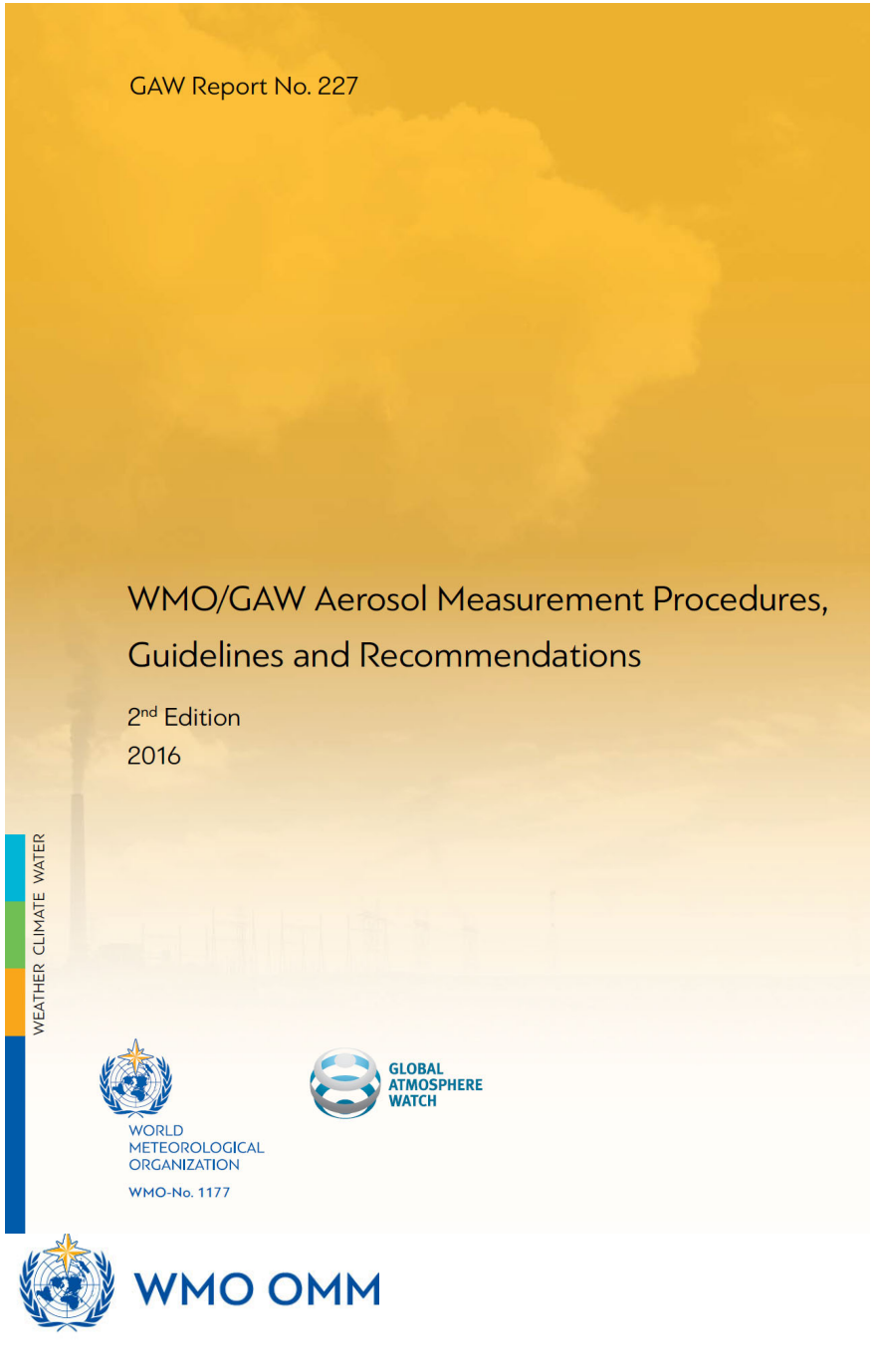
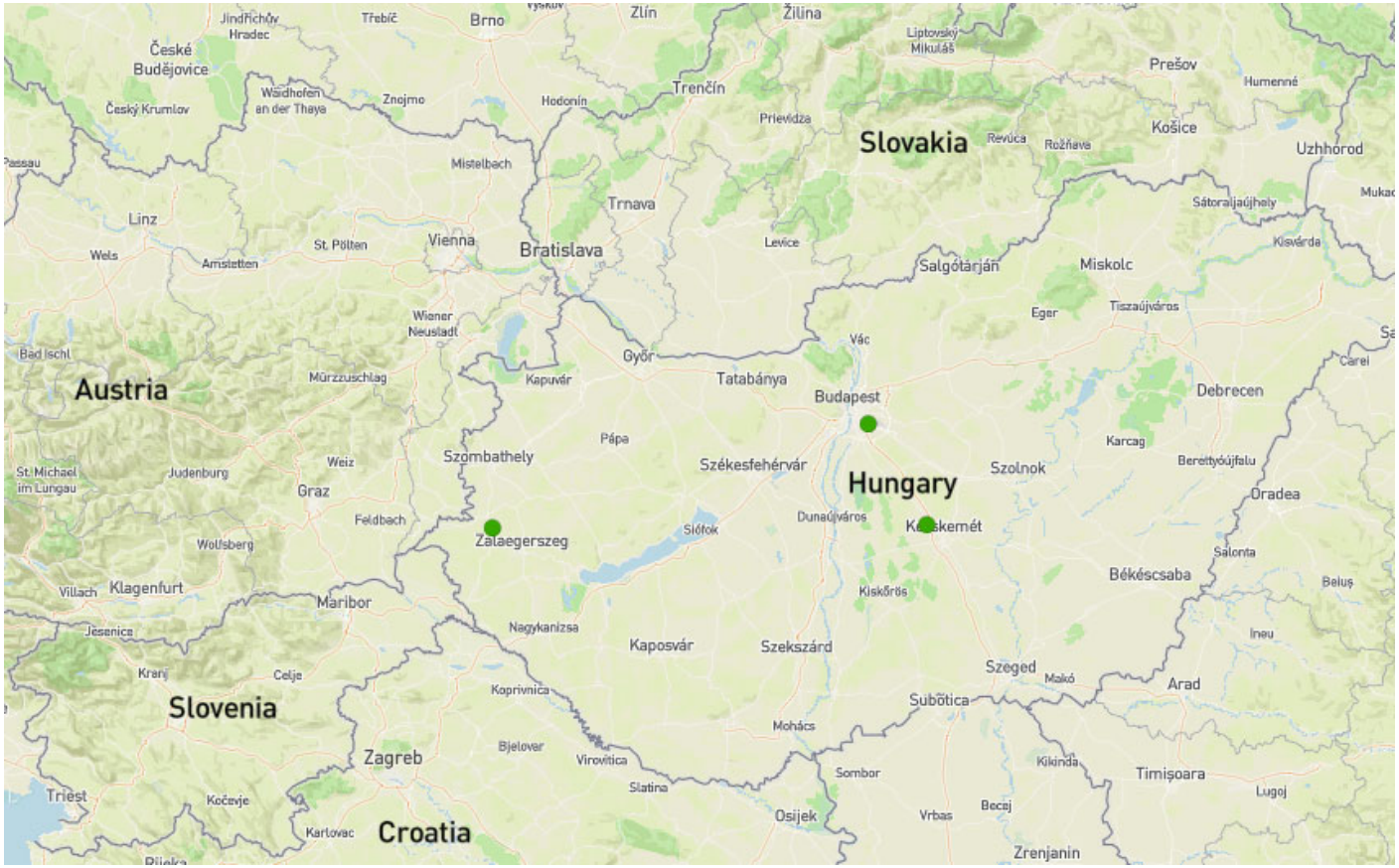



# GAW Observations

- Stratospheric Ozone and vertical ozone distribution
- Greenhouse Gases ($CO_2$ and its isotopes , $CH_4$ and its isotopes, $N_2/O_2$ ratio, $N_2O$, $SF_6$, CFCs and substitutes)
- Reactive Gases ($O_3$, CO, VOCs, $NO_x$, $SO_2$)
- Total atmospheric deposition
- Aerosols (chemical and physical properties, AOD)
- UV Radiation
- *GAW Urban Meteorology and Environment (GURME) project*
- *GAW Modelling Applications SAG*
- *GAW co-sponsors GESAMP*

# GAW observations in Hungary




- Budapest – Lorinc - GAW Regional Station (aerosol composition and precipitation chemistry)
- Hegyhatsal - GAW Regional Station (collect flasks for NOAA)
- **K-Puszta - GAW Regional Station** (aerosol physical and chemical properties, reactive gases and greenhouse gases, POPs, deposition)

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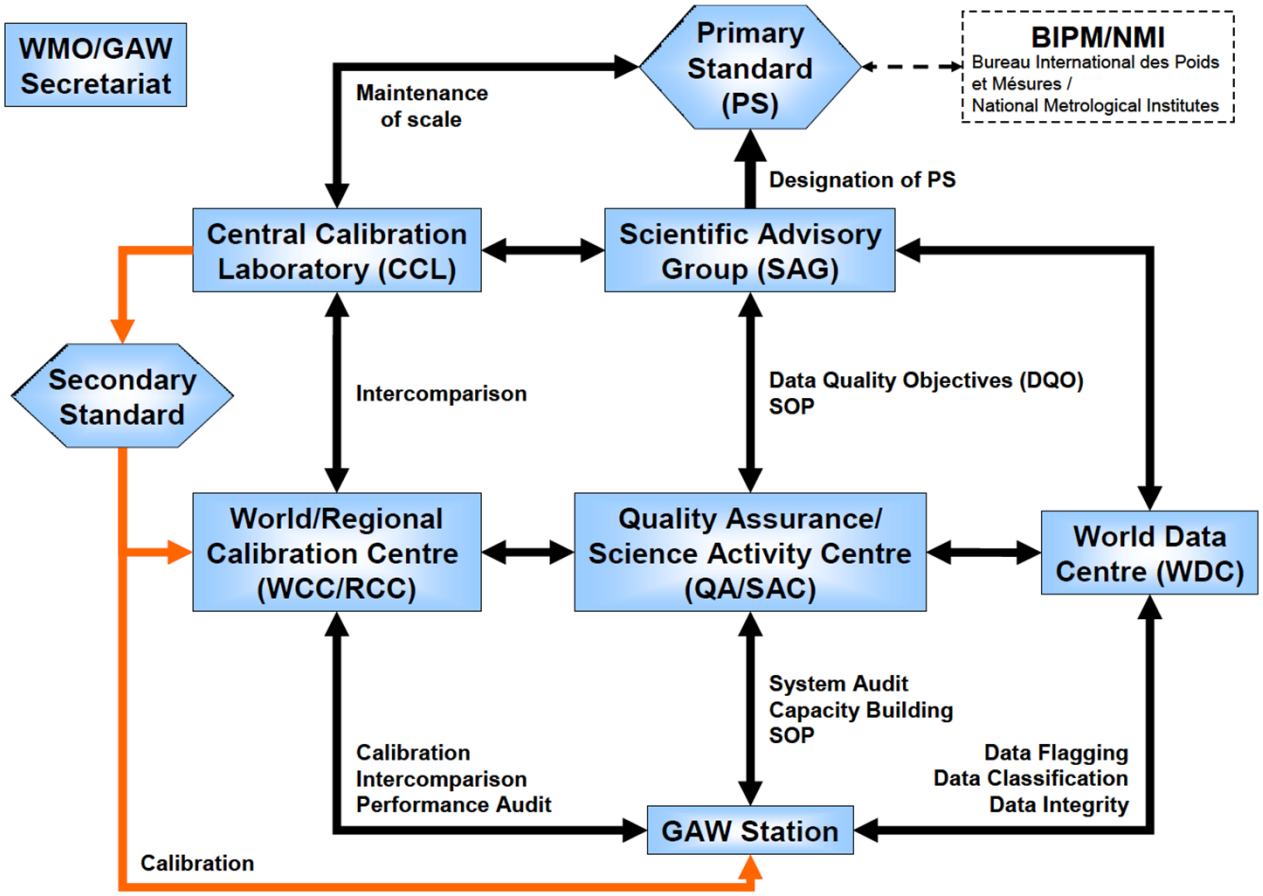
# Quality Assurance/Quality Control Concept of GAW




About 30 Central Facilities contributing to the global QA/QC system

Regular comparison exercises

Harmonized measurement guidelines

**To ensure proper inclusion of the new technologies in the evolving observing system**
**an assessment of the low-cost atmospheric composition sensors was performed**

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# Low Cost Sensors Statement

- Based on peer-reviewed publications through 2017
- Applications of sensors, definitions, sensor performance, evaluation exercises and facilities, quality assurance , conclusions and recommendations
- Covers on-line sensors for:
  - Reactive gases or other air pollutants including NO, $NO_2$, $O_3$, CO, $SO_2$, and total VOCs.
  - Long-lived greenhouse gases: $CO_2$ and $CH_4$
  - Airborne particulate matter (PM)



