# 大気組成データ同化システムの開発と長期再解析

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JAMSTEC

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

第４回データ同化ワークショップ、気象庁、2014年1月8日

1. 大気組成データ同化とは

2. システムの開発

3. 解析結果の検証

4. 長期再解析の実施

5. 今後の課題

Miyazaki et al., Global lightning NOx production estimated by an assimilation of multiple satellite datasets, *ACPD, 2013.*

Miyazaki et al., Constraints on surface NOx emissions by assimilating satellite observations for multiple species, *GRL*, 2013.

Nakamura, Miyazaki et al., A multi-model comparison of stratospheric ozone data assimilation based on an ensemble Kalman filter approach, *JGR*, 2013.

Miyazaki et al., Simultaneous assimilation of satellite NO2, O3, CO, and HNO3 data for the analysis of tropospheric chemical composition and emissions, *ACP*, 2012b.

Miyazaki et al., Global NOx emission estimates derived from an assimilation of OMI tropospheric NO2 columns, *ACP*, 2012a.

Miyazaki et al., Assessing the impact of satellite, aircraft, and surface observations on CO2 flux estimation using an ensemble-based 4D data assimilation system, *JGR*, 2011.

Miyazaki, Performance of a local ensemble transform Kalman filter for the analysis of atmospheric circulation and distribution of long-live tracers under idealized conditions, *JGR*, 2009.

with thanks to Henk Eskes (KNMI), Kengo Sudo (Nagoya Univ.), Folkert Boersma (Einthovohen Univ.), Michiel van Weele (KNMI)

