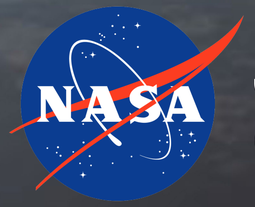
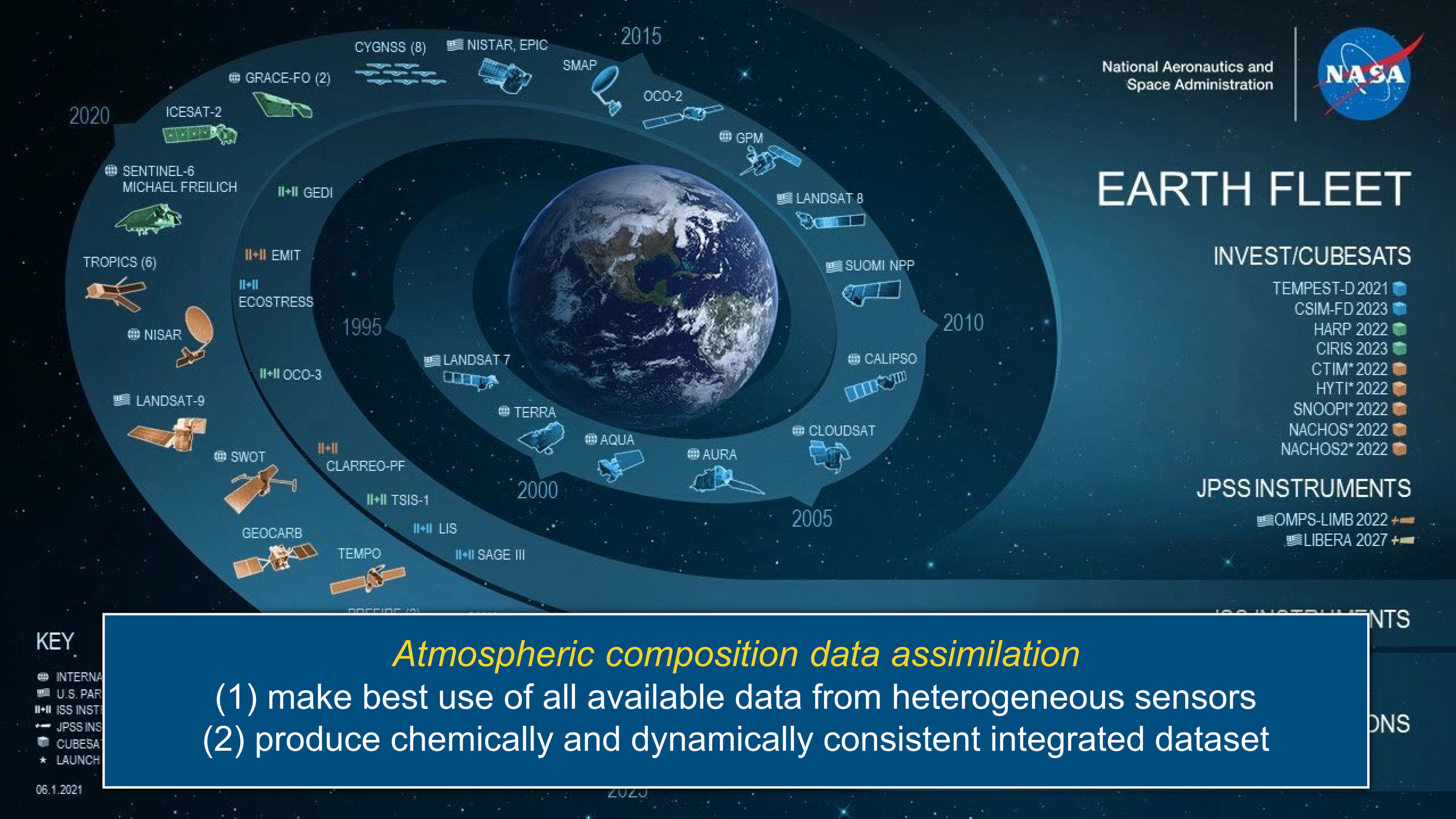
Multi-mOdel Multi-cOnstituent Chemical (MOMO-Chem) DA

Kazuyuki Miyazaki, Kevin Bowman

NASA Jet Propulsion Laboratory, California Institute of Technology



Jet Propulsion Laboratory
California Institute of Technology



Atmospheric composition data assimilation

(1) make best use of all available data from heterogeneous sensors

(2) produce chemically and dynamically consistent integrated dataset

MOMO-Chem (Multi-mOdel Multi-cOnstituent Chemical) Data Assimilation System

MLS

TES

OMI

MOPITT

AIRS

SCIAMACHY

GOME-2

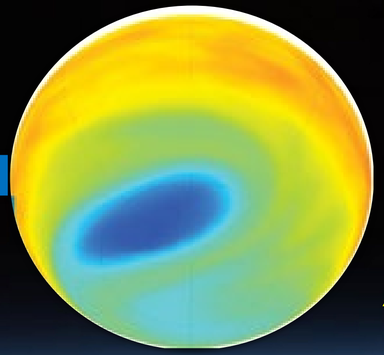
TROPOMI

Satellite Observations Assimilated in MOMO-Chem

Satellite

(O3, CO, NO_2, HNO_3, CO)

Data Assimilation

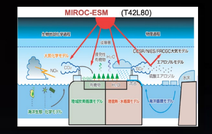


Physical model

(4 models)

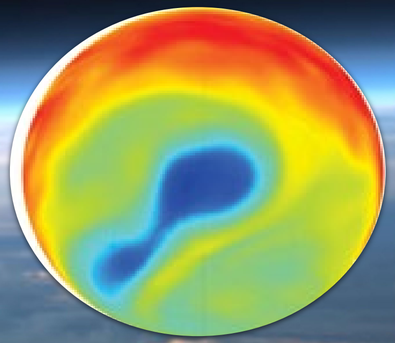
Models Used for Assimilation

CHASER Chemistry Climate Model



TCR

GEOS-Chem



Tropospheric Chemical Reanalysis

- 19 years (2005-present), two-hourly, global, chemical concentrations of 35 species
- Anthropogenic, biogenic, biomass burning, and lightning emissions (NOx, CO, SO_2)
- Used in various science applications, including validation of NASA satellite products
- Supporting OSSE activities in NASA's explore-class mission formulation