**WMO-No. 1215**
**ISBN 978-92-63-11215-6**

To share your experience, publications and related meetings please use the LCS forum
**https://wmoairsensor.discussion.community/**

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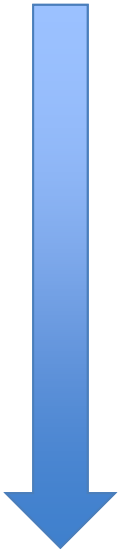
# Covered technologies

- Electrochemical method
- Metal oxide
- Photo-ionization detectors (PID)
- Optical (light scattering, NDIR)



Continuous in-situ analyzers

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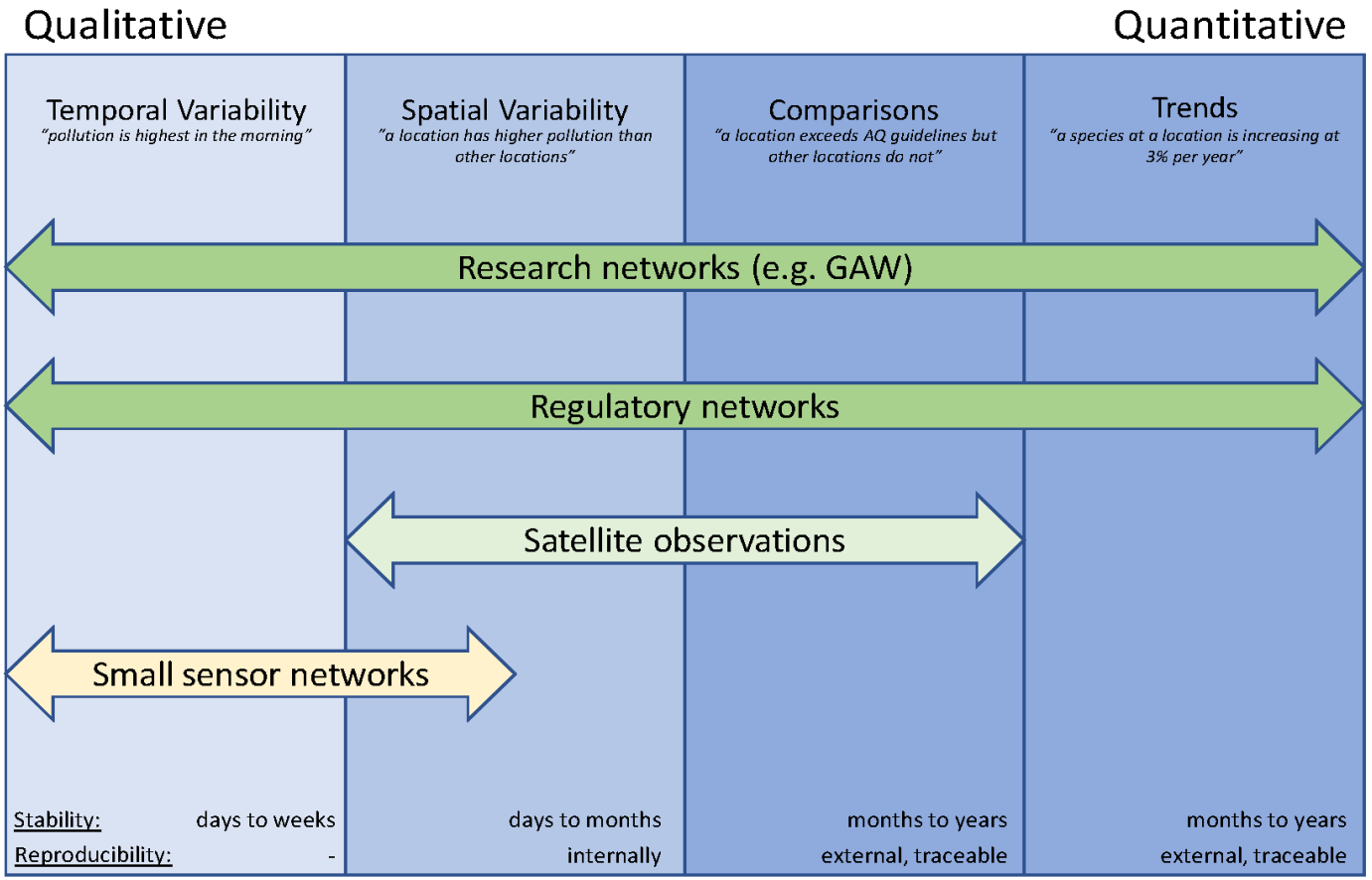
# Where sensors seem to fit best (now, at least)

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# LCS Document Conclusions

| Can LCS measure… | Literature-based Conclusions |
|---|---|
| …Temporal Variability | Useful for short-term trends (hours to days to months) |
| …Spatial Variability | Useful, as long as sensors report reproducible measurements across different sensors |
| …Concentration Dependence | Limited evidence, because it requires comparison against long term trends; quantitative insufficiency. |
| …Personal Exposure | Not suitable for quantitative assessment. |
| …Long Term Trends | Not suitable |

# Applications and service development in GAW

- **Climate**
- **Air quality and health**
- **Ecosystem**
- **Urban services**

Development of the new services is driven by the CLEAR USER community

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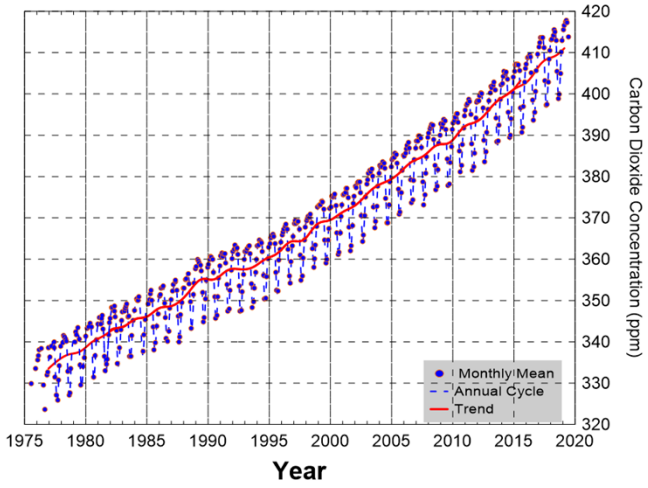
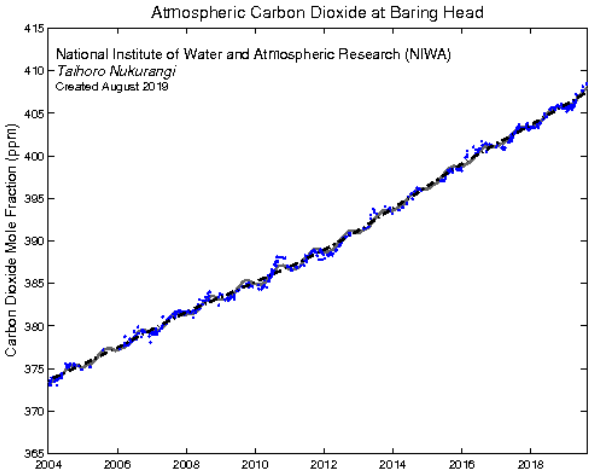
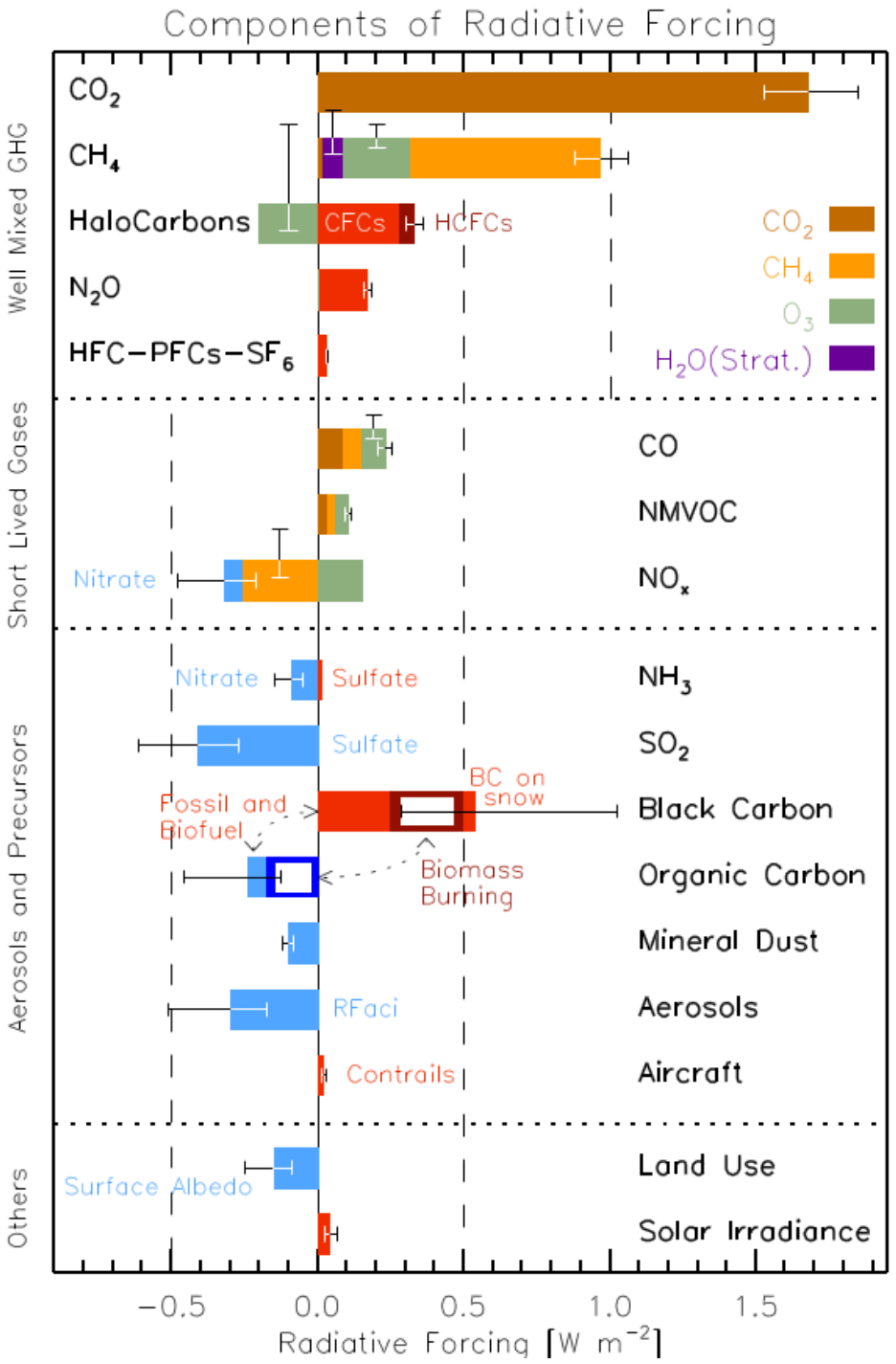
# Radiative Forcing – Why we have climate change