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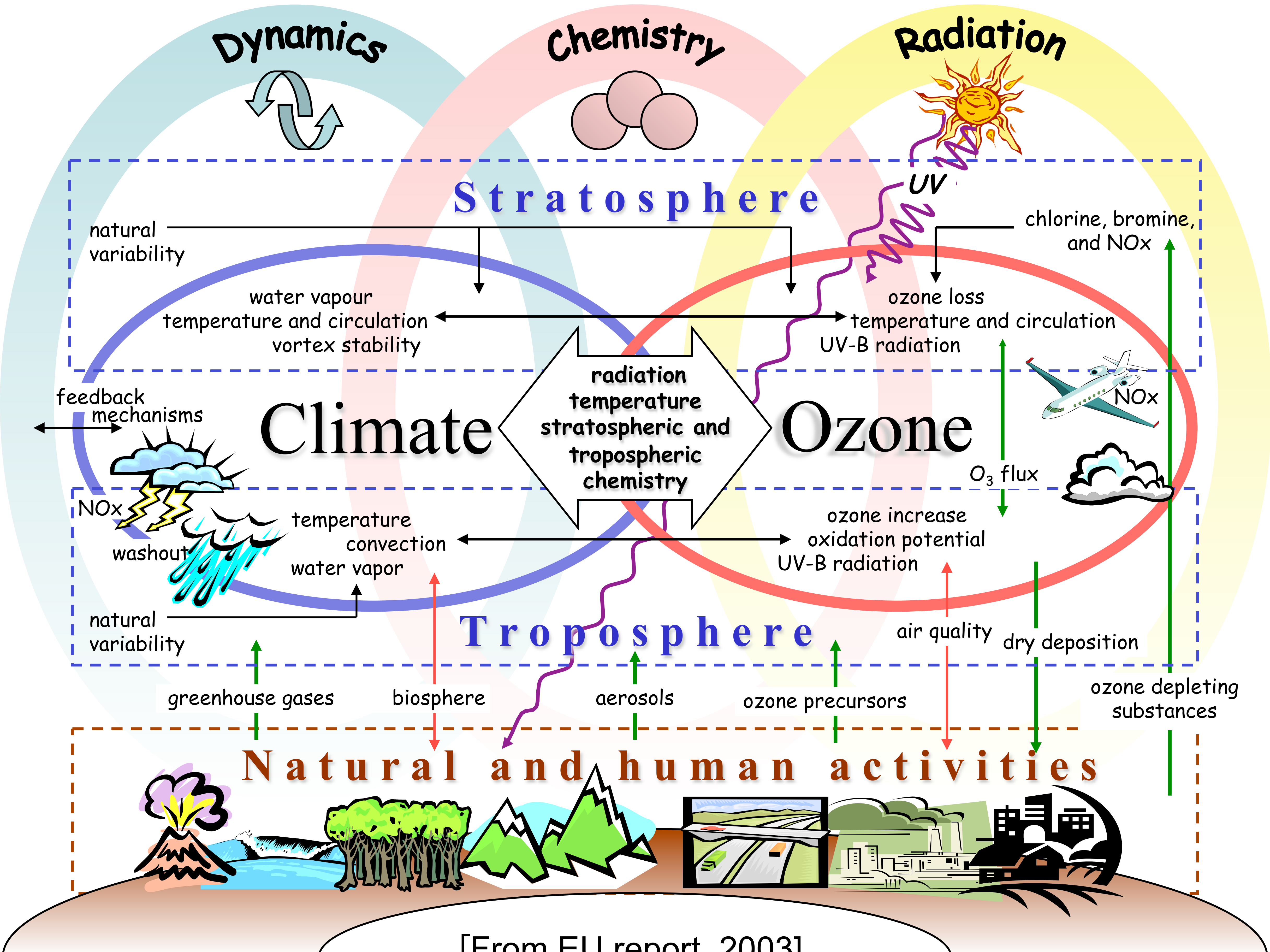
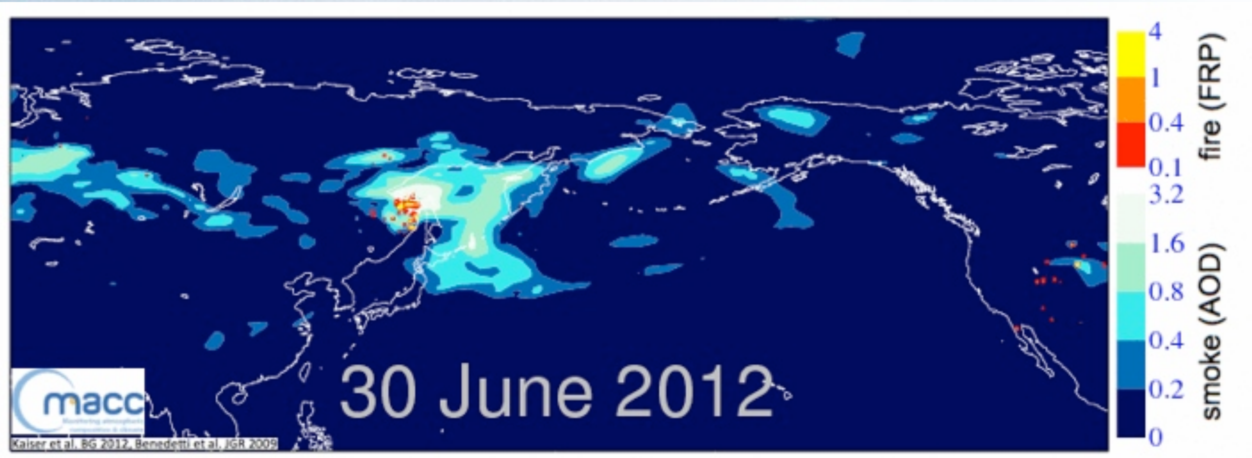