Validation against in-situ & aircraft measurements

DISCOVER-AQ

KORUS-AQ

ARCTAS

SEAC4RS

INTEX-B

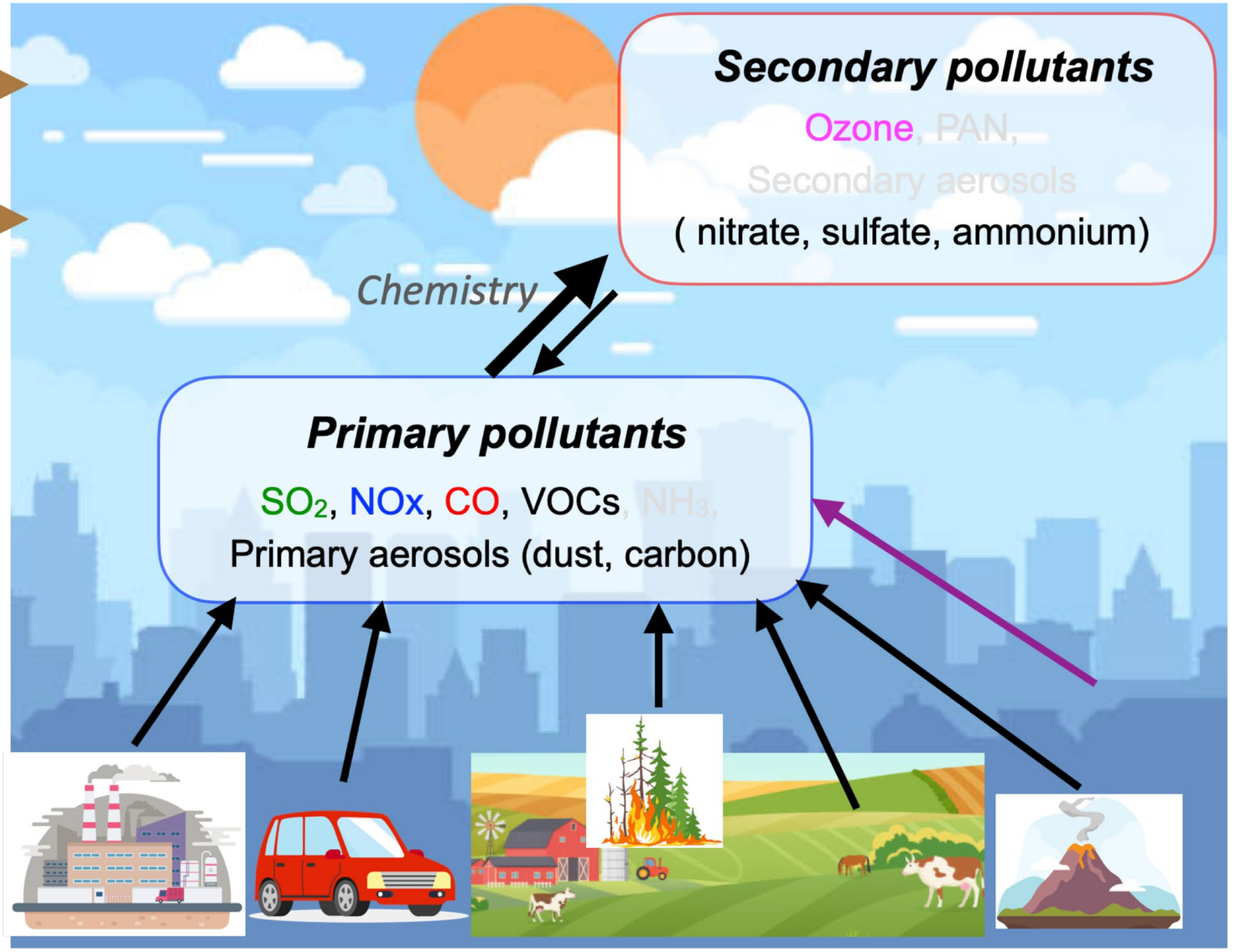
SHADOZ

ATom

TCR-2

MLS
(O_3, CO, HNO_3)

TES
(O_3)



… improve estimates of emissions because of reduced model errors unrelated to emissions.

“Decadal Aura era” chemical reanalysis

Assimilation

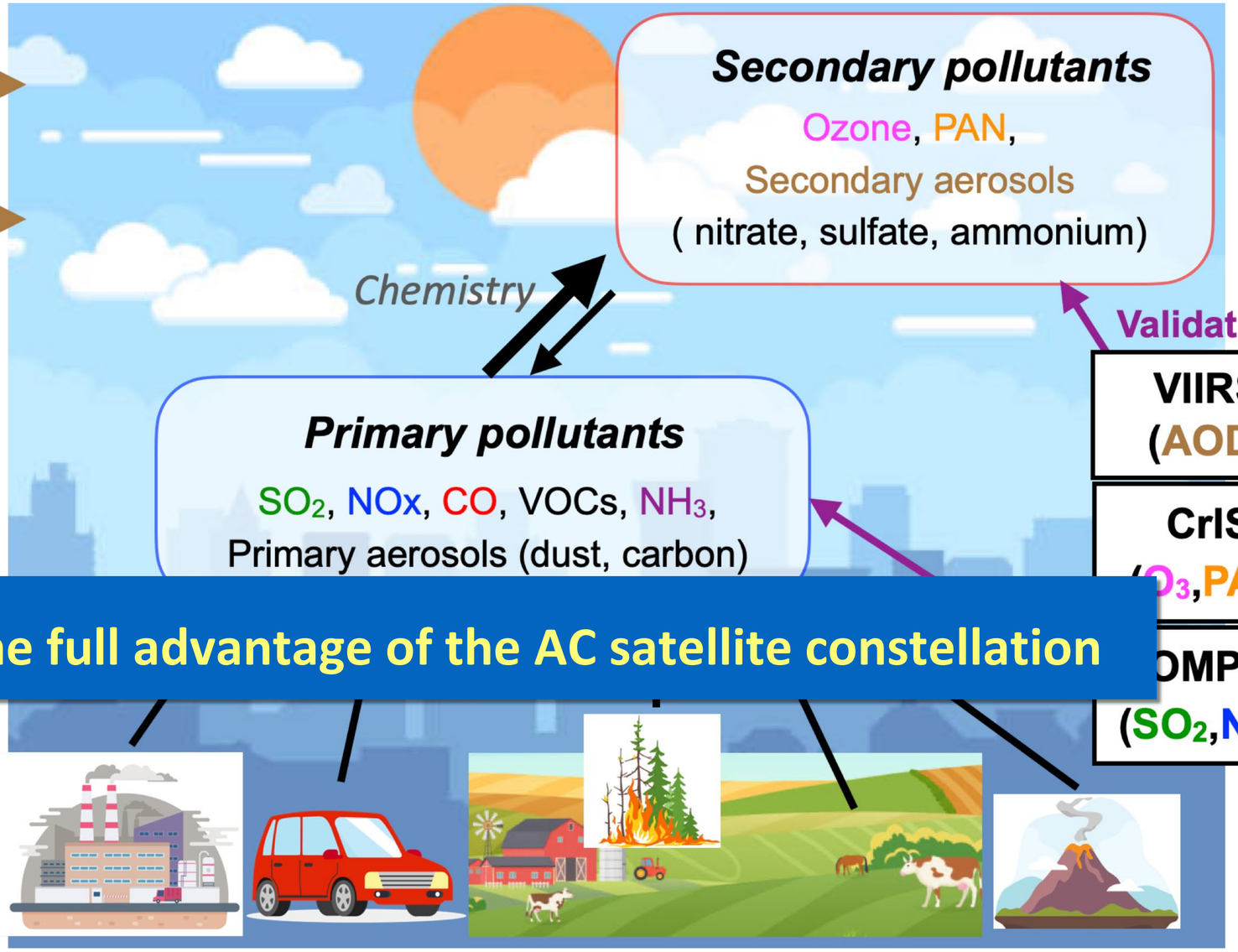
OMI (SO_2,NO_2,, CH_2O)

MOPITT (CO)

TCR-3

MLS
(O_3, CO, HNO_3)

TES, AIRS/OMI
(O_3)



Validation

VIIRS
(AOD)

CrIS
(O_3,PAN)

OMPS
(SO_2,NO_2)

Long-lived GHGs

Oxidation capacity (OH)
↓
OH

AQ-GHG co-emissions
↓
CO_2

MOMO-Chem takes the full advantage of the AC satellite constellation

Assimilation

OMI, TROPOMI (SO_2,NO_2,, CH_2O)

CrIS (NH_3)

MOPITT (CO)

"Decadal Aura era"
"New satellite era"
chemical reanalysis

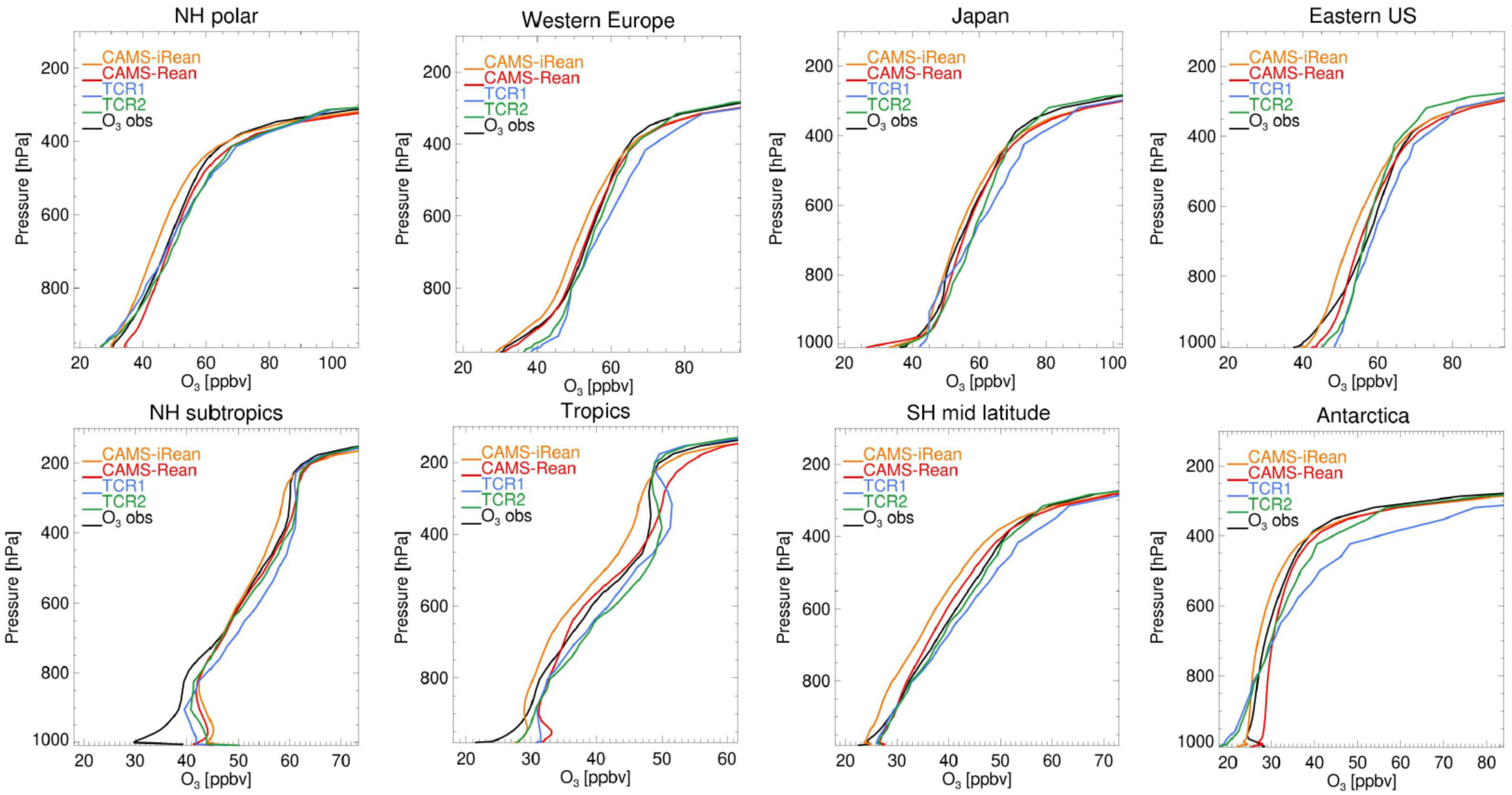
Tropospheric ozone reanalyses considered in IGAC TOAR-2