Alert station in the Arctic




Baring Head, New Zealand

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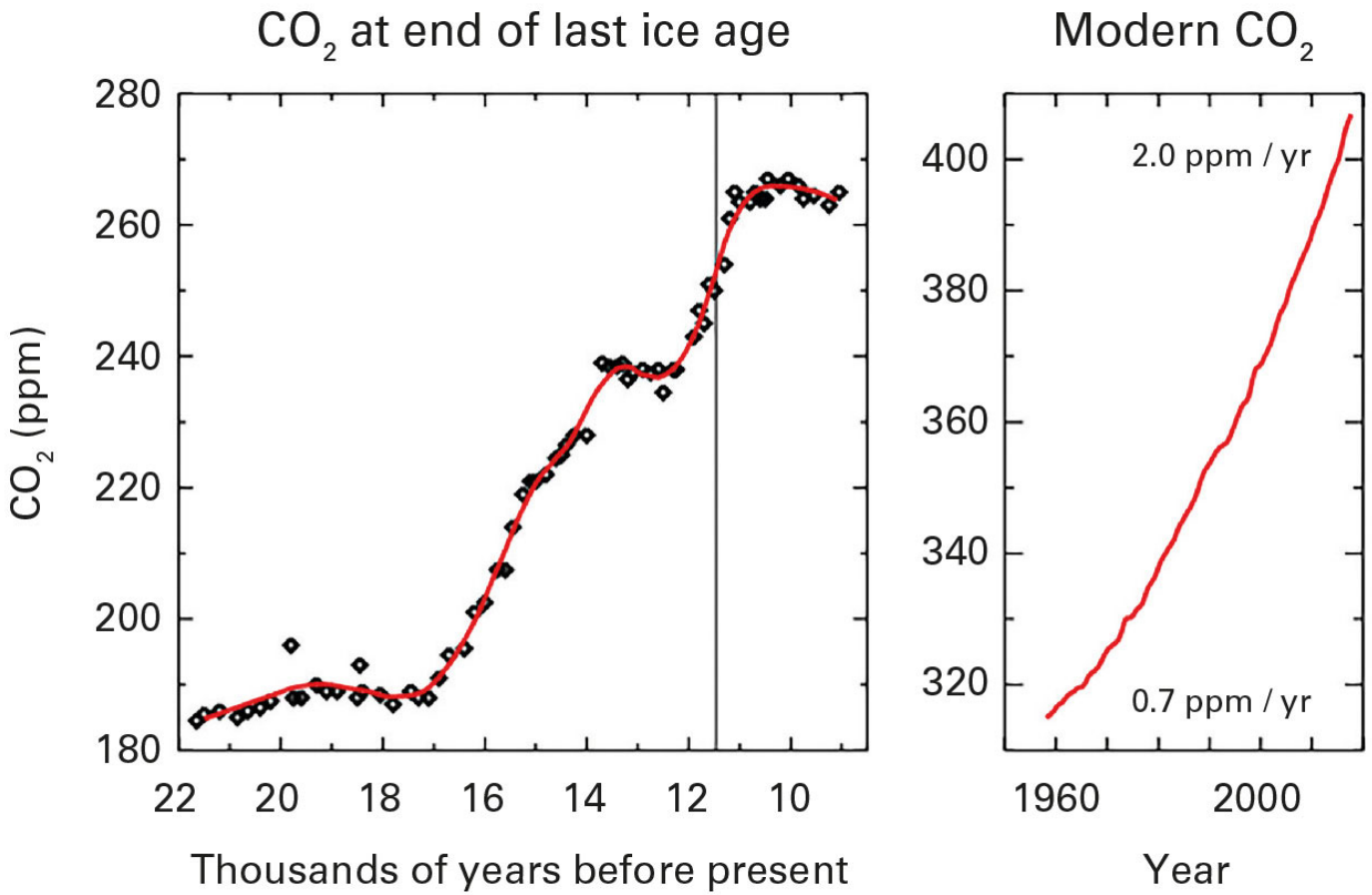
# WMO GREENHOUSE GAS BULLETIN

The State of Greenhouse Gases in the Atmosphere
Based on Global Observations through 2016

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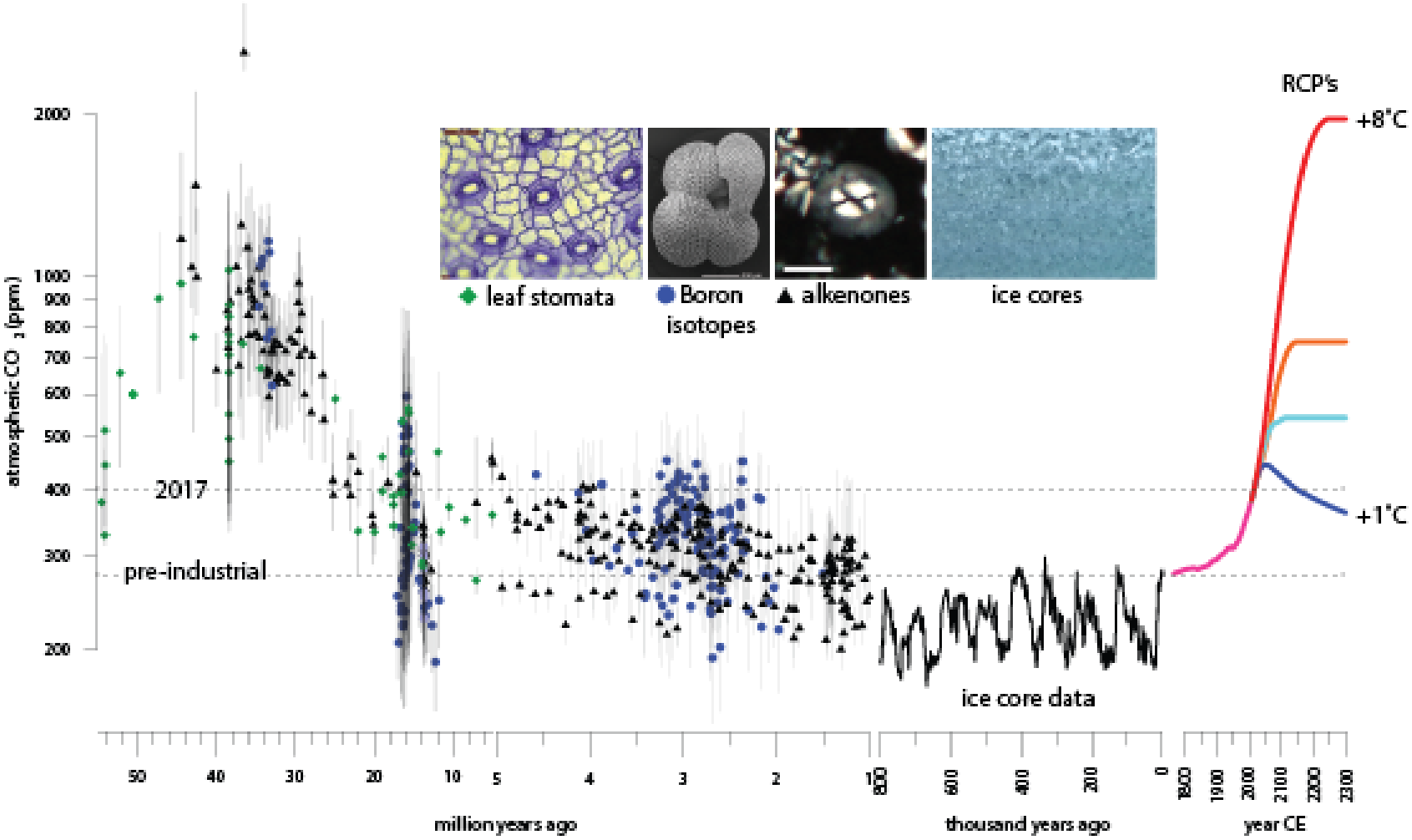
# Paleo records of $CO_2$

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# The Integrated Global Greenhouse Gas Information System (IG³IS)


**Goal:** Support the success of post-COP21 actions of nations, sub-national governments, and the private sector to reduce climate-disrupting GHG emissions through a sound-scientific, **measurement-based approach** that:

- Improve knowledge of the national emissions, **WHAT?**
- identifies large and additional emission reduction opportunities, **WHERE?**
- provides nations with timely and quantified guidance on progress towards their emission reduction strategies and pledges (e.g., NDCs) **EFFECT?**

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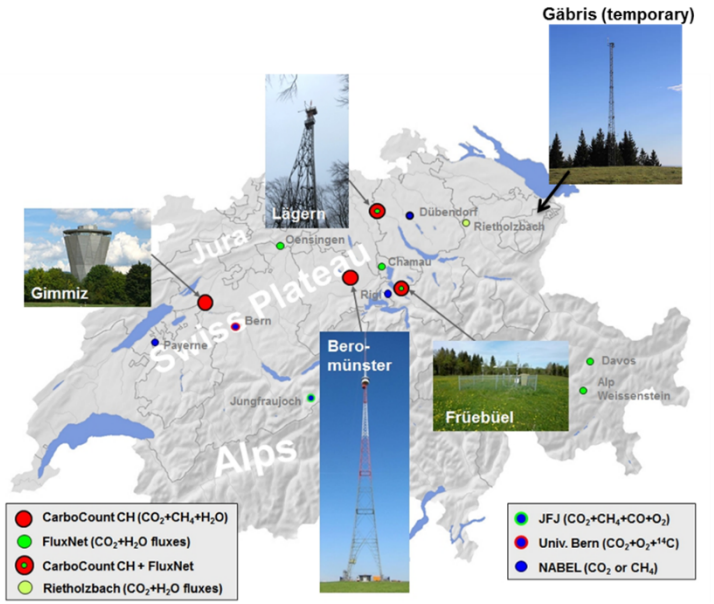
HOW? ➡ IG³IS Science Implementation Plan was approved by EC-70

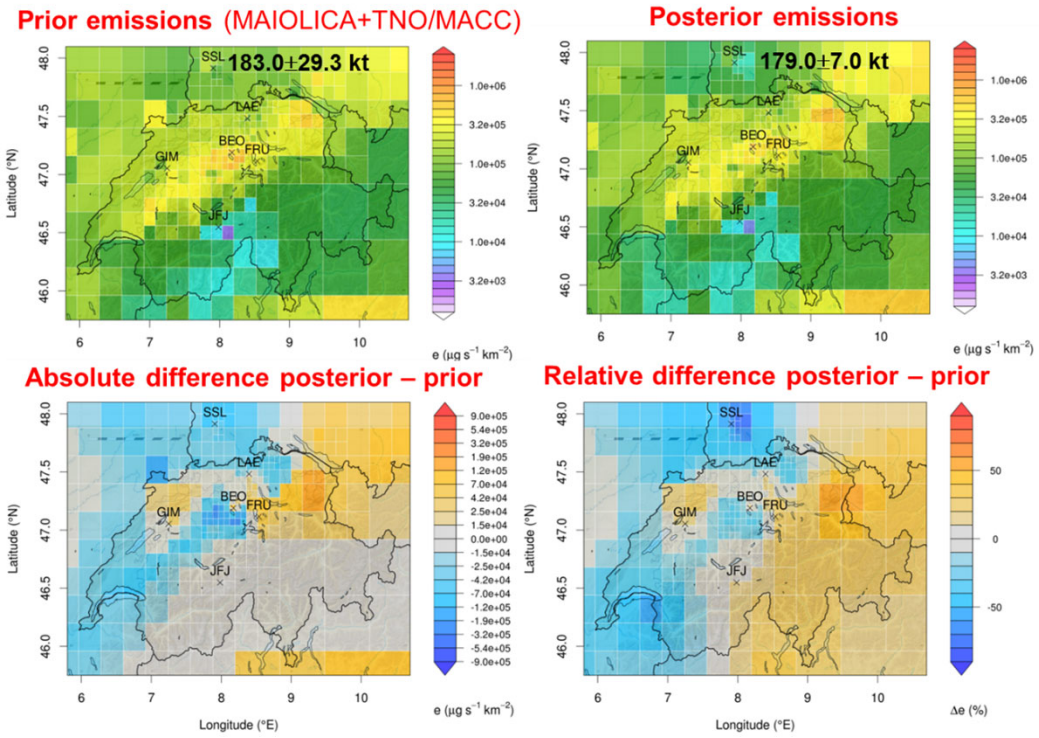
# IG³IS good practice example from Switzerland




New GHG measurement network established (project CarboCount-CH)

## $CH_4$ emissions in Switzerland 2013

Henne, S.,D Brunner et al.,2016 : Validation of the Swiss methane emission inventory by atmospheric observations and inverse modelling, Atmos. Chem. Phys., 16, 3683–3710, www.atmos-chem-phys.net/16/3683/2016/

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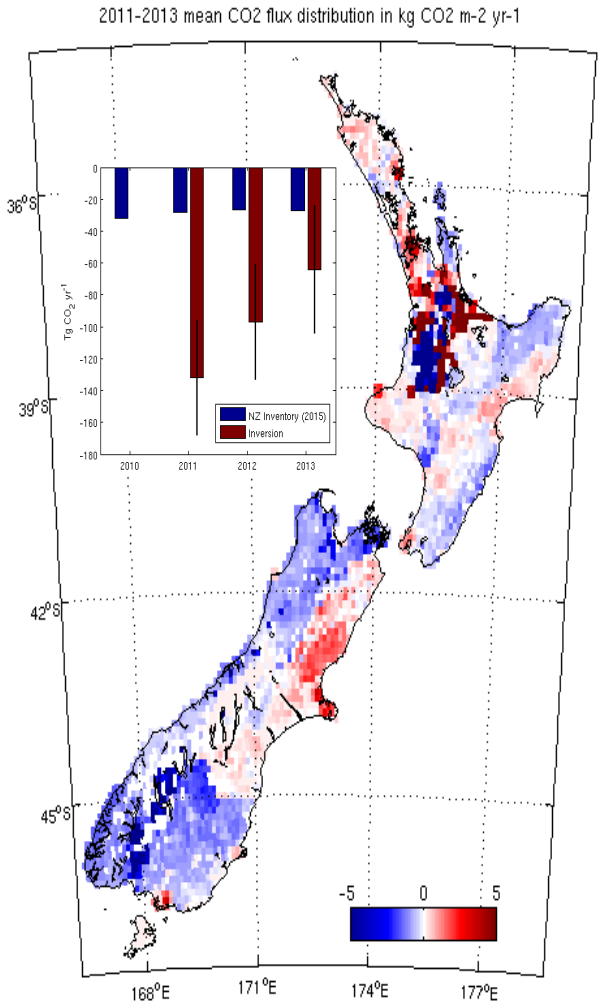
# $CO_2$ inversion for NZ indicates larger land carbon uptake than expected