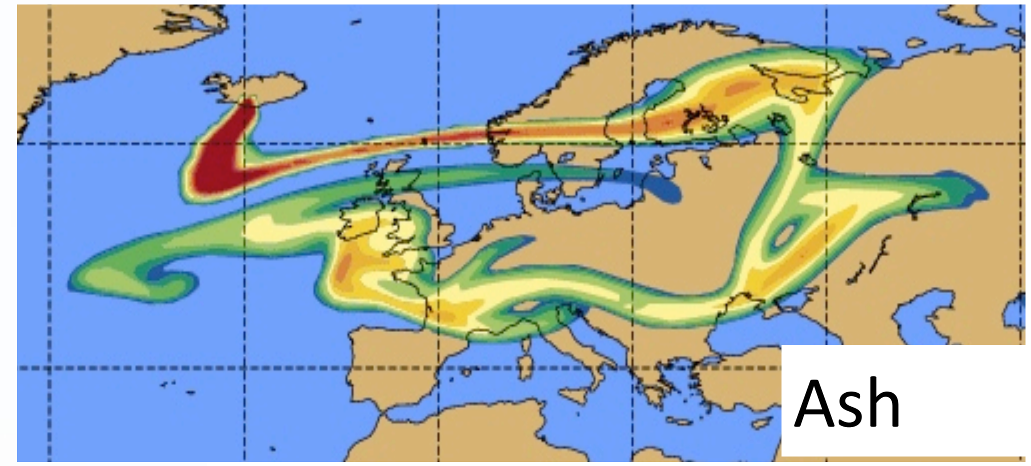


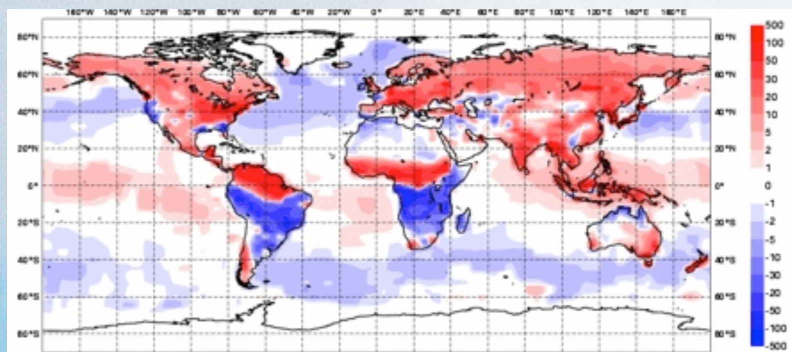

[From EU report, 2003]