				Assimilated measurements				
Reanalysis system	**Grid**	**Resolution**	**Period**	**Strato/Column ozone**	**Tropo ozone**	**Precursors**	**Surface**	**Scheme**
IASI-R (E. Emili)	GLOBAL, 0.1-1000 hPa	2° x 2°		MLS	IASI			3D-Var
CAMSRA (A. Inness)	GLOBAL	T255, available at 0.75° x 0.75°	-2003	SBUV, OMI, MLS, GOME2, SCIAMACHY, MIPAS, TROPOMI, OMPS		CO, NO2		4D-Var
TCR2 (K. Miyazaki)	GLOBAL, 70 - 1000 hPa		2005-2021	MLS	TES, AIRS/OMI	OMI/TROPOMI NO2, SO2, MLS HNO3		EnKF
CAQRA (X. Tang)	REGIONAL (CHINA)	15 km x 15 km	-2013			MOPITT CO, OMI NO2	China	EnKF
CMAQ-GSI (R. Kumar)	REGIONAL (US)	12 km x 12 km	2005-2018			MOPITT CO		3D-Var

IGAC Tropospheric Ozone Assessment Report Phase-2 (TOAR-2) Chemical Reanalysis WG

- *Do they agree/disagree with each other and with independent observations?*
- *What is the relative importance of assimilated measurements to improve ozone?*

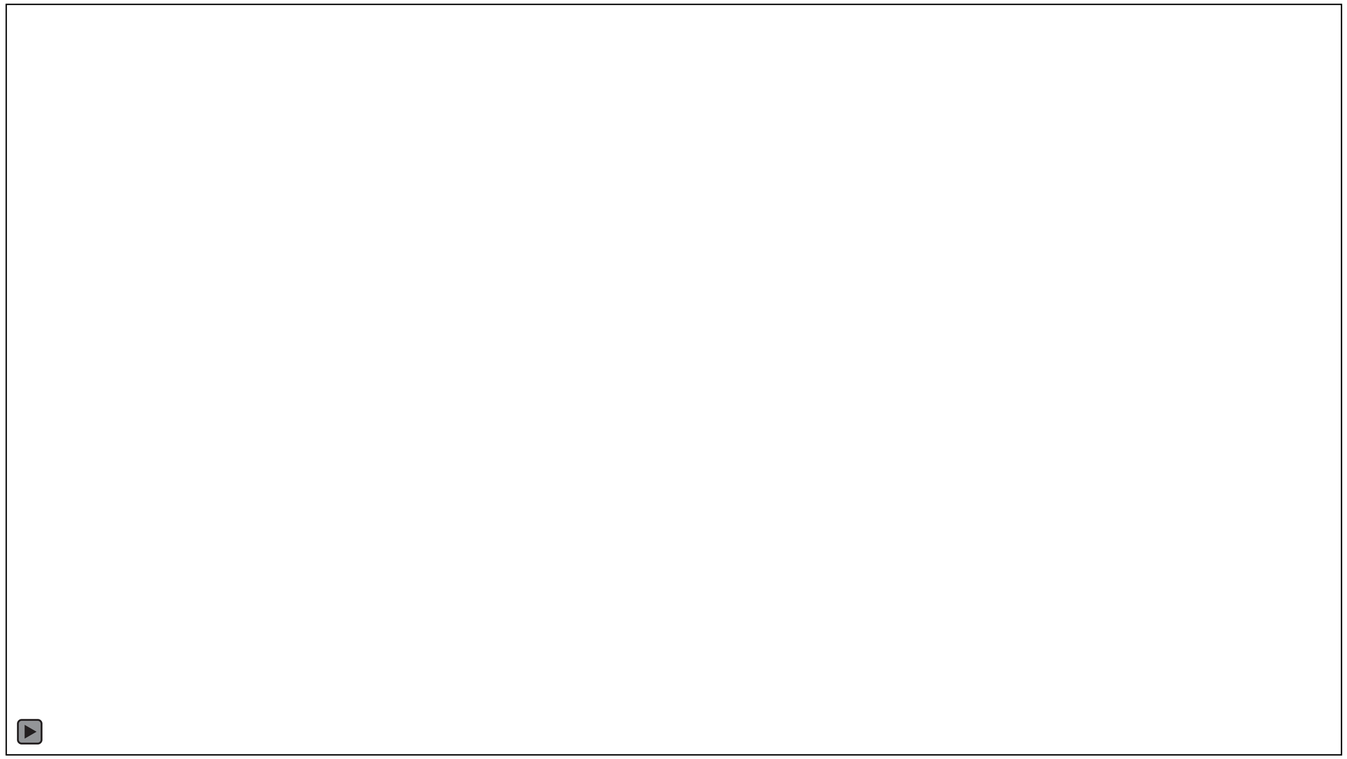
Chemical reanalysis inter-comparisons: CAMS & TCR



Huijnen et al. 2020

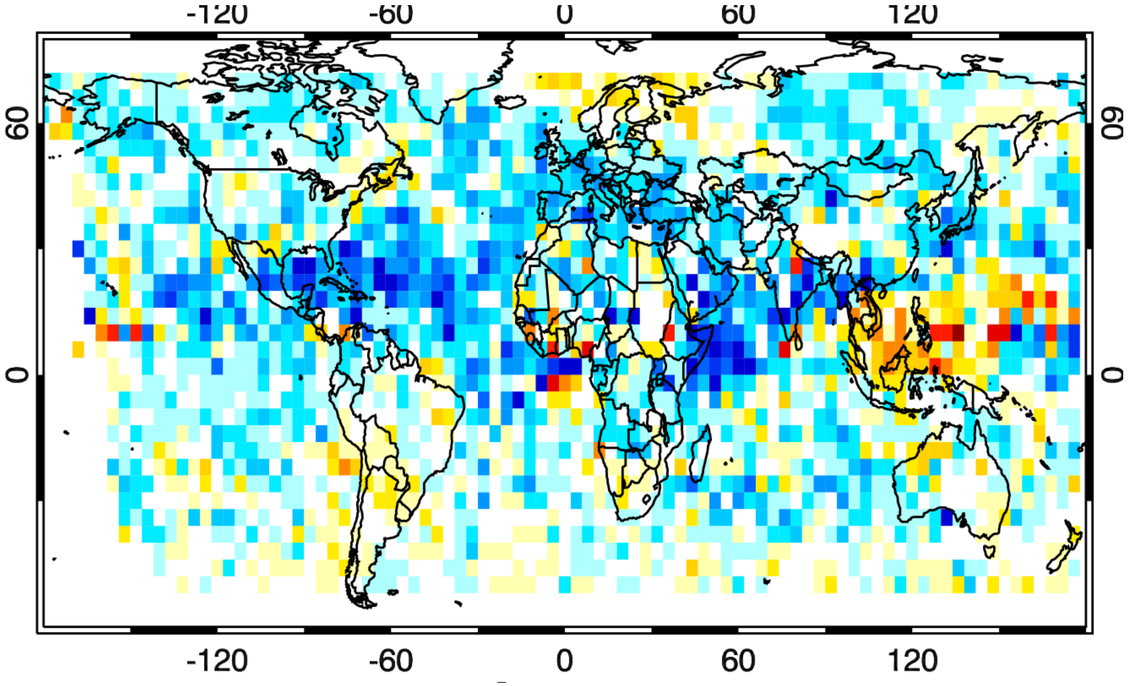
MOMO-Chem allows for attribution analysis