- Atmospheric measurement and analysis shows **30 to 60% more $CO_2$ land uptake** than expected from the NIR and the land model (when accounting differences are resolved)
- **Interannual variability in the land carbon sink not present in NIR**
- Much of this **additional $CO_2$ uptake** apparently occurs in Fiordland – **old growth forested wilderness**

**New NZ National and Auckland Projects Initiated**

- Process studies of natural, plantation, pasture, and urban biosphere
- Detailed emission modelling and atmospheric inversions at national and regional scales
- Combine atmospheric observations and bottom-up information to refine both and provide best national estimates

Jocelyn Turnbull, GNS New Zealand

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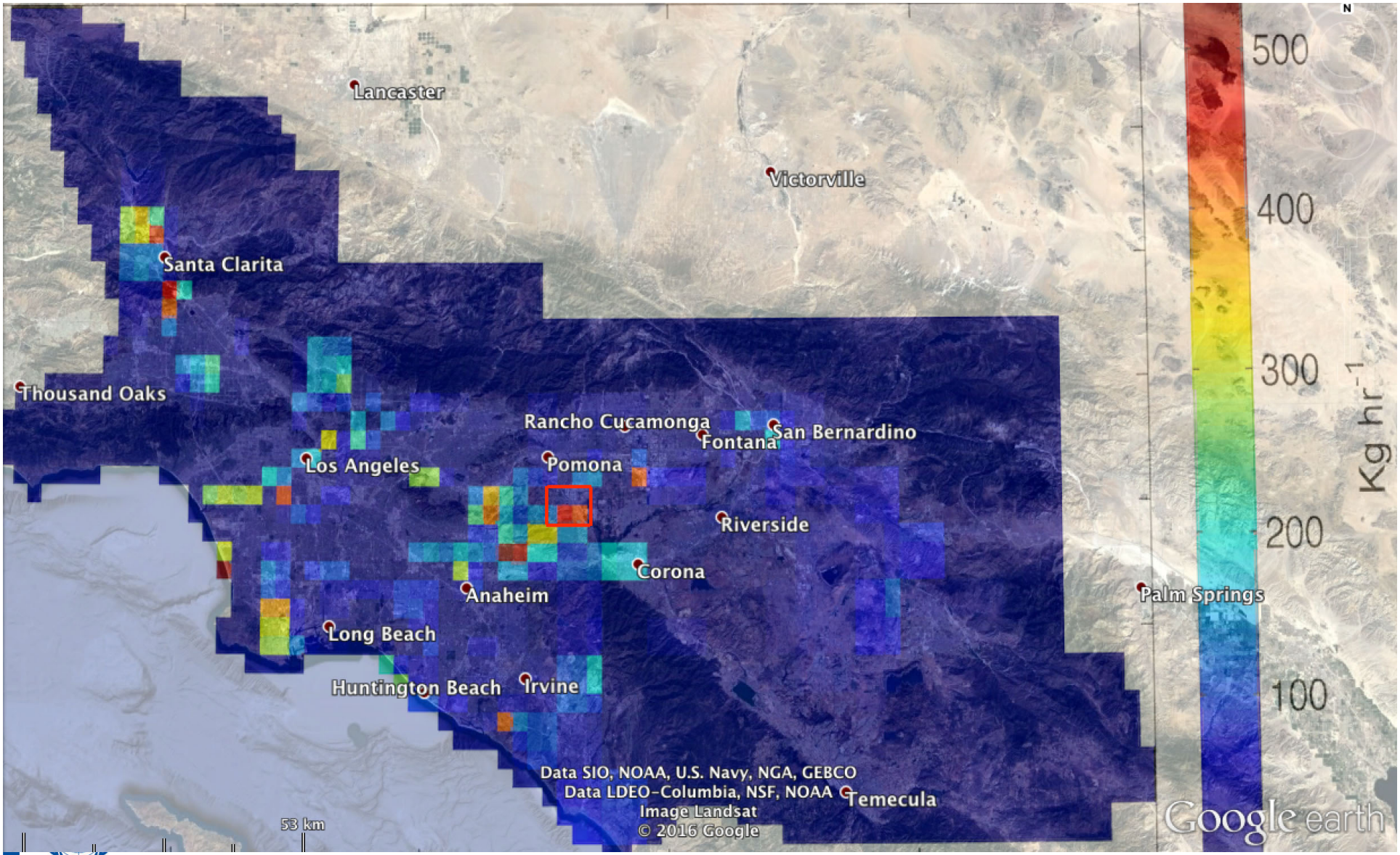
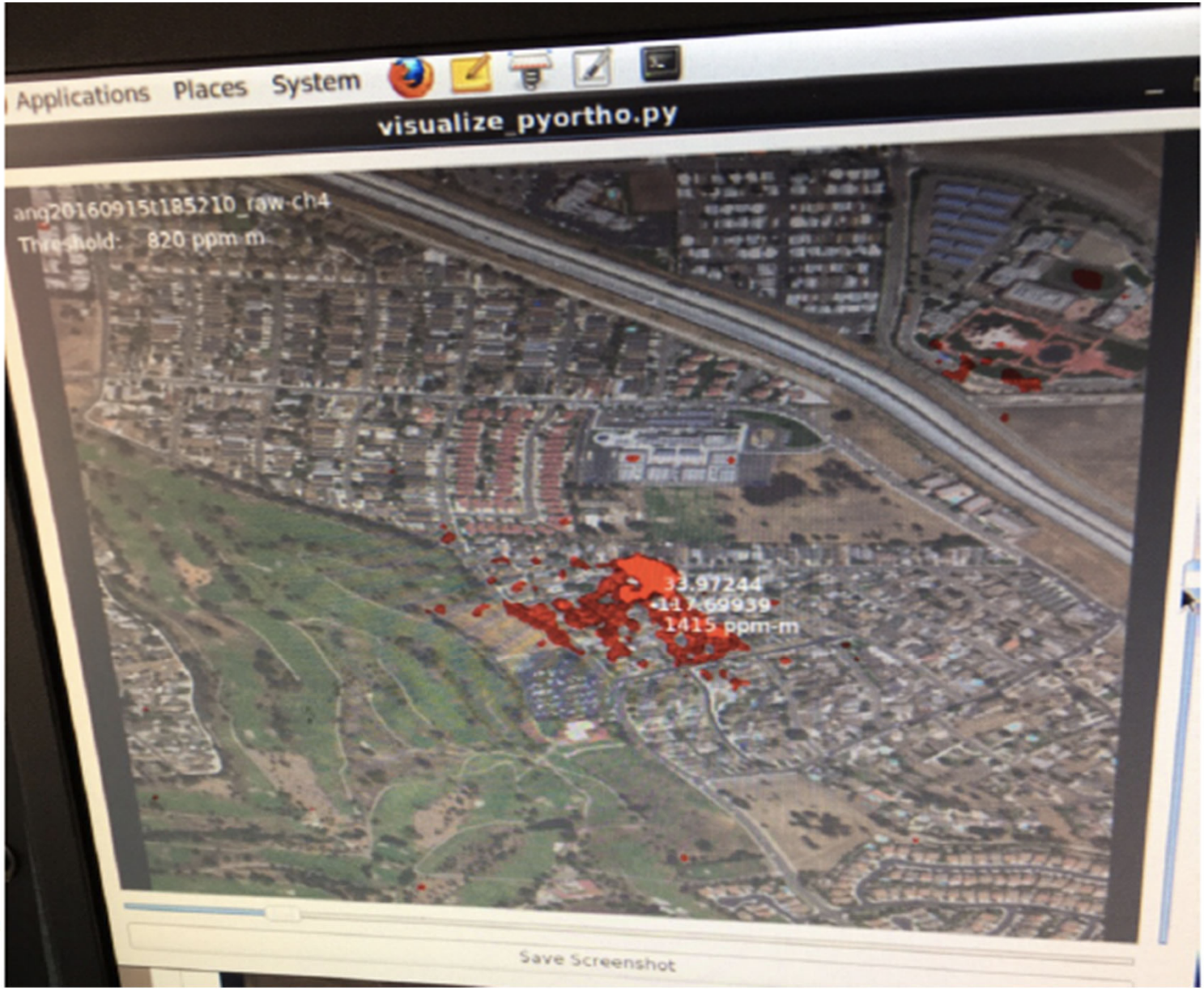
Atmospheric CO2 observations and models suggest strong carbon uptake by forests in New Zealand, Steinkamp et al, Atmos. Chem. Phys., 17, 47–76, 2017, doi:10.5194/acp-17-47-2017

# Los Angeles inverse model of 12 tower measurements shows methane hot spots at known & a large unknown source



# Airborne imaging spectrometer sees methane plume confirming large leak from distribution system



## 2019-2023

# Joint WHO and WMO Health, Environment, and Climate Action Plan

MOU with WHO signed May 2018

Agreed to develop **5 year Joint Workplan on Climate, Health, Environment**, and inform proposals for Integrated Health Services to WMO Congress-18

Objective: Enhance capacity building, technical support, and coordination for WHO and health partners to co-develop, access and use climate, weather, and environmental information**.**

Health Needs for **Data Services, Research, Operational Services** span four thematic areas:

1. **Air Quality**
2. **Climate and Climate Services**
3. **Extreme Weather**
4. **Water**

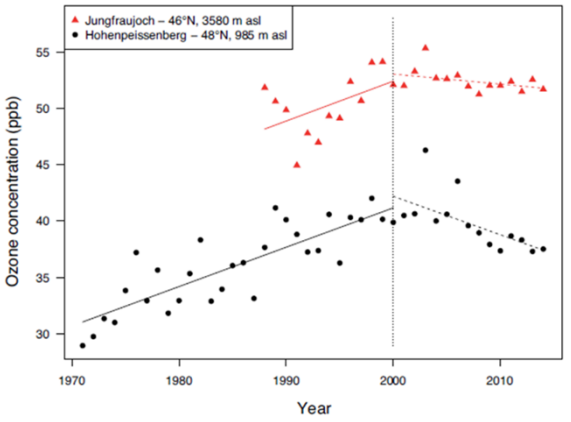
Two geographic focus areas of common interest:

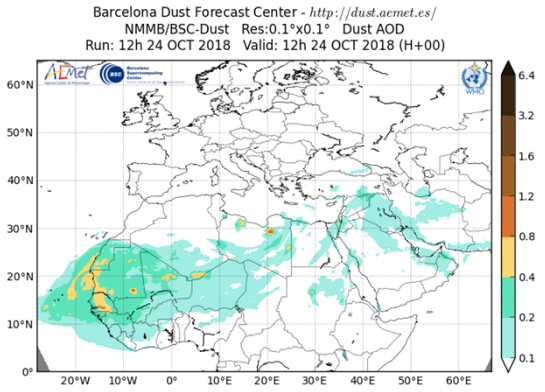
1. **small island developing states**
2. **urban areas**