# 大気組成 解析・予報の必要性

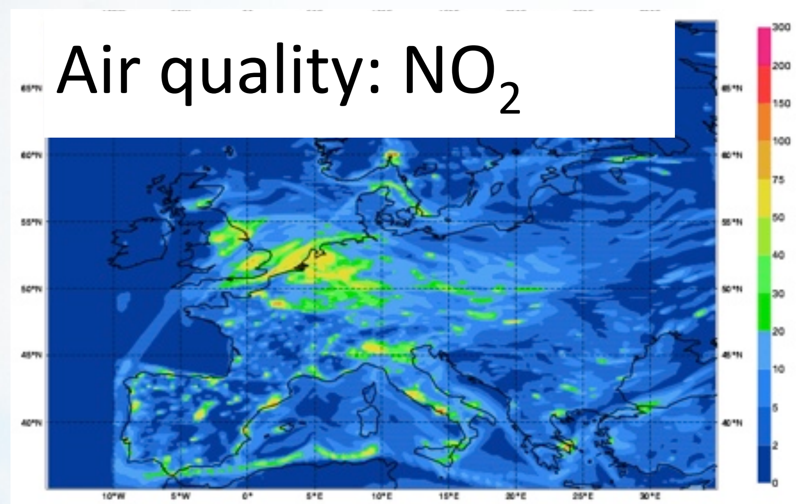



Fire and smoke

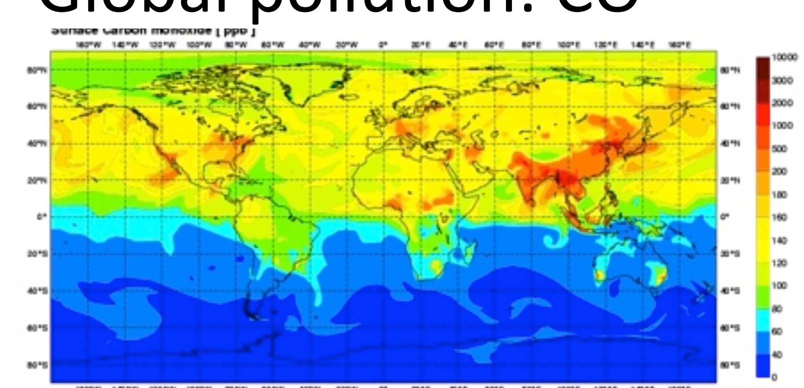


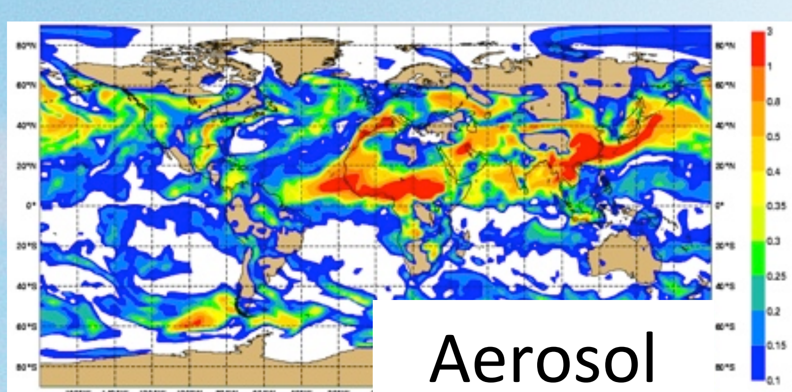



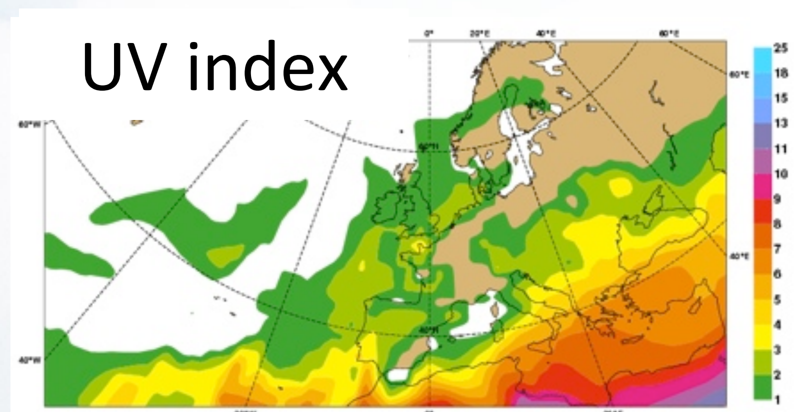
Flux inversions: $CO_2$

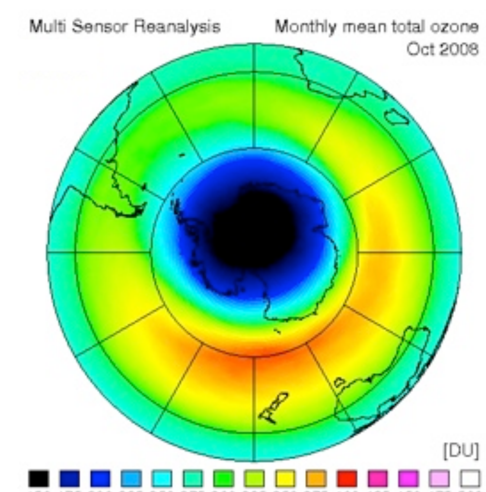



Global pollution: CO






Ozone

*(A. Thorpe, ECMWF DG, AMS Presidential Forum address)*