MOMO-Chem (with emission optimization)



Ozone anomaly during COVID

CrIS (TROPESS): 2020 minus 2019



1. Emissions (NOx, SO2, CO) → **2. Concentrations** → **3. Health and climate Impacts**

Jiang et al. 2020 ACP

Miyazaki et al. 2020 GRL

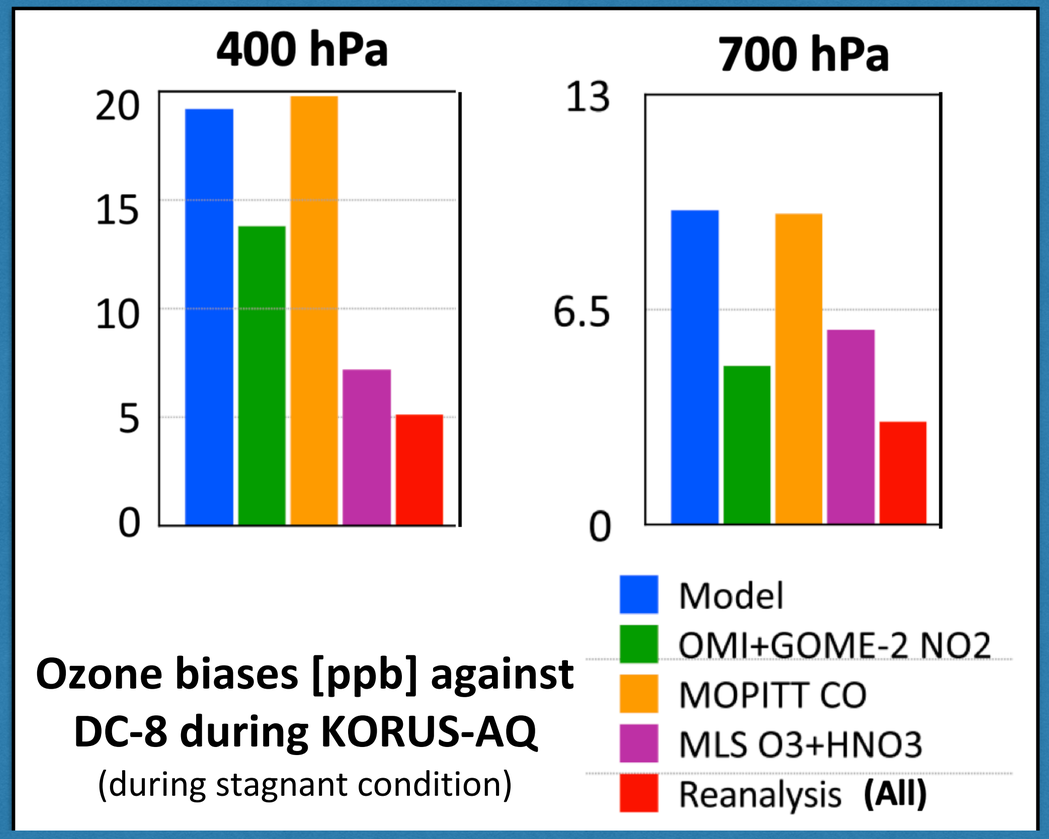
Miyazaki et al. 2021 Science Adv.

Laughner et al. 2021 PNAS

Sekiya et al. 2023 Science Adv.

Observing system impact assessment

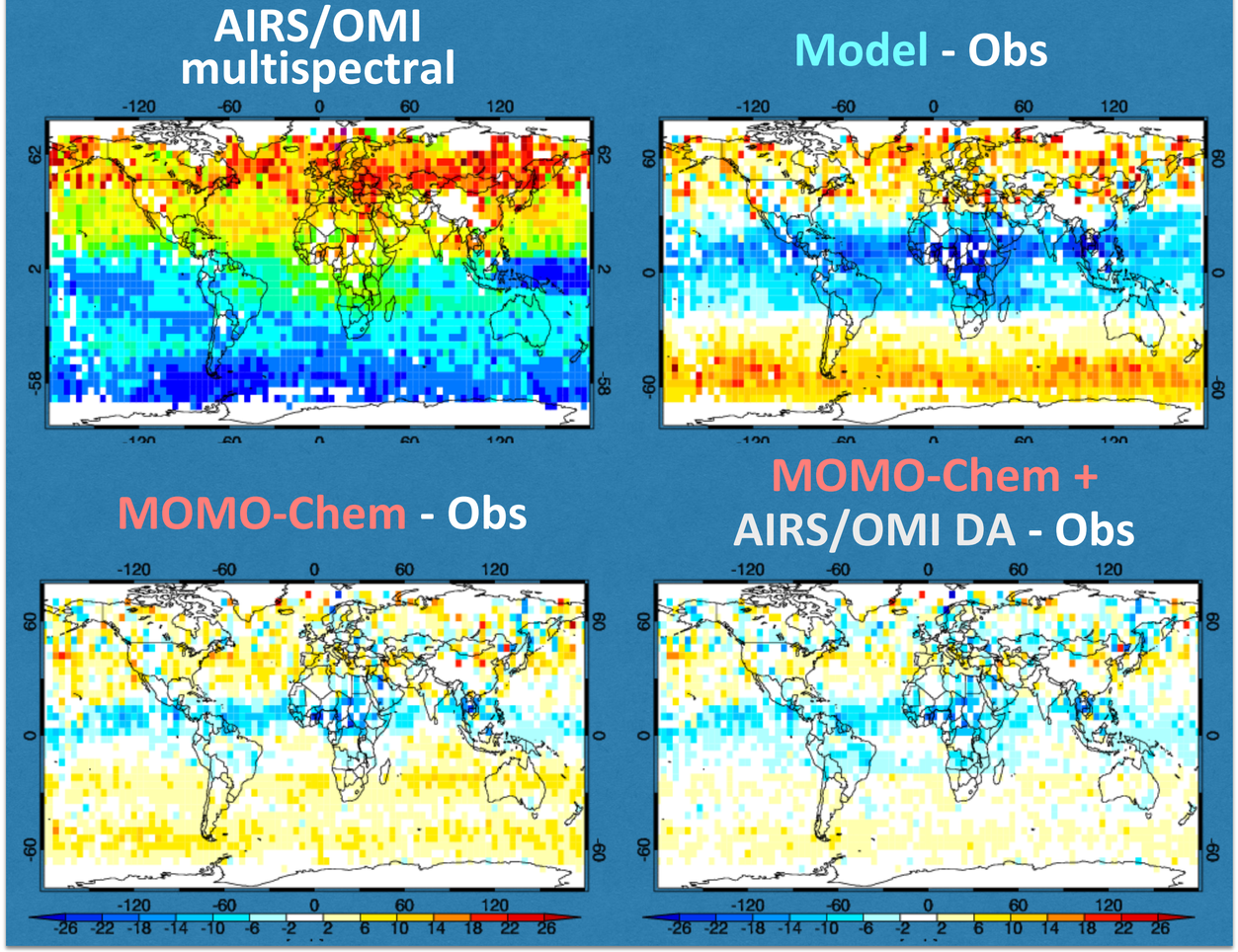
Harnessing EOS
→ entire tropo ozone profile



Ozone biases [ppb] against DC-8 during KORUS-AQ
(during stagnant condition)