# WMO commitments at the First WHO Global Conference on Air Pollution and Health

## Reduce the Number of Deaths due to Air Pollution by 2/3rds by 2030 !!

- providing scientific basis for policy-making and evidence-based monitoring of pollution via enhancing observations and communication, assessments and reports;
- providing tools to reduce risk via forecasts, warning and advisory services (including integrated urban and health services);
- enhance the capacity of the countries to support health sector in close collaboration with WHO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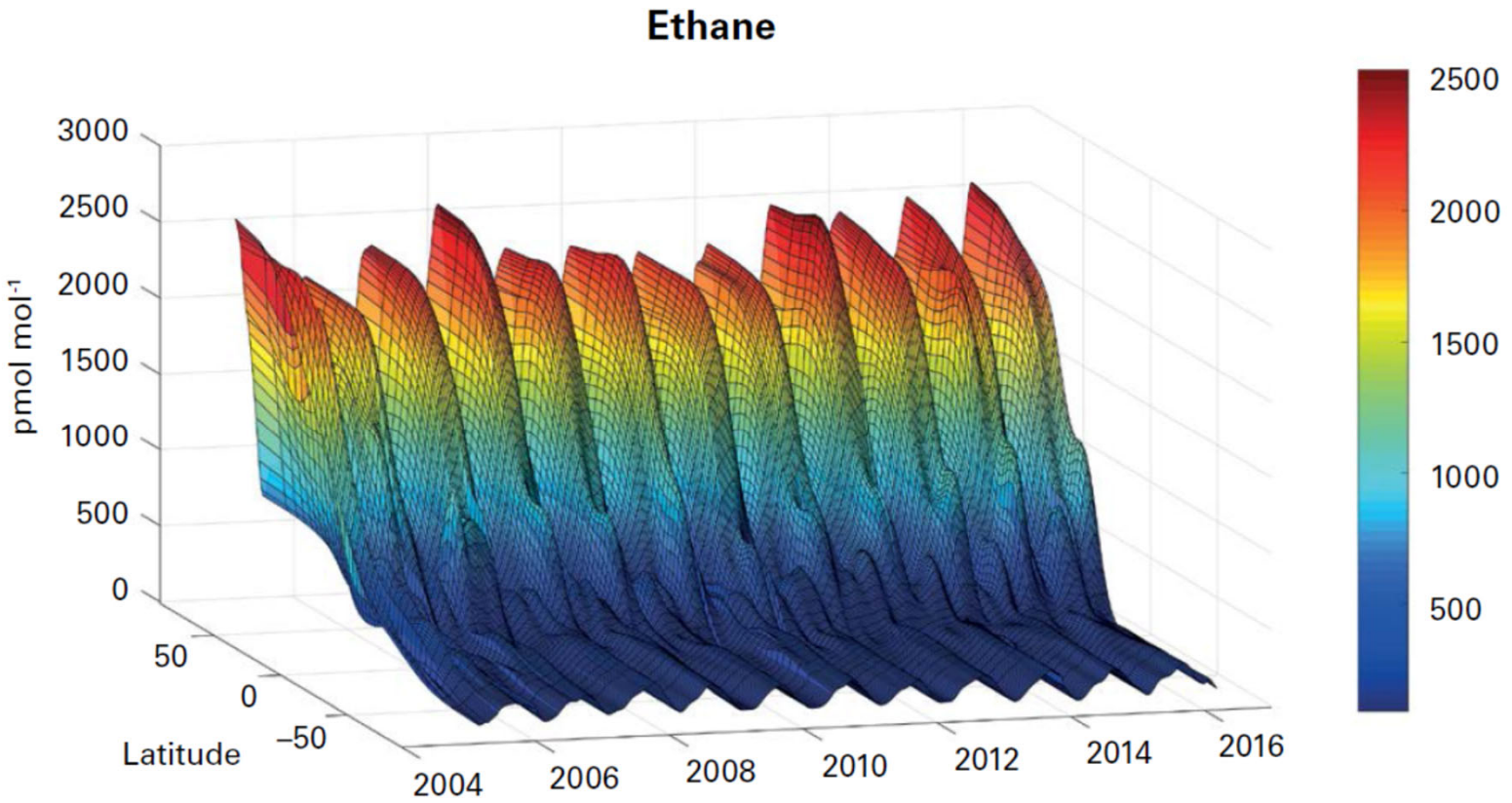
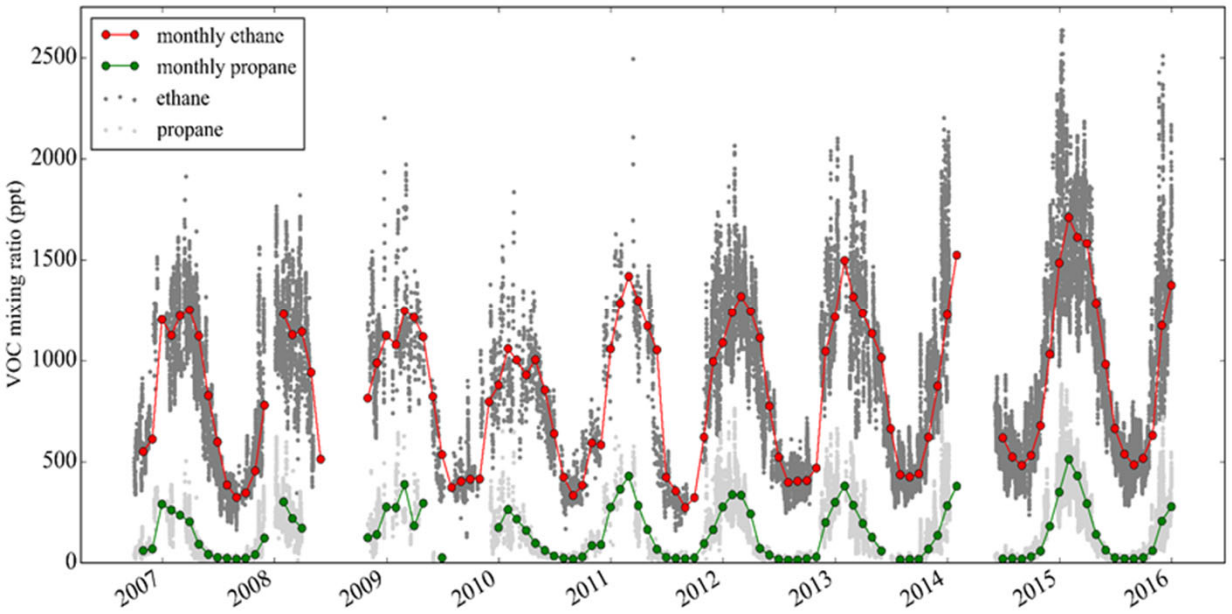
# Volatile organic compounds observations




2004-2016 atmospheric ethane mixing ratio obtained from the global monitoring of volatile organic compounds (VOCs) at more than 40 sites.

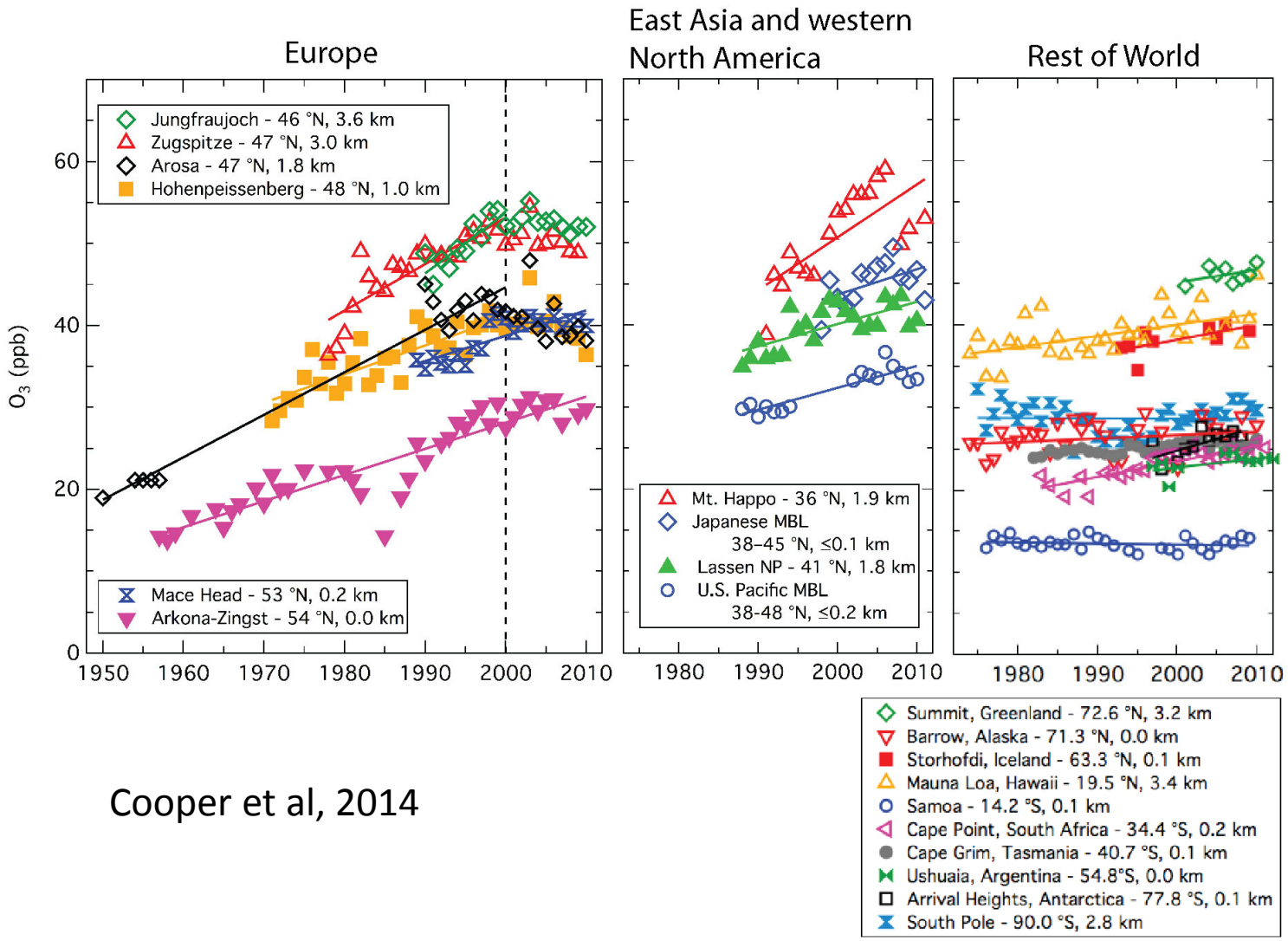
# Volatile organic compounds observations




Ethane and propane results from hourly monitoring at Cape Verde Observatory, as well as monthly averaged of the data.

- Similar findings from the FTIR measurements
- Confirmed average ethane increases of 3-5% per year in the Northern Hemisphere or around 20% in Northern Hemisphere atmospheric ethane during this 5-year period
- The geographical distribution of the rates of increase seen in propane – which cannot travel far from its source over its 11-day approximate lifetime – and the tight correlation between ethane and propane emissions, suggests that most of the new ethane emissions originate from North America

# TOAR project




Cooper et al, 2014

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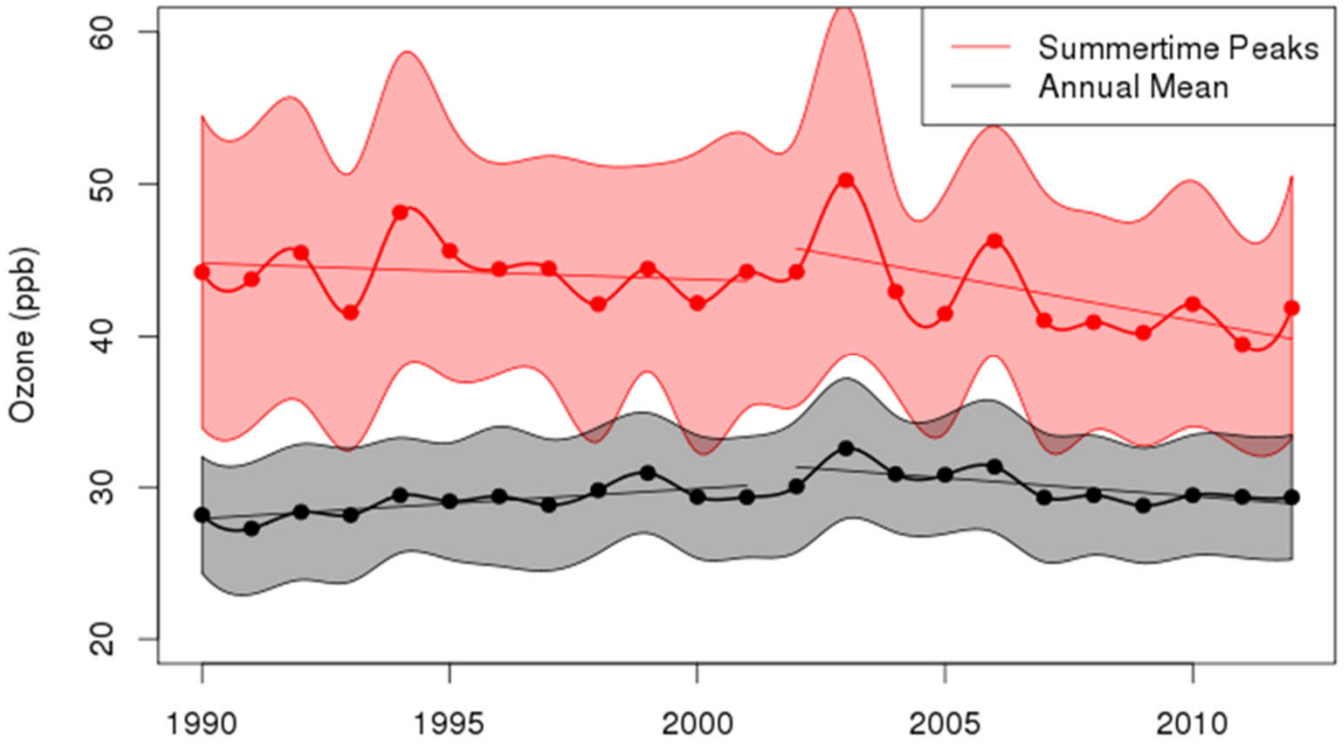
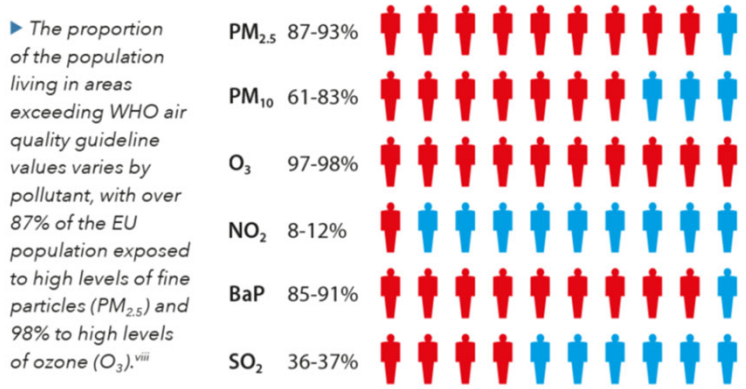
# Experience from the LRTAP convention




Evolution of ozone peak (summertime – JJA – average of daily maxima) and annual mean at EMEP monitoring stations. Trend lines are indicative for the periods 1990-2002 and 2002-2012. Data include a subset of 54 EMEP stations, with at least 75 % data coverage.