# 大気組成データ同化の特徴

- 様々なスケール(数秒から数10年)の現象が内在
- 化学システムは頑固(Stiff)、局所平衡濃度へ
- 初期値に加えて、排出量や化学反応係数の修正が重要

# 大気組成データ同化の必要性

- 初期値の高精度化:大気汚染・UV・オゾンホール予報
- 放射過程・背景誤差共分散を考慮した気象解析の向上
- 再解析データ: 人間活動と大気組成変動、放射伝達計算、気候モデル・気象再解析へのインプット

(Rood 2005; Lahoz et al., 2007)

# 大気組成データ同化システム

## NWPベース（現業センター）

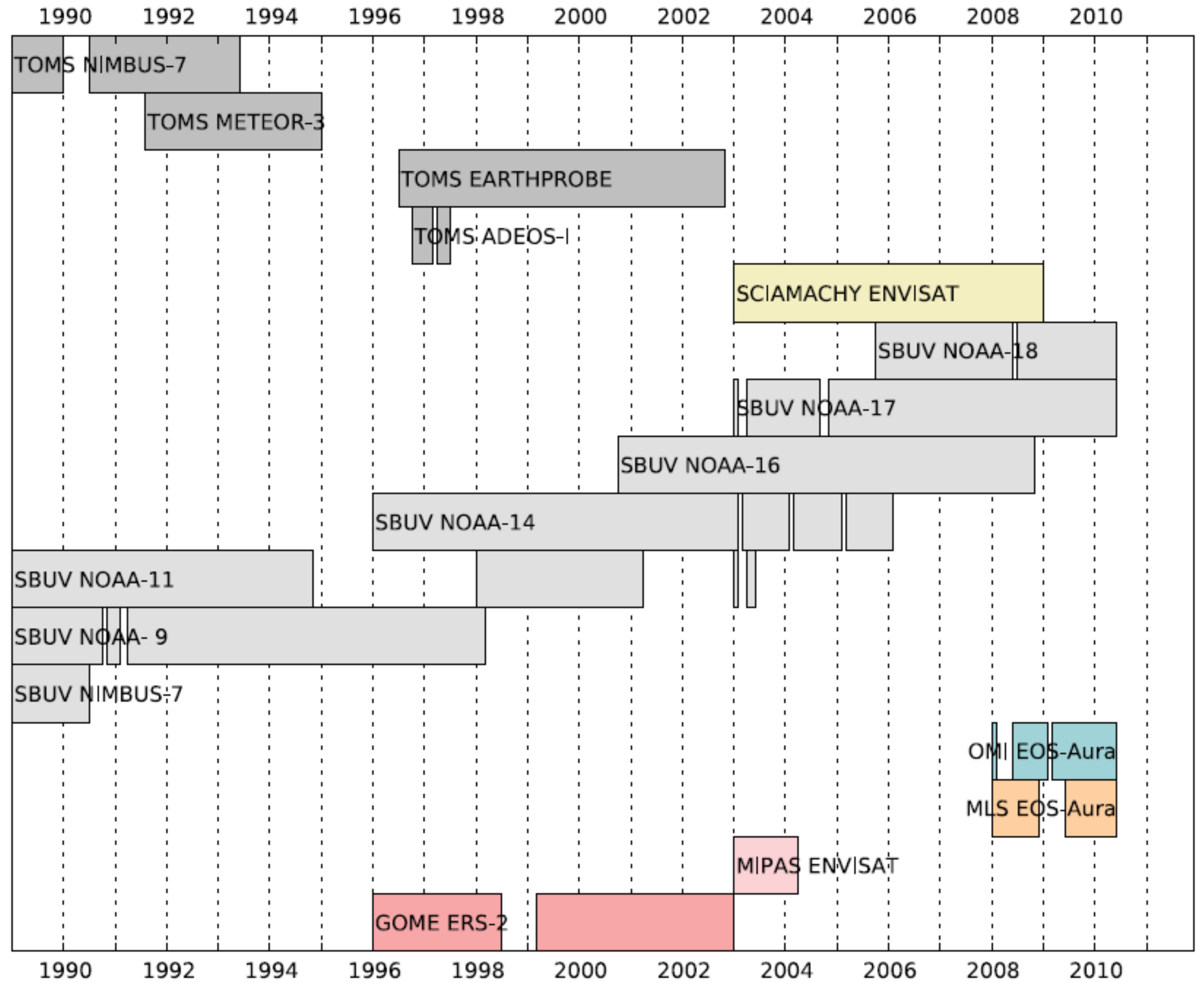
- 化学過程は簡略化して表現。主に成層圏オゾンのみを対象。
- 放射過程を介して気象解析を改善することが目的。