Miyazaki et al., 2019a; Fu et al., 2019

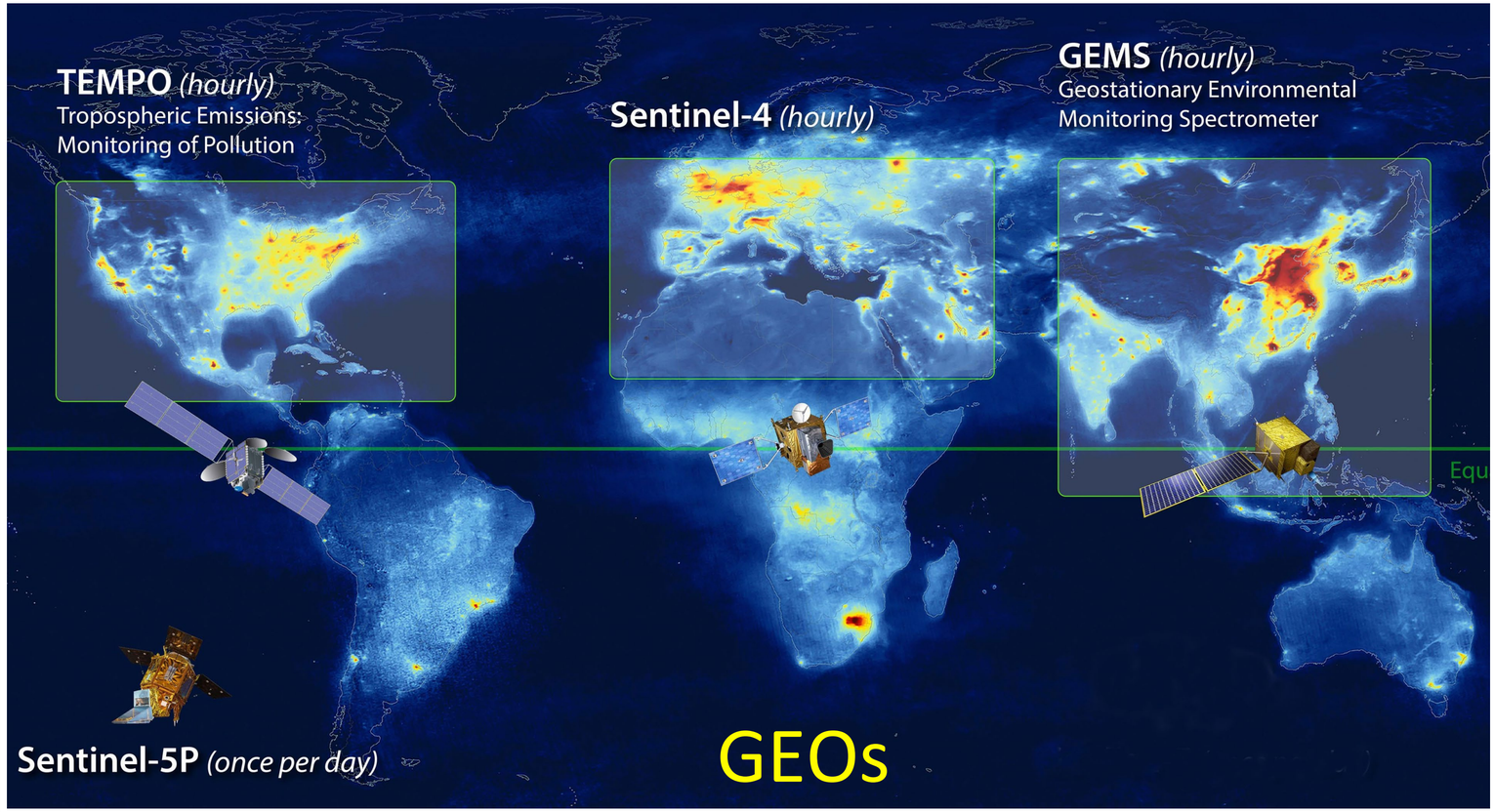
New satellite products can largely reduce errors in tropospheric ozone



Toward future mission formulation and Earth System prediction/reanalysis (NASA explore class, WMO)

Integration of the new generation satellite constellation

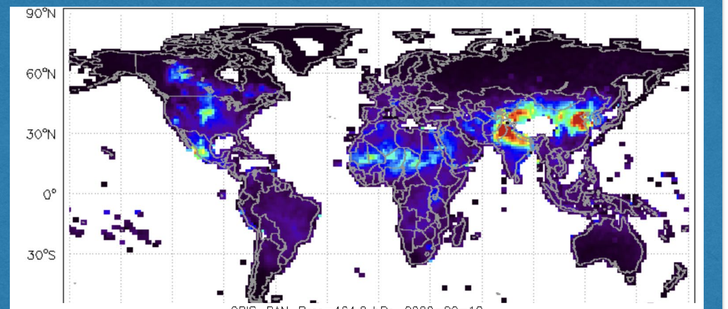
How does the constellation improve knowledge of regional/GL AQ?



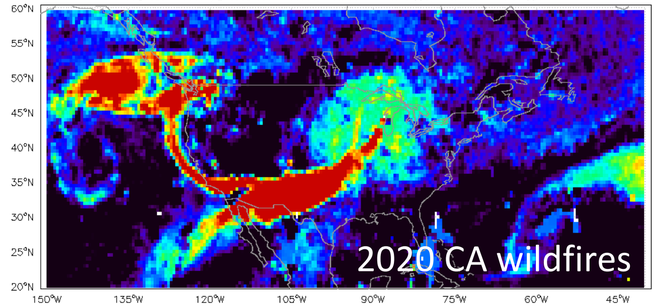
+

New LEO data

NH_3

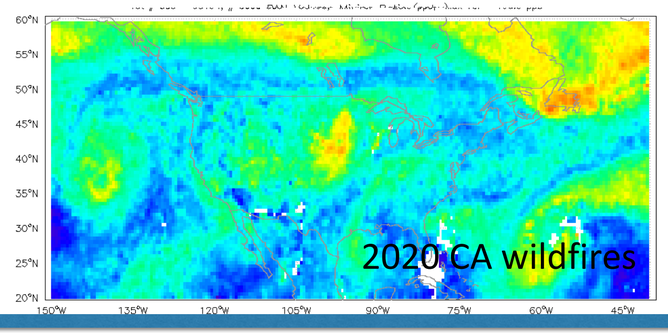


PAN



Trop O_3

(CrIS)

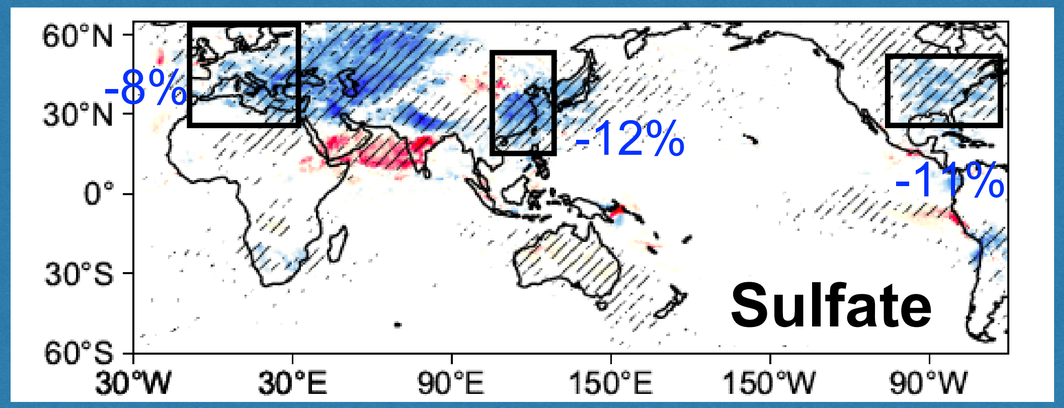


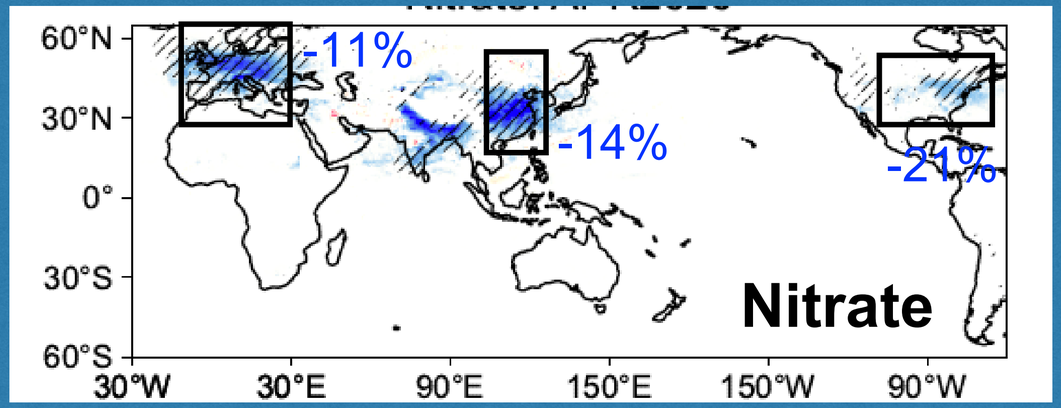
Global chemical DA plays an important role !