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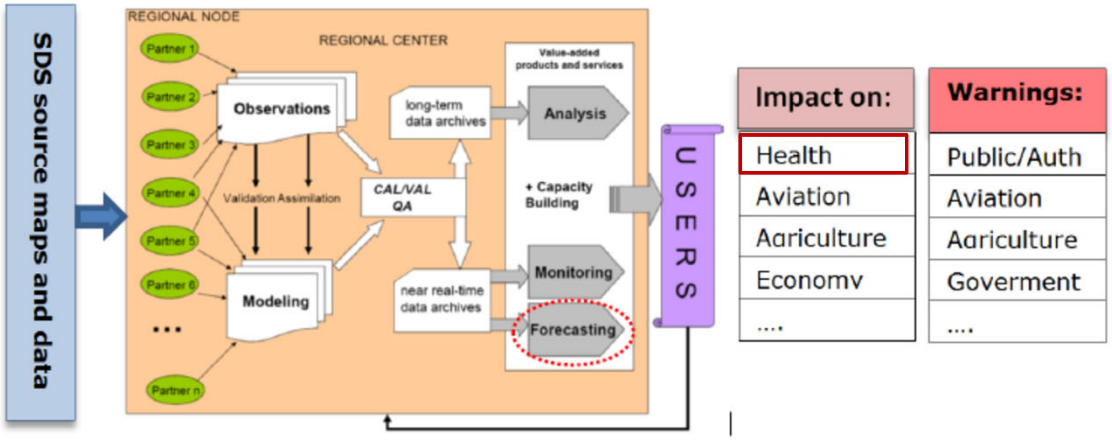
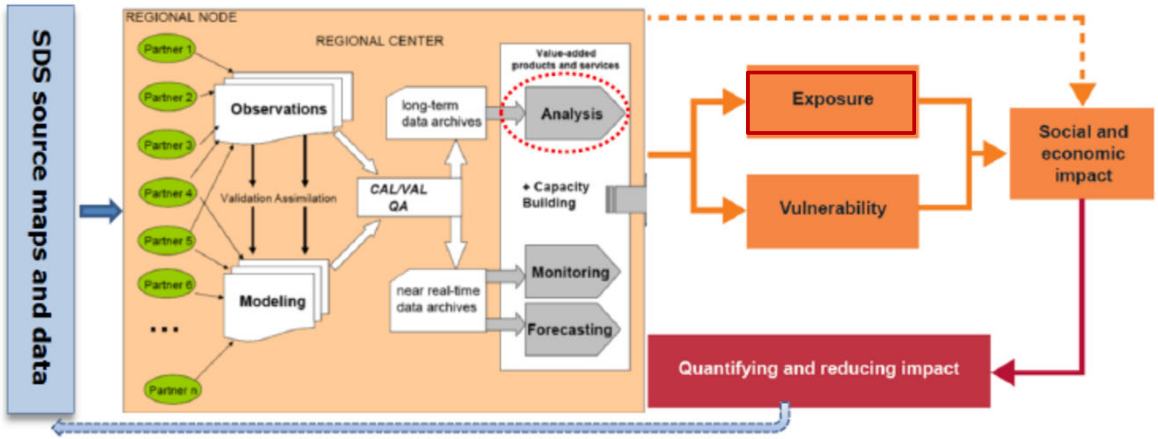
# WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) for UN SDS Coalition

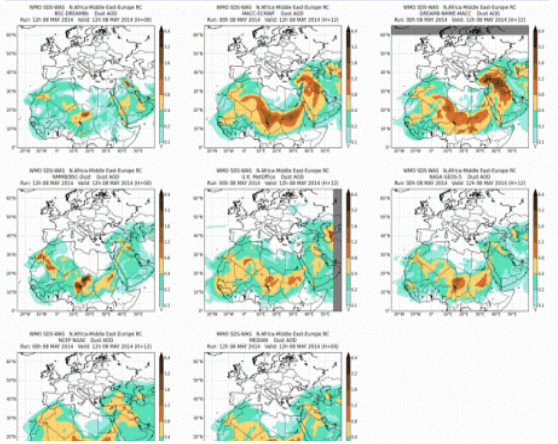
**SDS-WAS for Early Warning:**




**SDS-WAS for Impact Assessment:**




- 9 global models
- 11 regional models
- 25 organizations
- 3 regional nodes & centers (*NAMEE, Asia, Americas*)
- 2 regional dust operational centers



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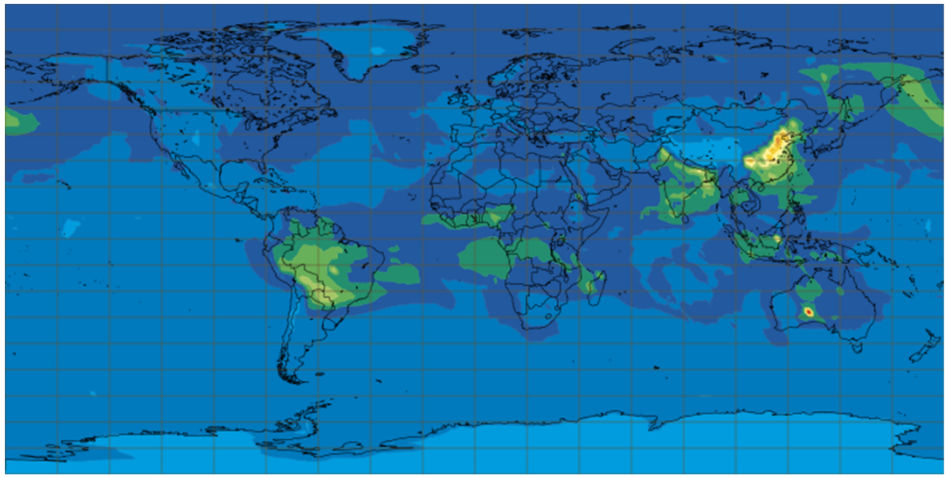
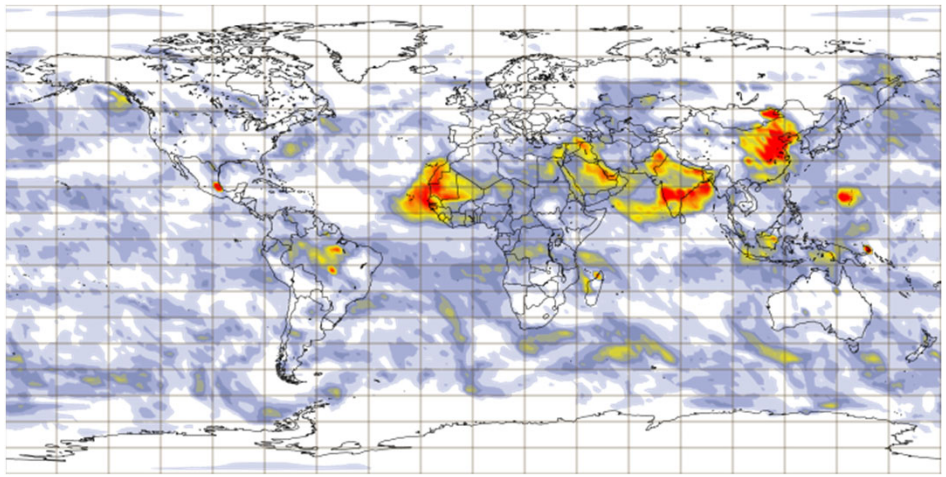
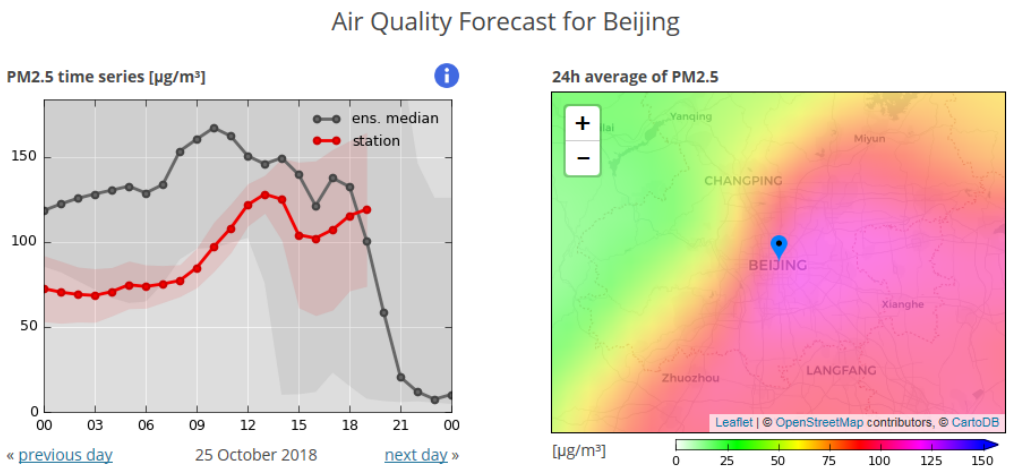
**Joint and coordinated efforts of several UN Agencies (e.g., WMO, UNEP, UNCCD, WHO), National Authorities and Research community are needed**

# Multi-scale Air Quality modelling, forecasting and assessments systems: from global to regional and urban

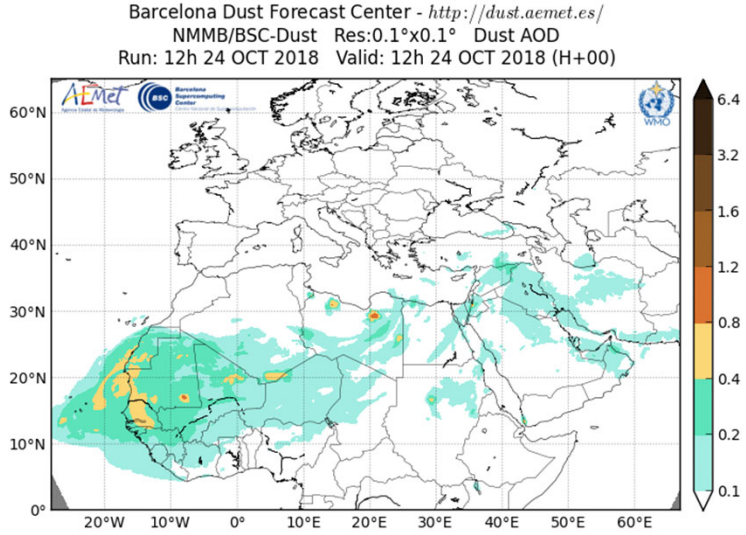




Example of CAMS forecast of PM2.5 and ground-level ozone for 5 days




MAP-AQ project forecast for China cities:
http://www.marcopolo-panda.eu/forecast/




Dust forecast for 72 hours by WMO SDS Barcelona Center:
https://dust.aemet.es/forecast

# Global Air Quality Forecasting and analysis system

Aligned with WMO strategic plan, the system will **enable access to, and use of, air quality prediction and analysis products at different temporal and spatial scales**. This will be done through coordination of activities to facilitate seamless provision of atmospheric composition information at various scales, also benefiting NWP and climate modelling. GAQF will, as much as possible, share air quality related products and services freely and openly. GAQF will also coordinate activities to facilitate Developing and Least Developed Countries in reaching their air quality standards and Sustainable Development Goals.

COMMENT

MATERIALS An entertaining journey through the weird world of liquids p.30

STRUCTURAL BIOLOGY Nobel memoir relives the ribosome marathon p.32

POLICY Power and bias shape science too — be frank about it in syntheses p.33

GENE EDITING Europe's politicians must put their trust in plant science p.33

Smog envelopes Santiago in Chile.

Five steps to improve air-quality forecasts

A worldwide monitoring and modelling network would reduce the dramatic toll of air pollution on health and food production, urge **Rajesh Kumar** and colleagues.

Seven million people die every year from the effects of air pollution. More than 90% of such deaths are in developing countries[1]. Across southern Asia, levels of fine particulate matter ($PM_{2.5}$) and surface ozone exceed the World Health Organization (WHO) limits for much of the year[2]. Ozone damage to crops and plants — especially to soya beans, wheat and maize (corn) — results in 79 million to 121 million tonnes of lost produce globally, at a cost of US$11 billion to $18 billion[3]. India's crop losses alone would feed 94 million people[4]. All this costs the world's economy US$5 trillion per year[5].