## CTMベース（主に研究機関）

- 複雑な化学・輸送過程を含み、様々な物質を対象。
- 大気組成変動要因の理解、化学天気予報などのため。
- 気象場は外部データ。排出量推定にも応用可能。

NWP

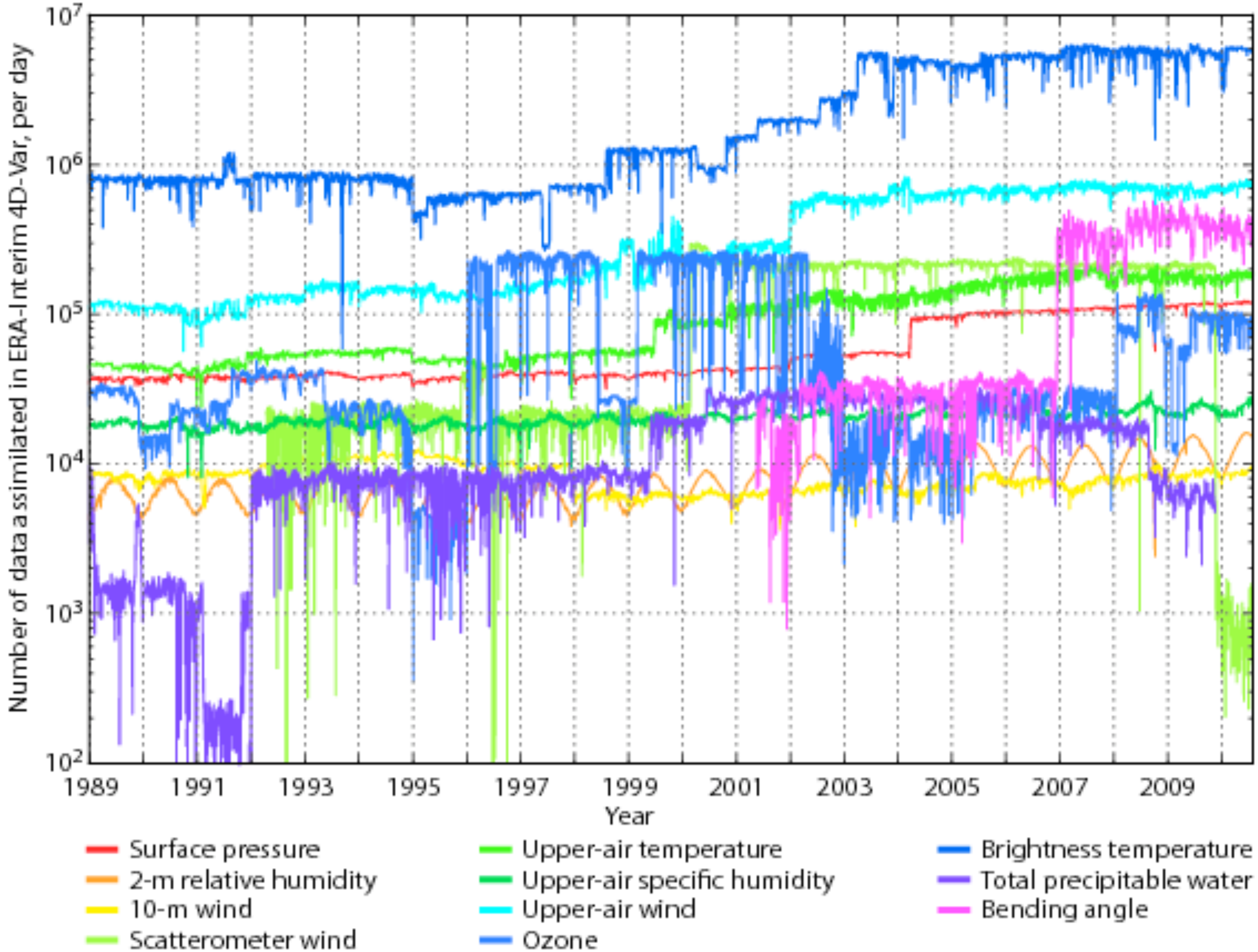
# ERA-Interim Sources of Profile and Total Ozone




gure 15. Timeline of ozone data assimilated in ERA-Interim.