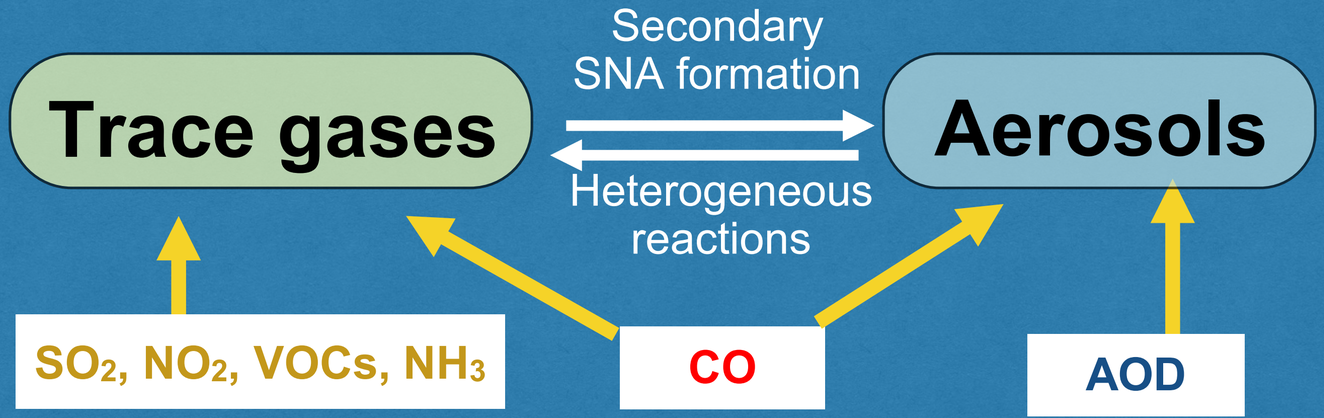
- MOMO-Chem can uniquely provide the basis for relating multi-platform observation information
- Assimilating the new generation satellite data will comprehend the understanding of attributions

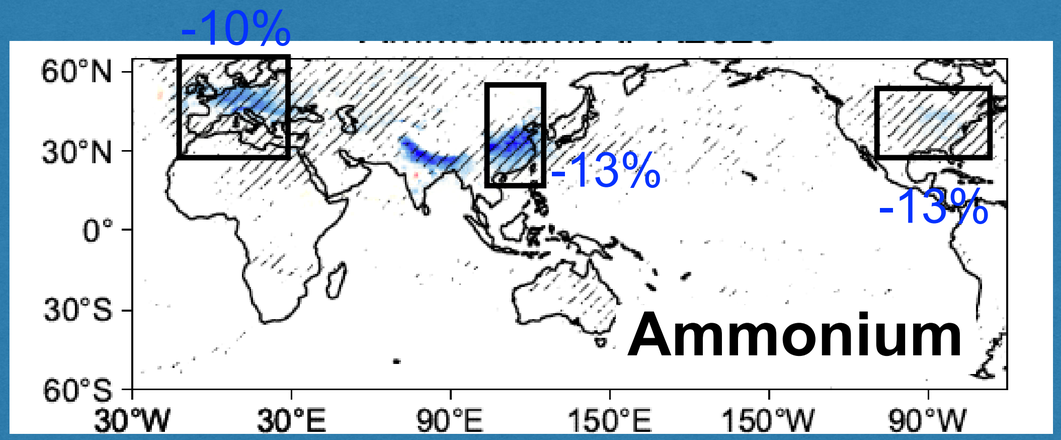
Aerosol - trace gas integration through chemical DA

SO_2, NO_2, NH_3 → Secondary aerosols (AOD → total)





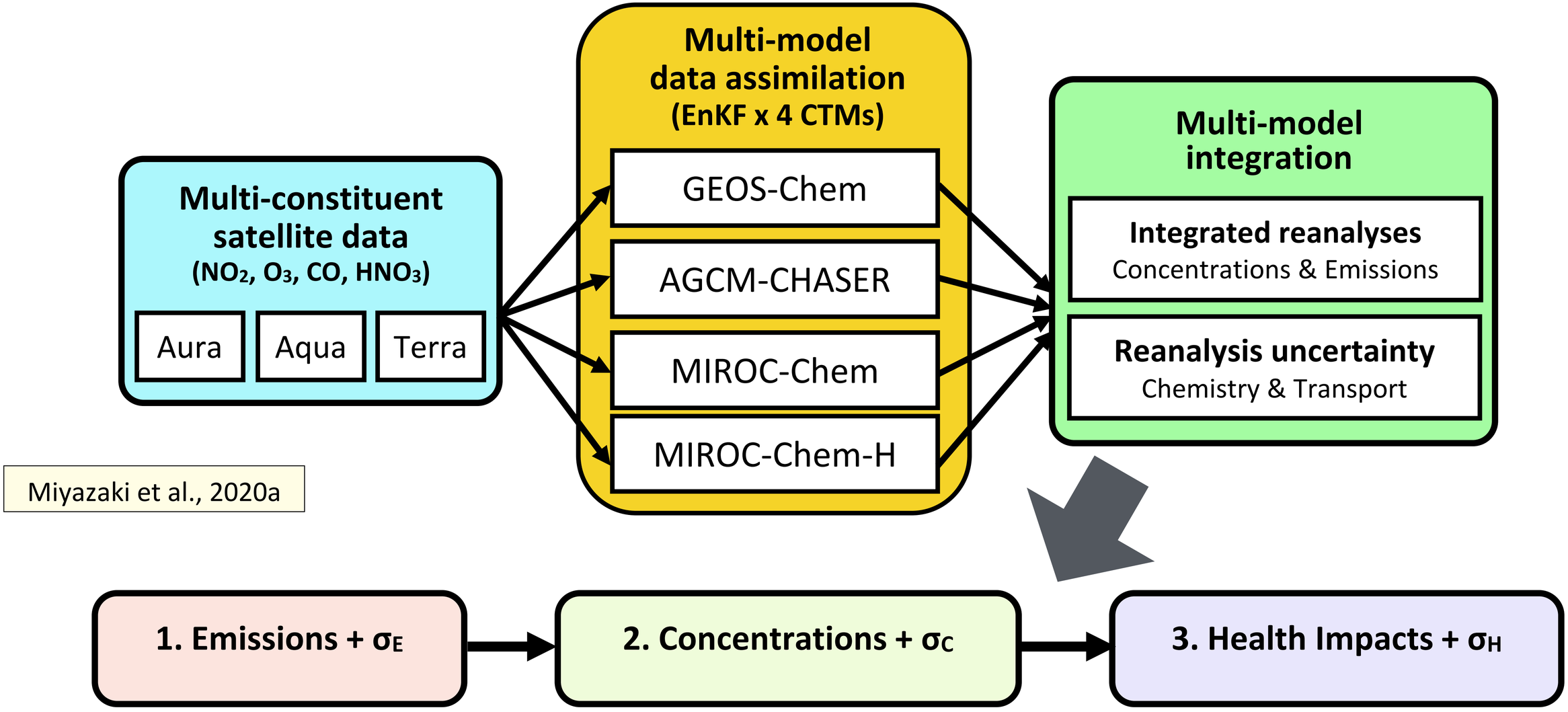




Sekiya et al.
(Sci Adv, 2023)

- Explain 43–79% of the observed AOD changes and lead to + 0.14W/m^2
  → importance of aerosol & trace gas DA in the AQ/climate impact assessment

Multi-mOdel Multi-cOnstituent CHEMical data assimilation (MOMO-Chem)



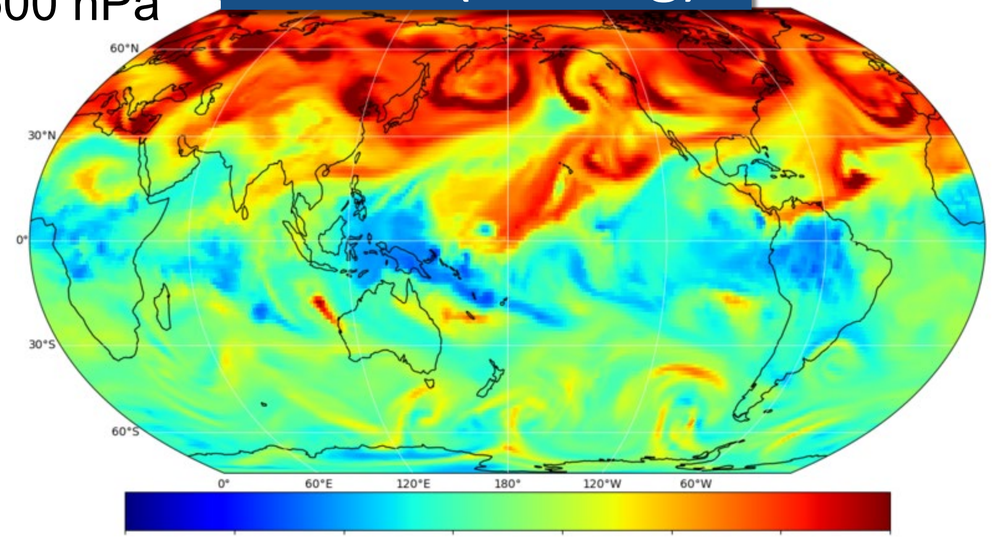
Miyazaki et al., 2020a

- Possible uncertainty ranges in top-down NOx emissions due to model errors: 13–31%
- OPE varied by a factor of 2 among models, highlighting fundamental differences in the fast processes