But air pollution often goes unmonitored. Some of the fastest-growing cities in Africa, including Lagos, Kinshasa, Abidjan and Dakar, have no air-quality alert systems. Governments can be reluctant to acknowledge the problem, or lack the tools to address it. There is no international strategy for dealing with the issue. And few people are trained in how to collect and interpret air-quality data.

Improvements can take decades. It took the US city of Atlanta, Georgia, 15 years to reduce emissions from power plants by around 80% and from traffic by up to 90%, avoiding more than 50,000 hospital visits for asthma and lung diseases (ref. 6). Los Angeles in California took 50 years to reduce ozone levels by two-thirds[7].

Forecasts of hazardous air pollution are crucial to help reduce exposure. Vulnerable people can avoid strenuous outdoor activities or stay indoors. Schools might restrict outdoor sports activities, parents can limit the time their children spend outdoors and doctors might advise their patients to stay inside when levels are high. In Canada, ▸

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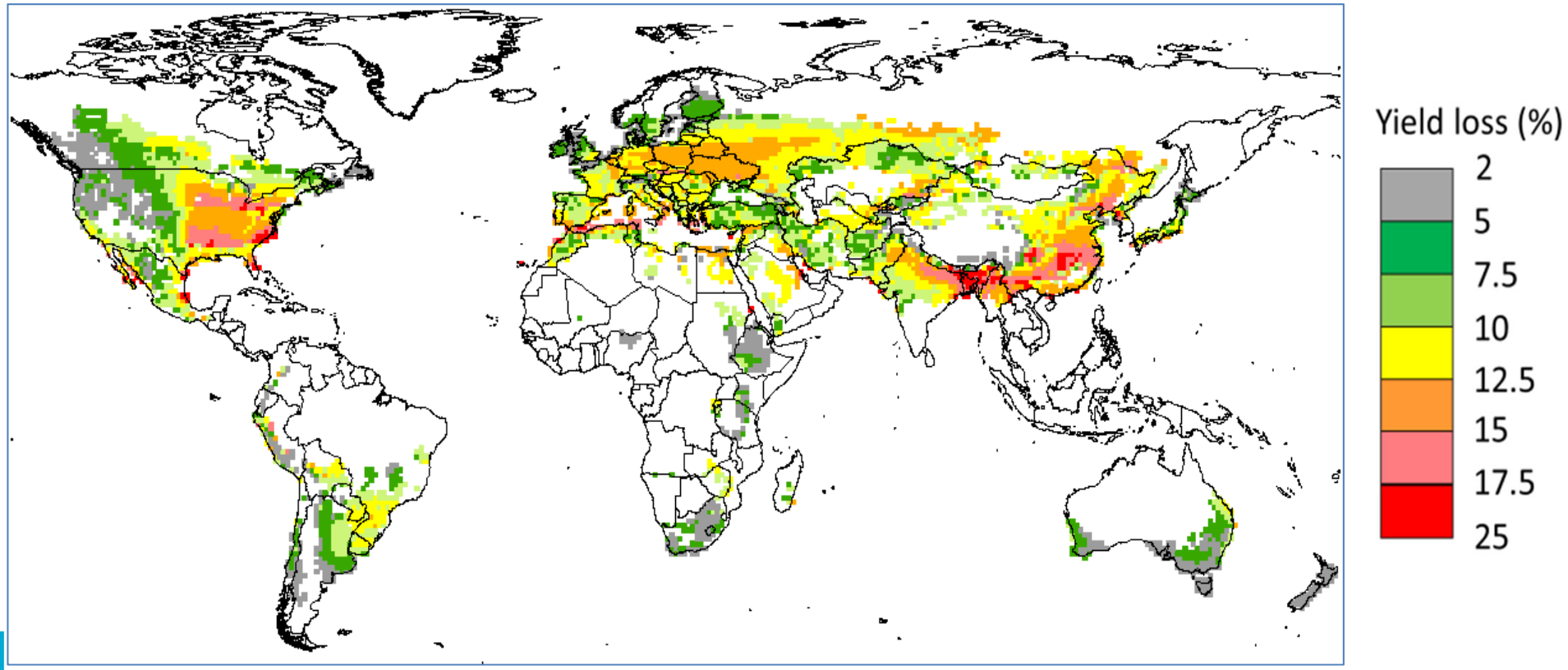
# Impact of ozone deposition on agriculture




**Wheat yield loss** due to ozone deposition onto plant stomata (from Mills et al., 2018)

**Estimated financial losses:** 14-26 billion US$ $yr^{-1}$ (van Dingenen et al., 2009)

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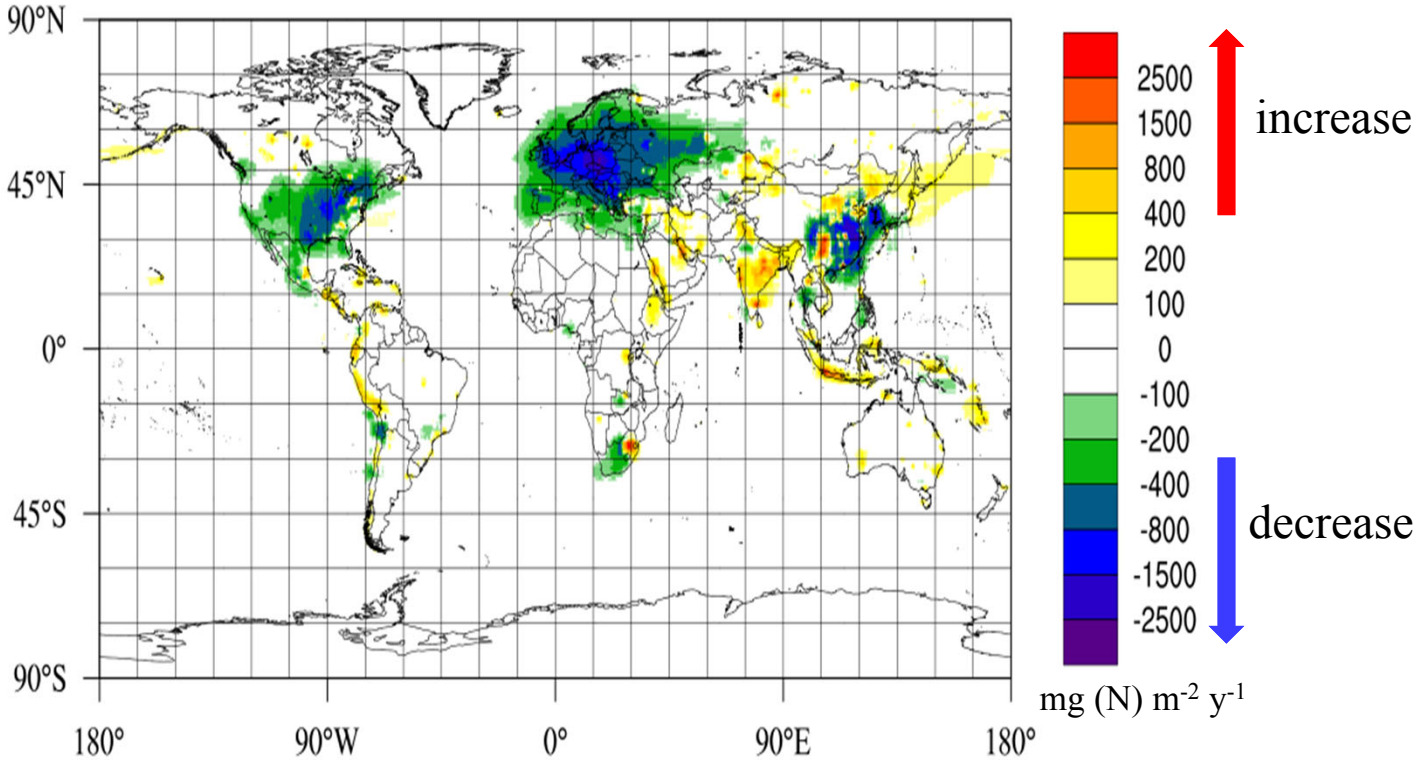
# Changes in N Deposition from 2001 to 2010

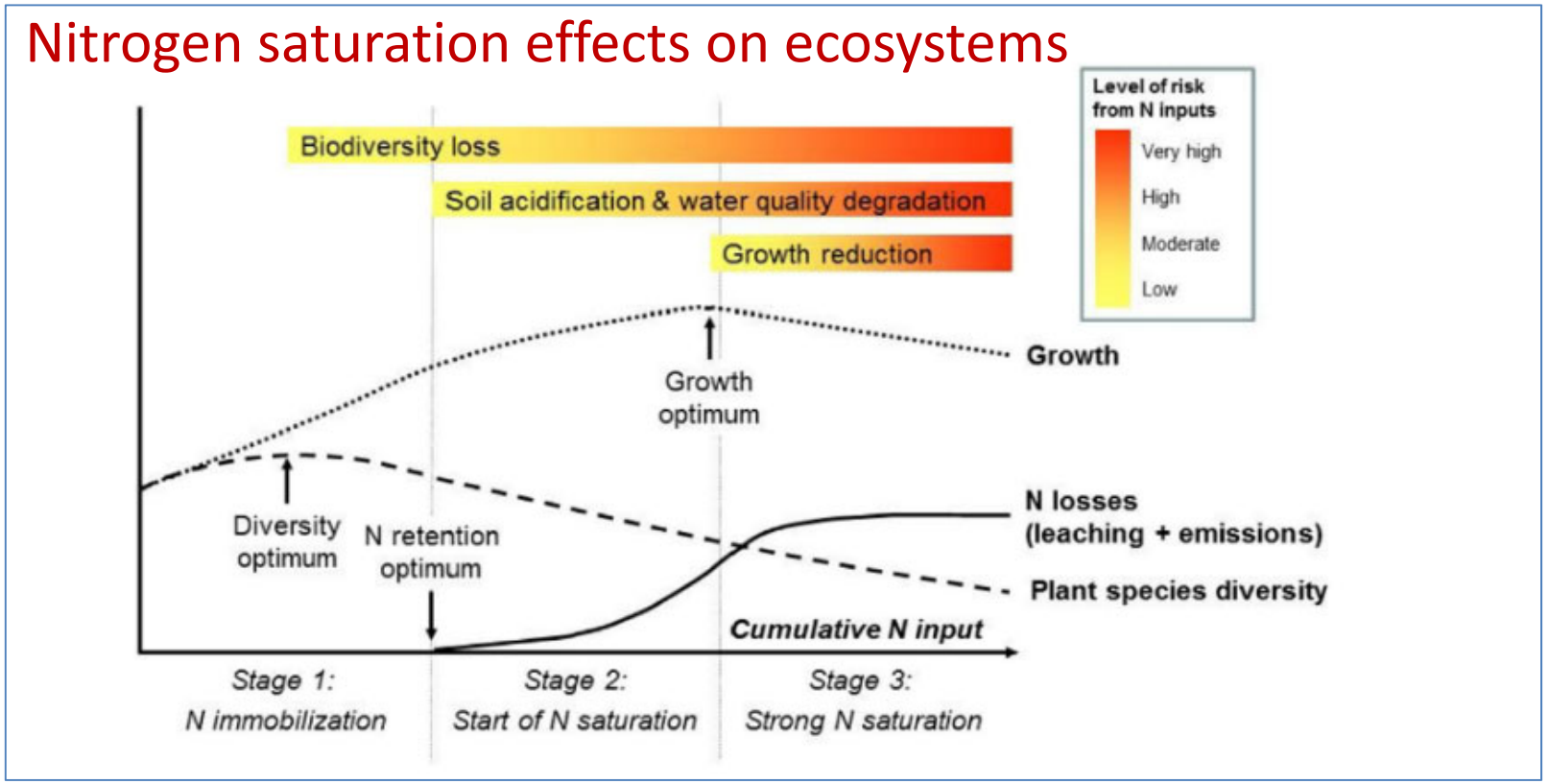
Calculated as 2010 deposition – 2001 deposition (mg (N) $m^{-2}$ $y^{-1}$)




N deposition decreased by 3% and 11% in North America and Europe, and increased by 27%, 54% and 80% in East Asia, Southeast Asia and South Asia, respectively.