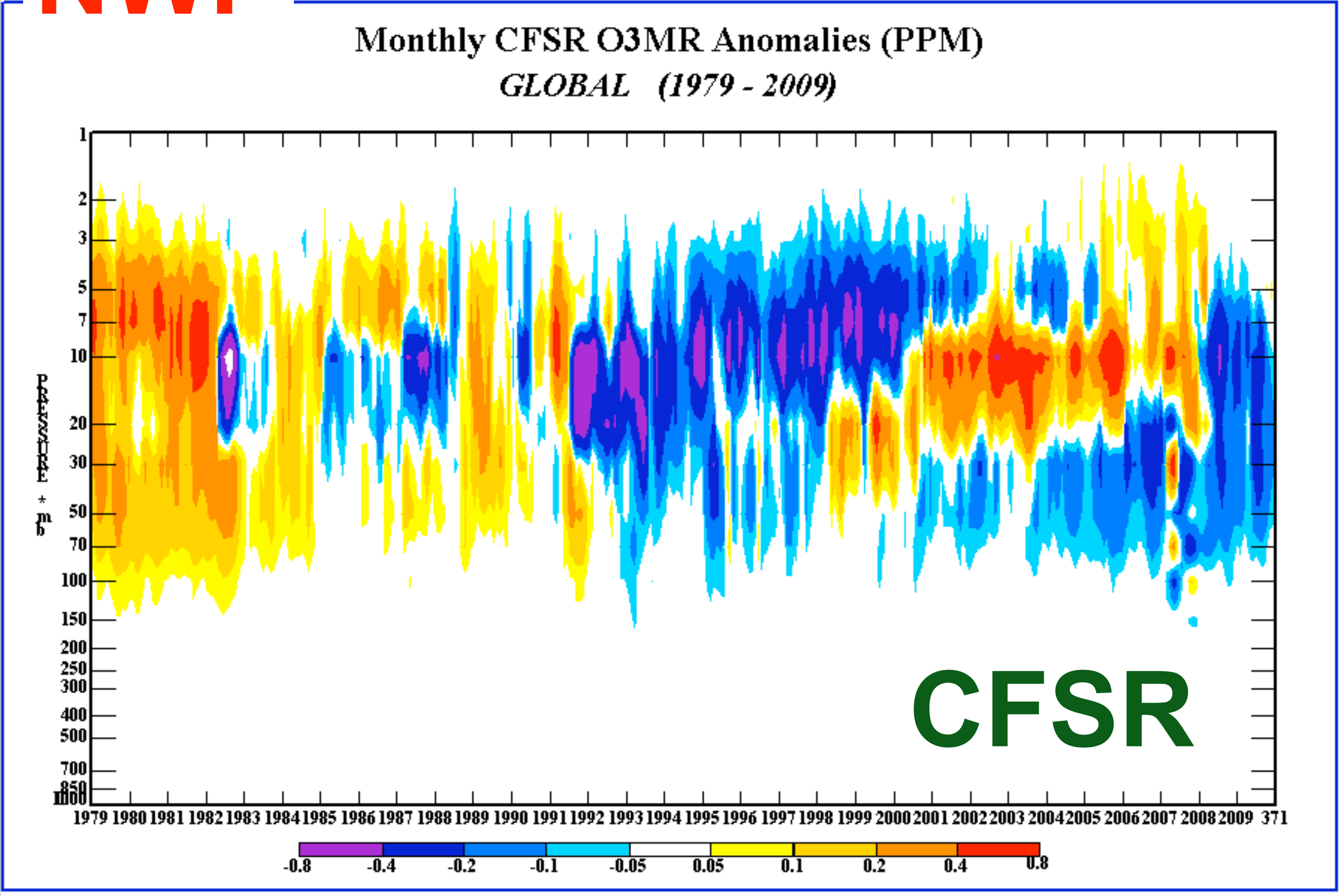
NWP

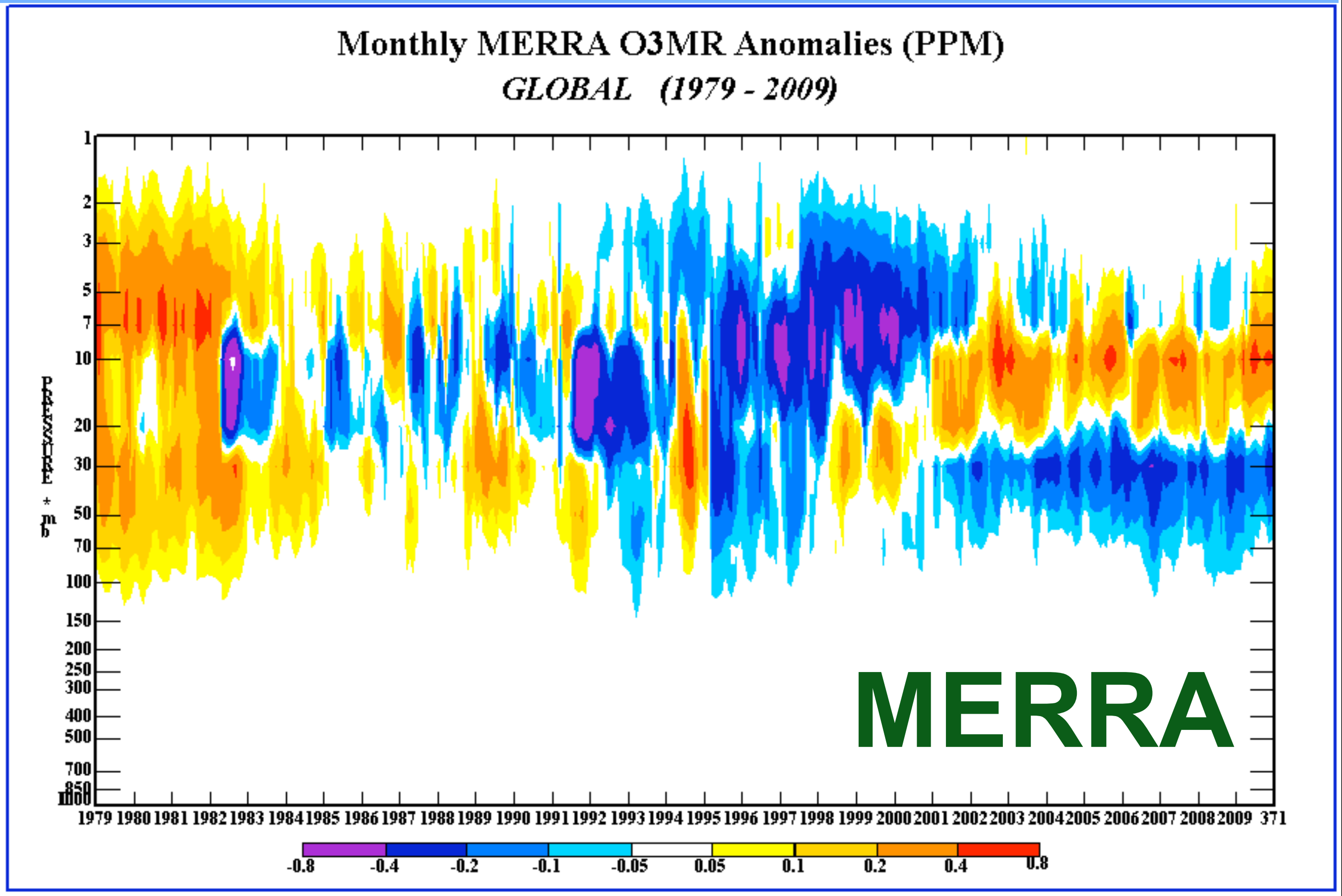
# Observations used in ERA-Interim: Data counts