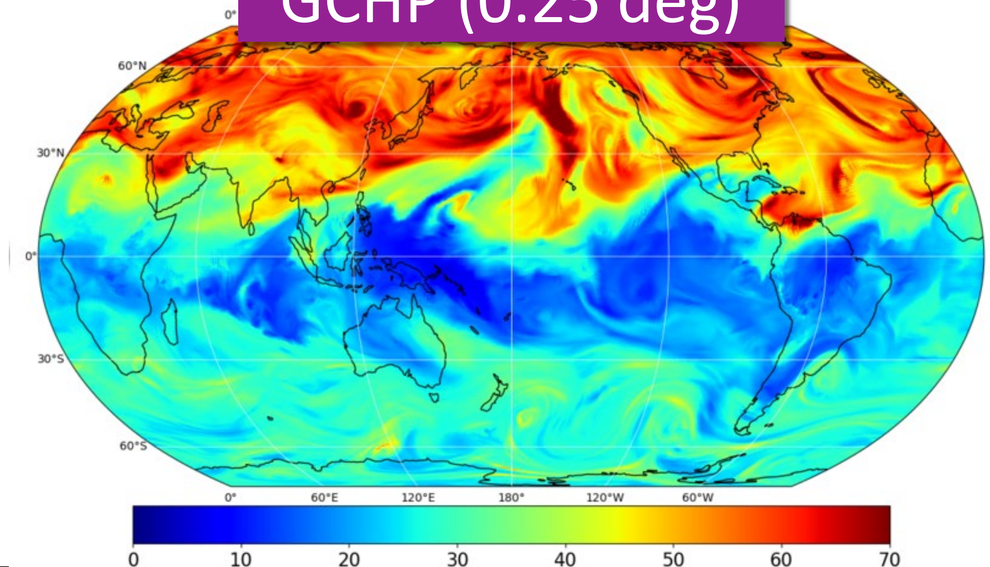
MOMO-Chem will be higher resolution for city-to-global scale analysis

Ozone at 500 hPa

TCR-2 (1.1 deg)

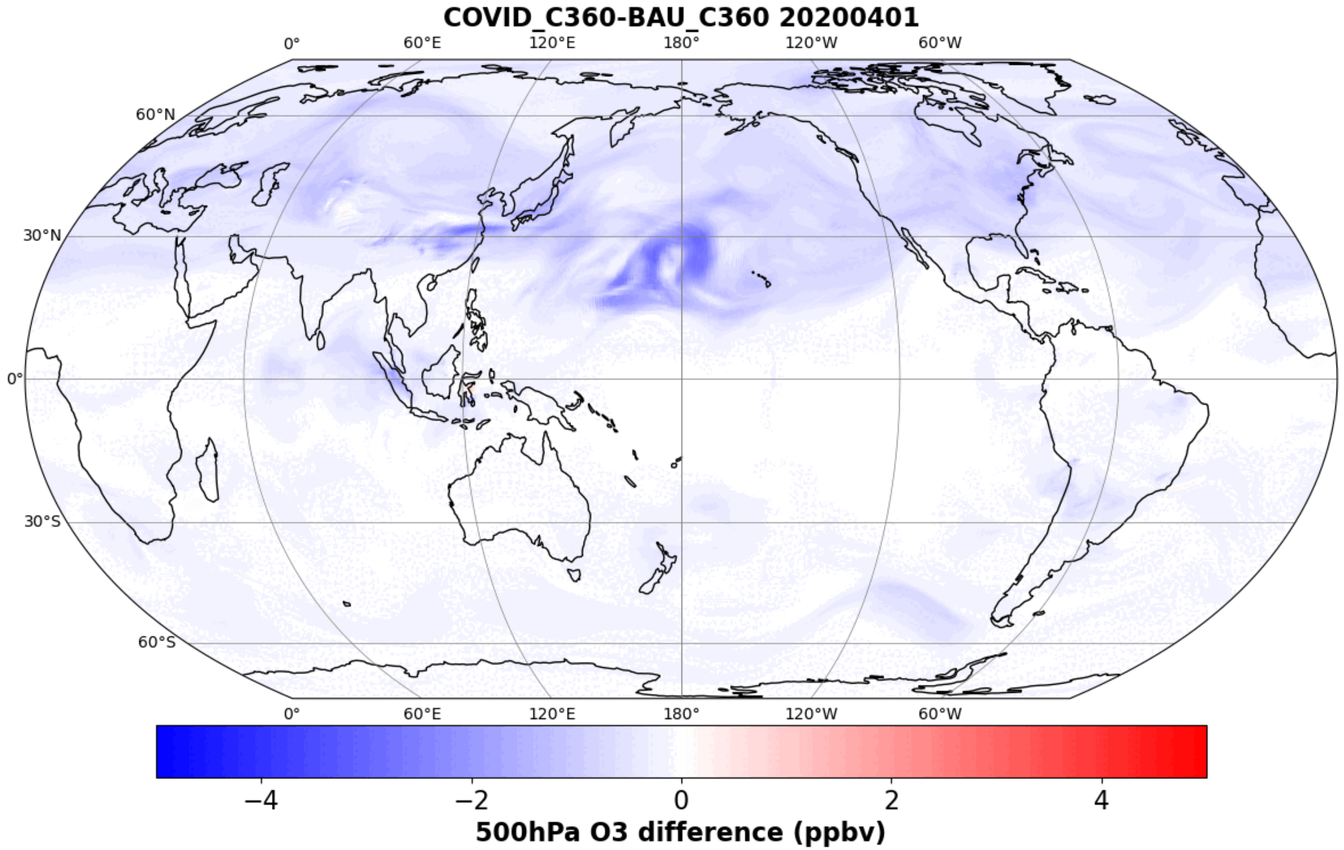


GCHP (0.25 deg)



GCHP (0.25 deg)

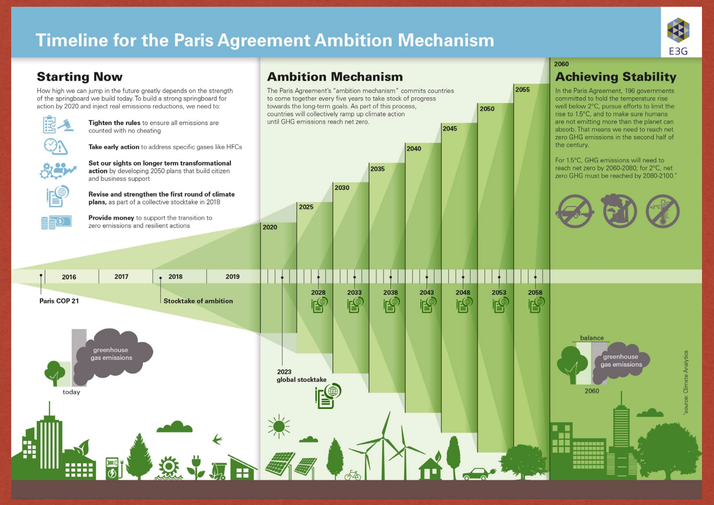
COVID ozone anomaly



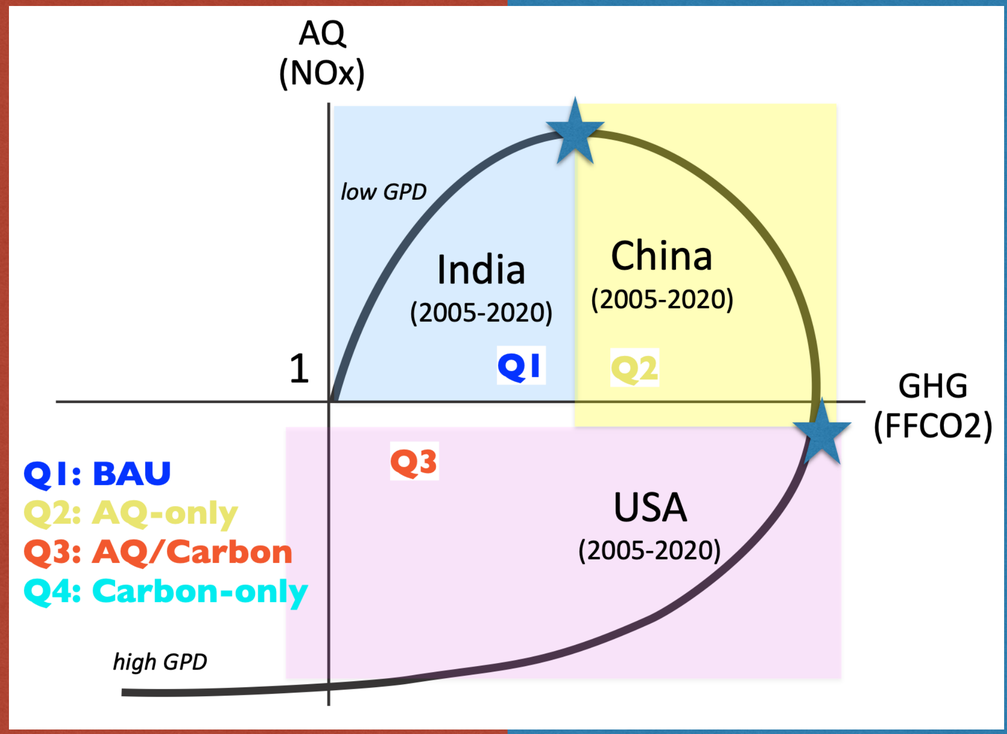
- more effectively assimilate high-resolution information
- evaluate possible uncertainty ranges due to model errors