Fu et al., HTAP multi-model analysis

# Dependence of impacts on deposition fluxes and ecosystem type




Increasing N deposition →

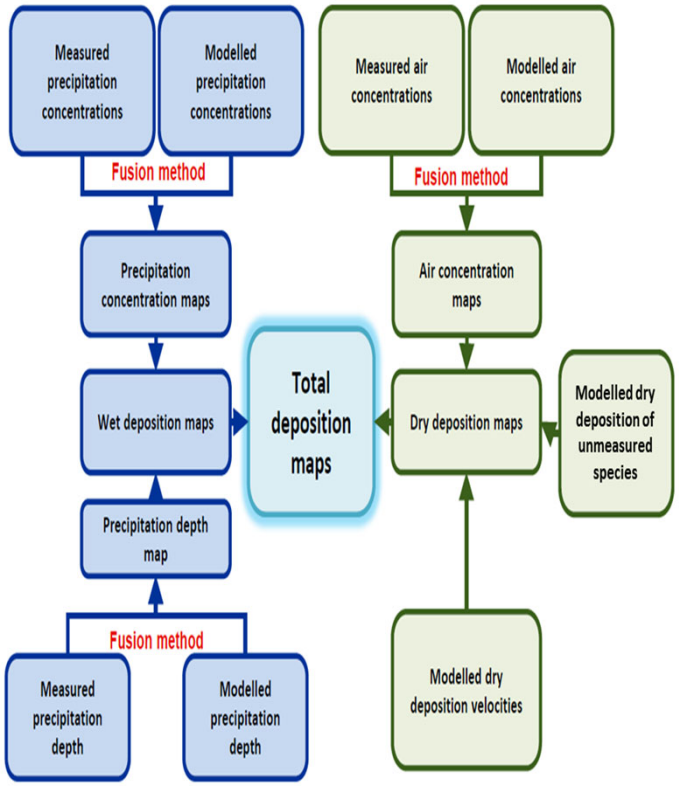
Adapted from Schmitz et al. (2019)

# MMF-GTAD approach

- **MMF brings together best-available data and modelling results** on precipitation chemistry, precipitation depth, air concentrations and dry deposition velocities to estimate wet, dry and total deposition

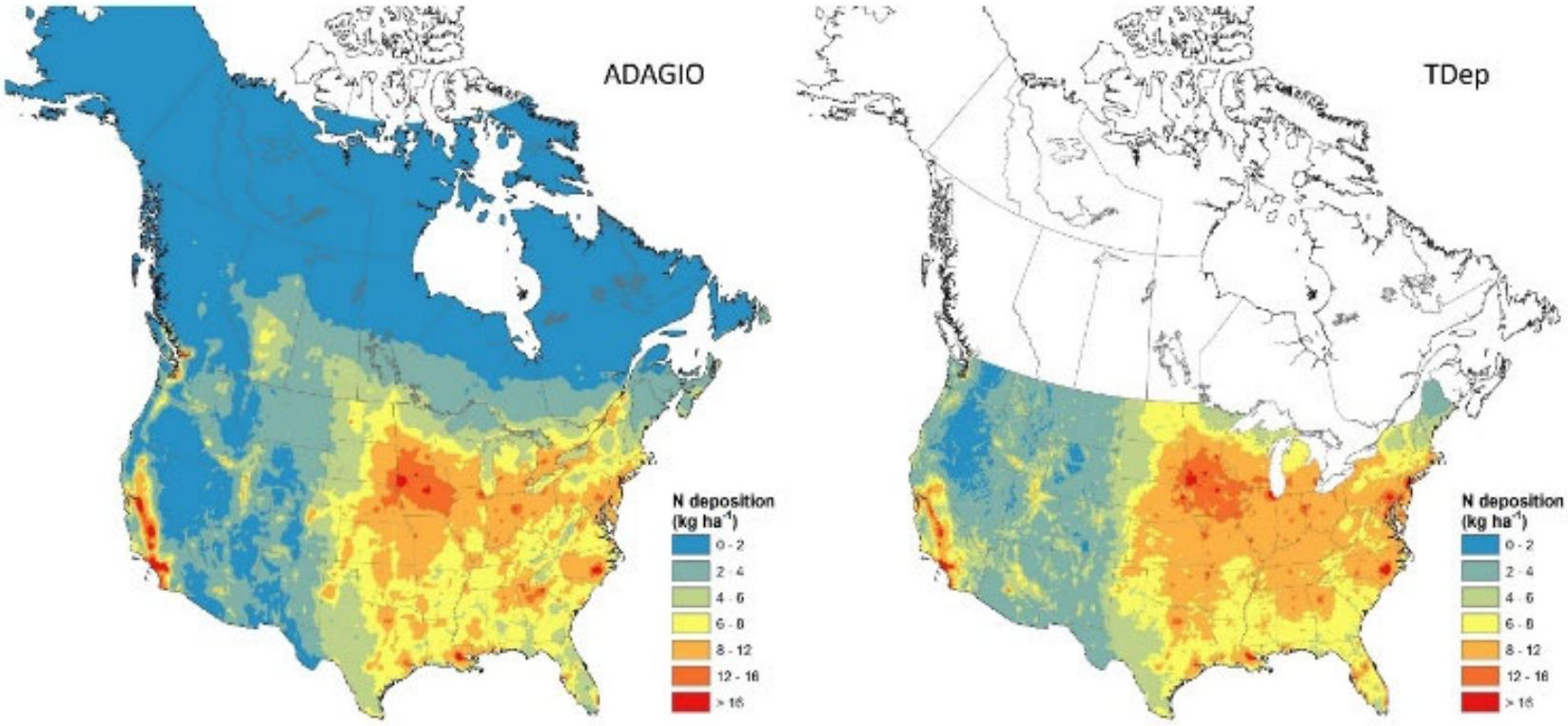
- **Combines measured and modelled**
    1. precipitation concentrations
    2. air concentrations
    3. precipitation depth

- **Uses dry deposition estimates of unmeasured species**




Fu et al., INI2020

# Current MMF maps: ADAGIO and Tdep, N deposition




Adapted from Schwede, D., A. S. Cole, R. Vet, G. Lear. Ongoing US-Canada collaborations on nitrogen and sulfur deposition, Environmental Management, June 2019.

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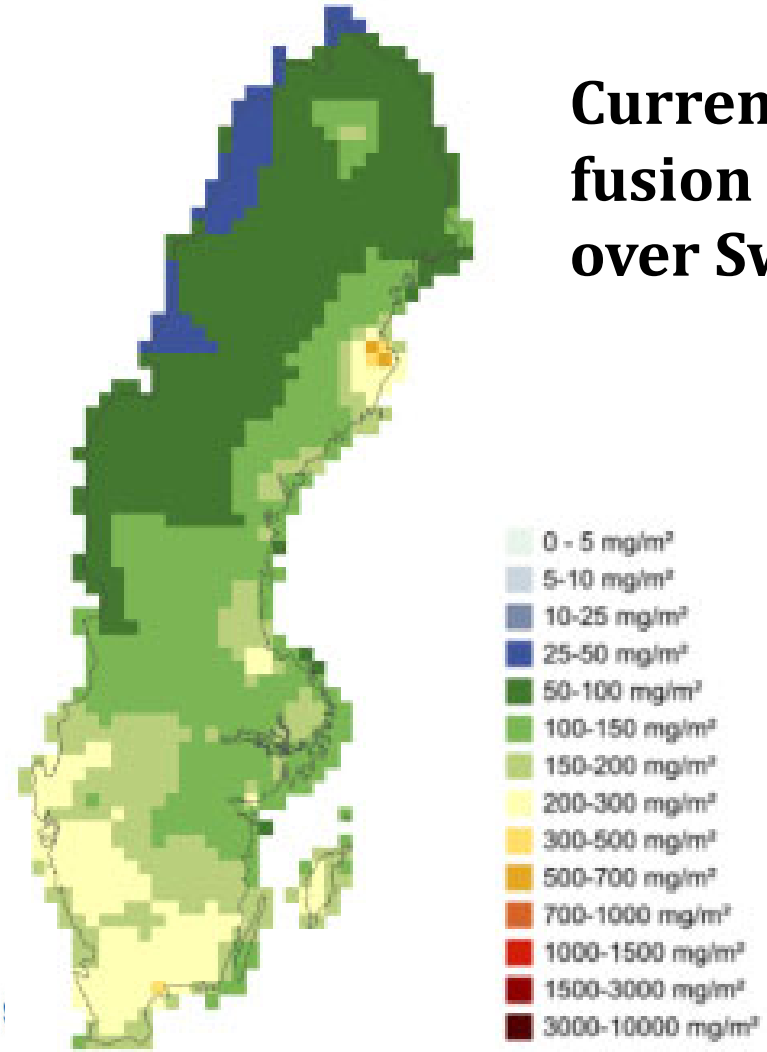
# Current MMF maps - S




**Current maps of measurement-model fusion of total atmospheric deposition over Sweden**

2017 sulfur deposition in Sweden in mg S $m^{-2}$ $yr^{-1}$ produced by the Swedish Meteorological and Hydrological Institute (adapted from Leung et al., 2019 ).

# MMF-GTAD
# a Science for Services Project

**Vision:** stakeholders will be able to access high-resolution, high-quality, global-scale maps of total atmospheric deposition
to meet societal needs as they relate to the environment and global sustainable development.

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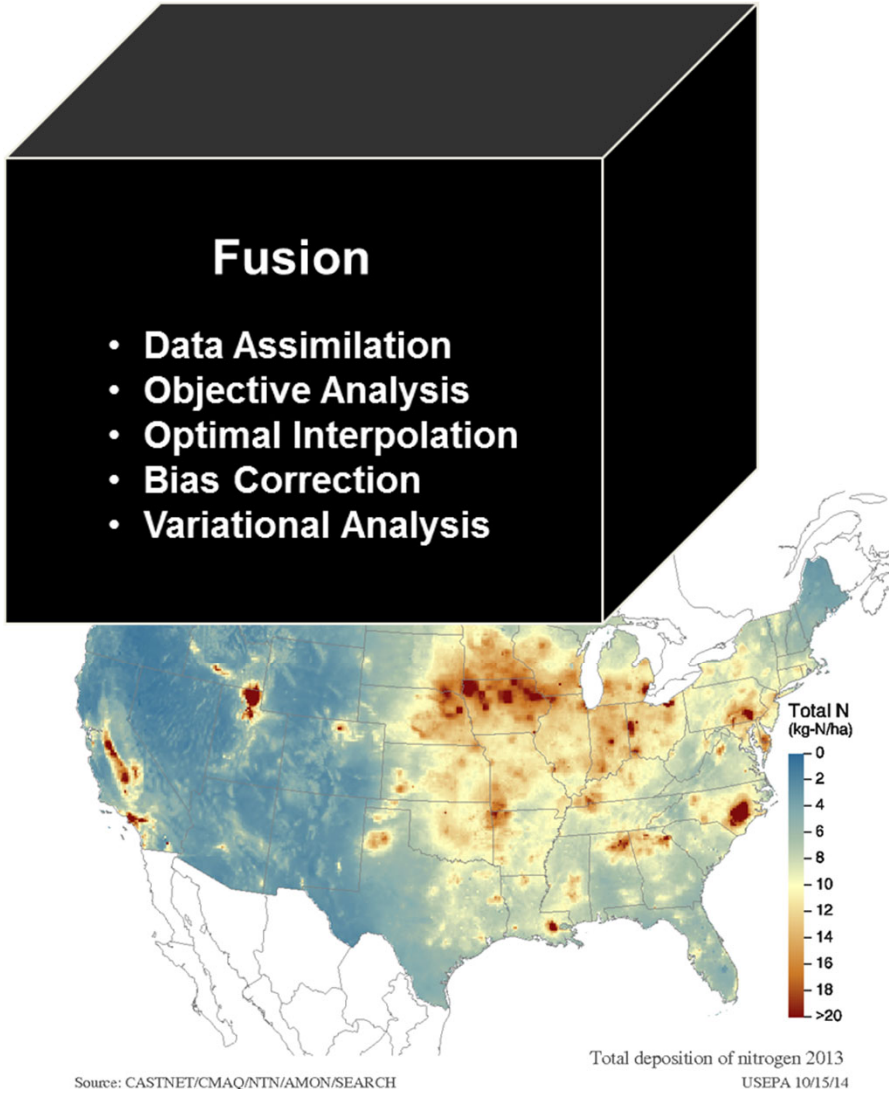
# Measurement-Model Fusion for Total Atmospheric Deposition

✓A plan for a three-phase project:

- **Phase 1 Short Term.** MMF of existing 2010 ensemble global model results with existing data sets (HTAP, AQMEII). Products: comprehensive data set and model ensemble output files and gridded MMF maps.
- **Phase 2 Medium Term**. Stitching together existing and new regional/global MMF-TAD maps (Canada, USA, UK, Sweden, Norway, Asia, Europe) to produce global maps
- **Phase 3 Long Term.** Ongoing operational re-analysis using data assimilation (ECMWF/Copernicus)

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# GAW – What's Next?

**Advance** observations and analysis of chemical constituents of the atmosphere and UV radiation to help **reduce** environmental risks to society from **high-impact weather and air pollution**, and to mitigate the impacts of, and adapt to, changing **climate**.

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# Thank you!
# Merci!


WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

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World Meteorological Organization
Organisation météorologique mondiale

GLOBAL ATMOSPHERE WATCH