MOMO-chem integrates AQ and GHG satellites

GHG (FFCO2) ← Air pollutants

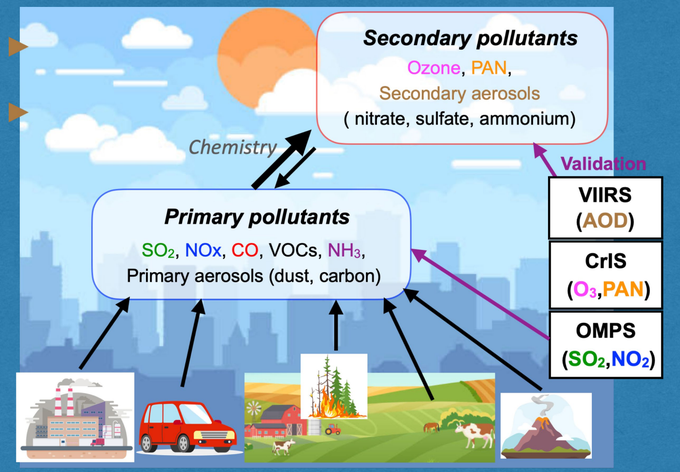


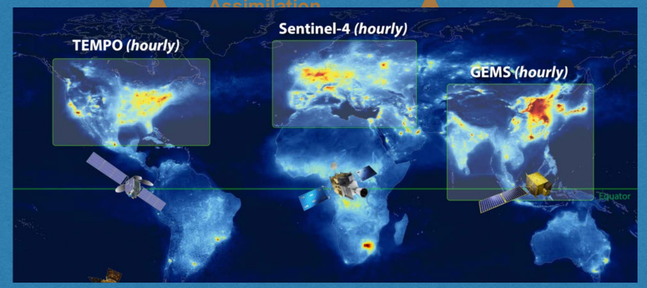
The Global Stocktake



MEKC combines GHG and AQ emissions wrt GDP into a single graph

(Miyazaki and Bowman, Nature comm, 2023)



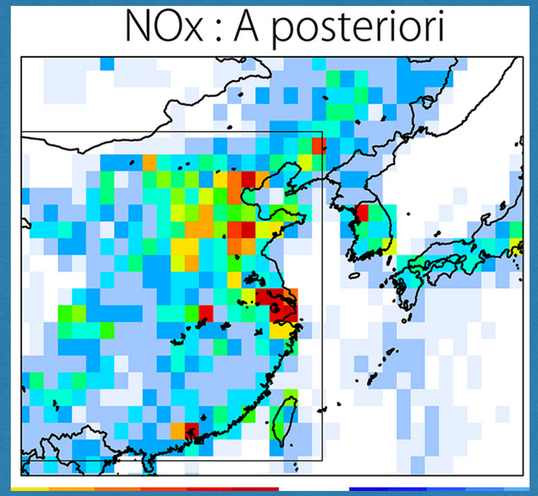


NASA Earth Science U.S. Participating Investigator (2023-2028):

New satellite-based products of global fossil fuel CO_2 emissions from **GOSAT-GW**

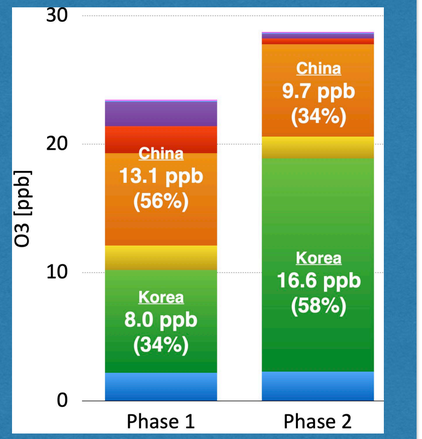
MOMO-Chem will contribute to the future missions

Emission optimization

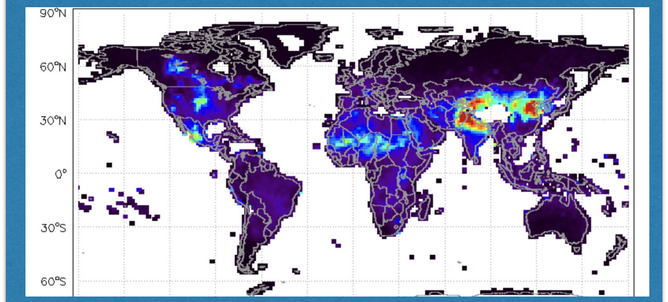


Miyazaki et al., 2019a;
Fu et al., 2019

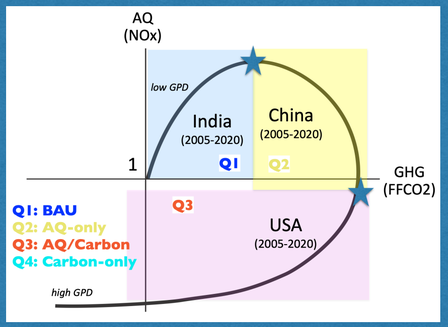
Attribution



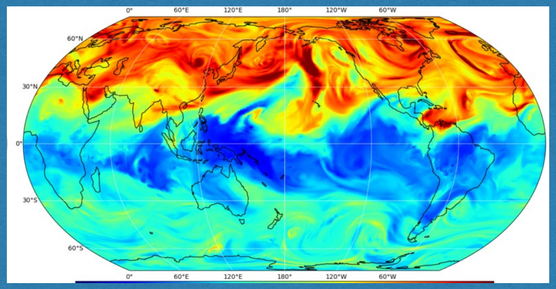
New species



AG-GHG synergy



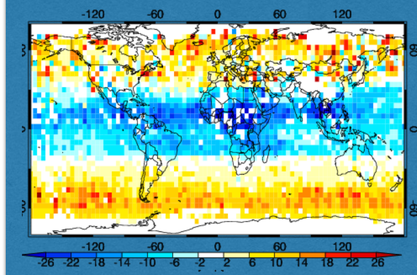
High-resolution model



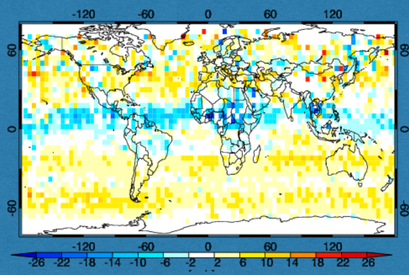
KORUS-AQ

New tropospheric ozone

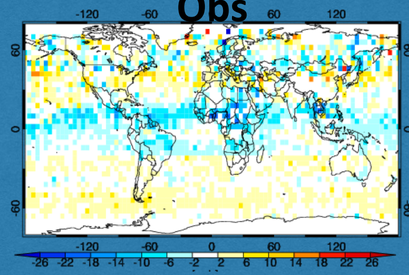
Model - Obs

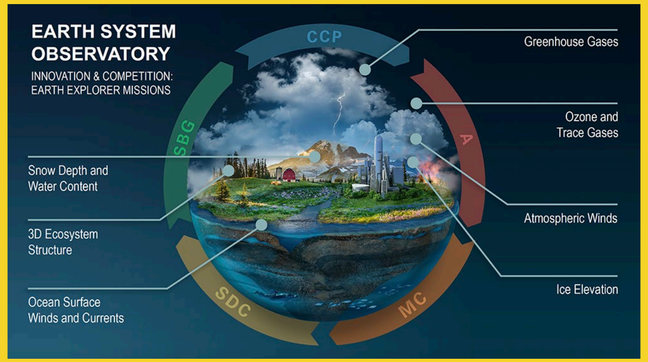


Reanalysis - Obs



Reanalysis + AIRS/OMI DA - Obs





Summary

- The chemical reanalysis data, combined with suborbital and ground-based measurements, has been used to improve our understanding of atmospheric composition and to evaluate new satellite data products.
- New LEO and GEO measurements and multi-spectral retrievals of composition provide much-improved spatial and temporal resolution and coverage in conjunction with the chemical reanalysis. They should lead to greater usefulness of satellite measurements for climate and air quality applications.
- Future applications: New satellites (GOSAT-GW, CO2M, GEMS, OCO-3, TROPOMI, TEMPO, GEO-XO, S4), aircraft missions (ASIA-AQ), new focuses (trace gas & aerosol interactions, OH, wildfires, biogenic), new techniques (ML).