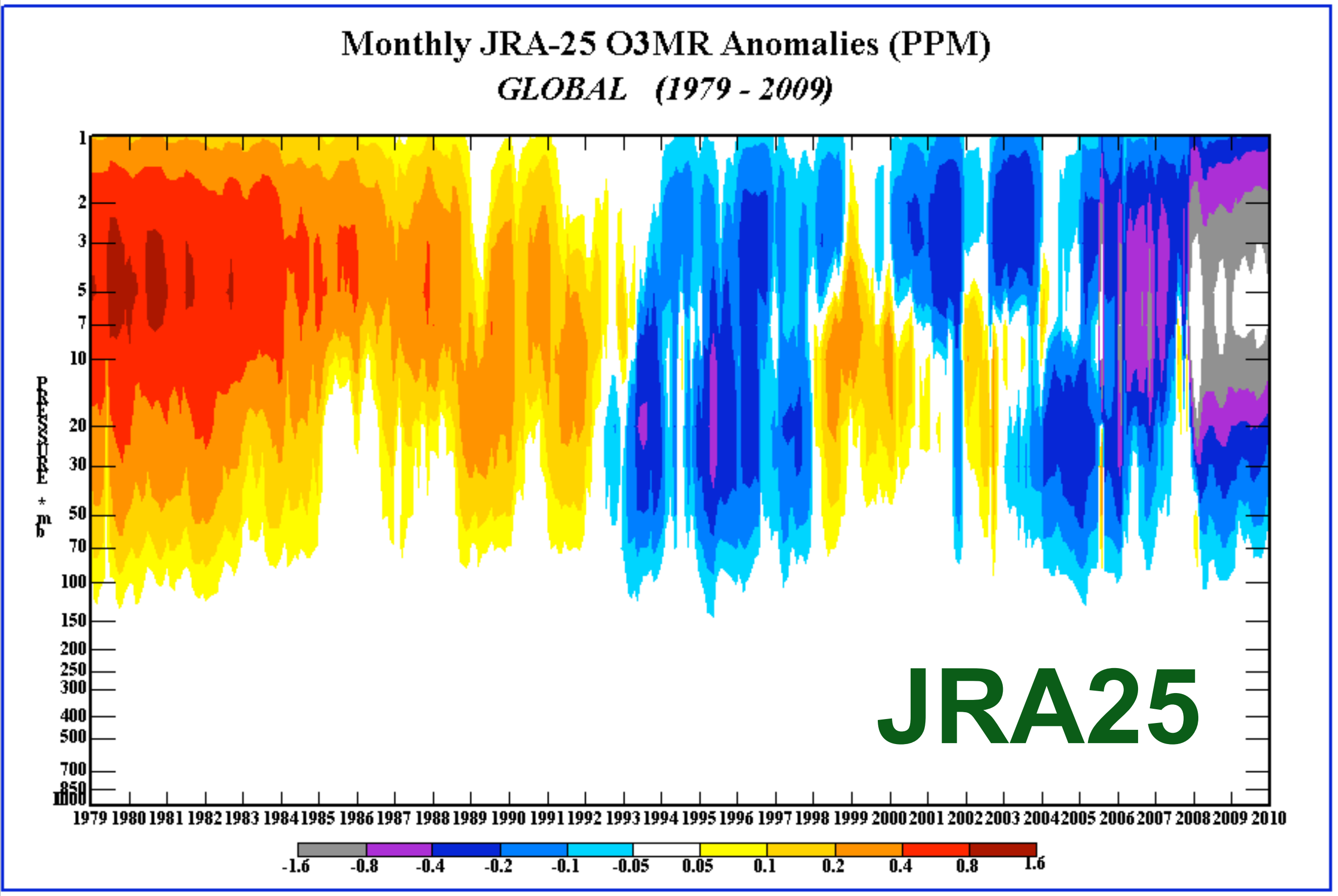


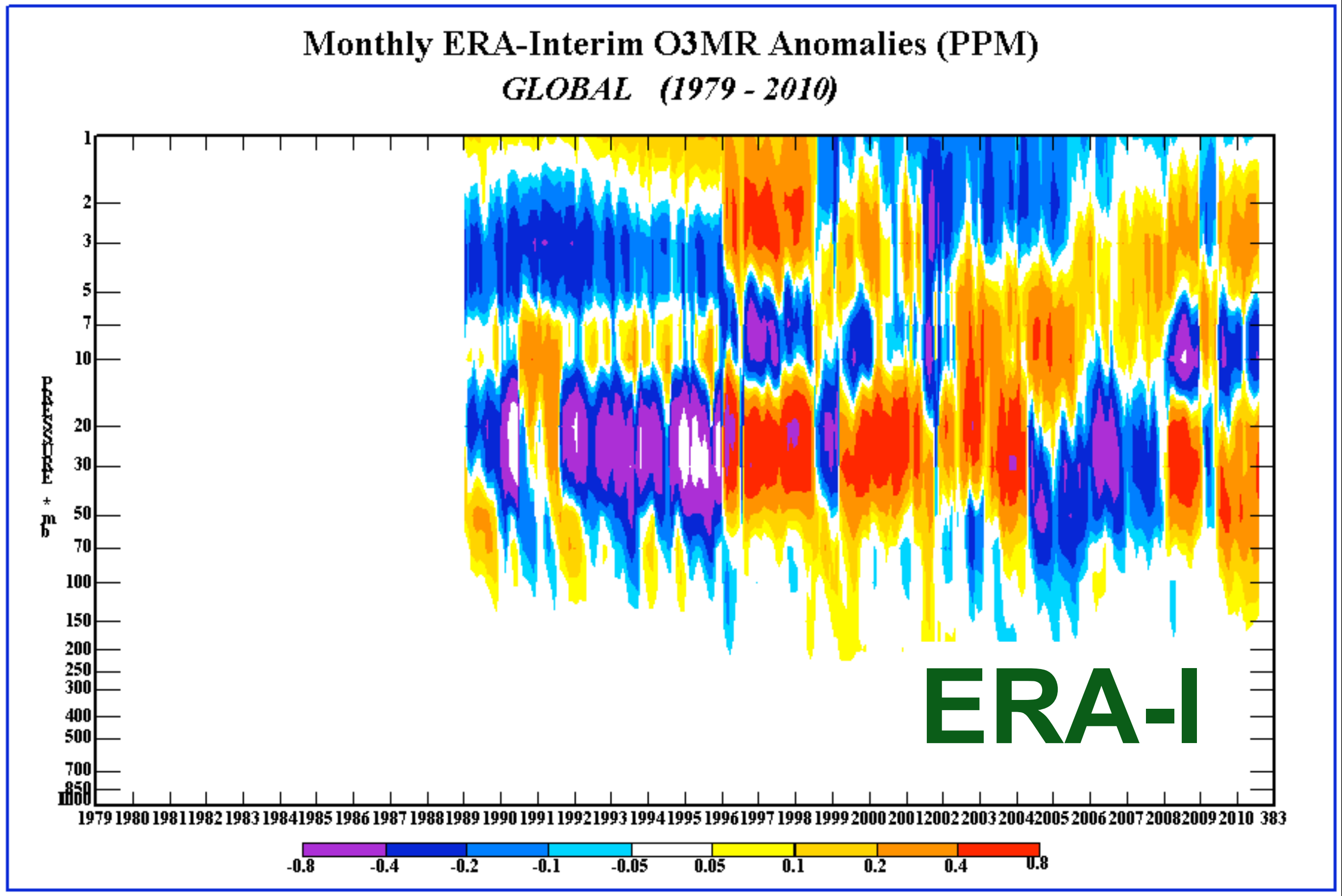
# Global O3MR Anomalies

NWP



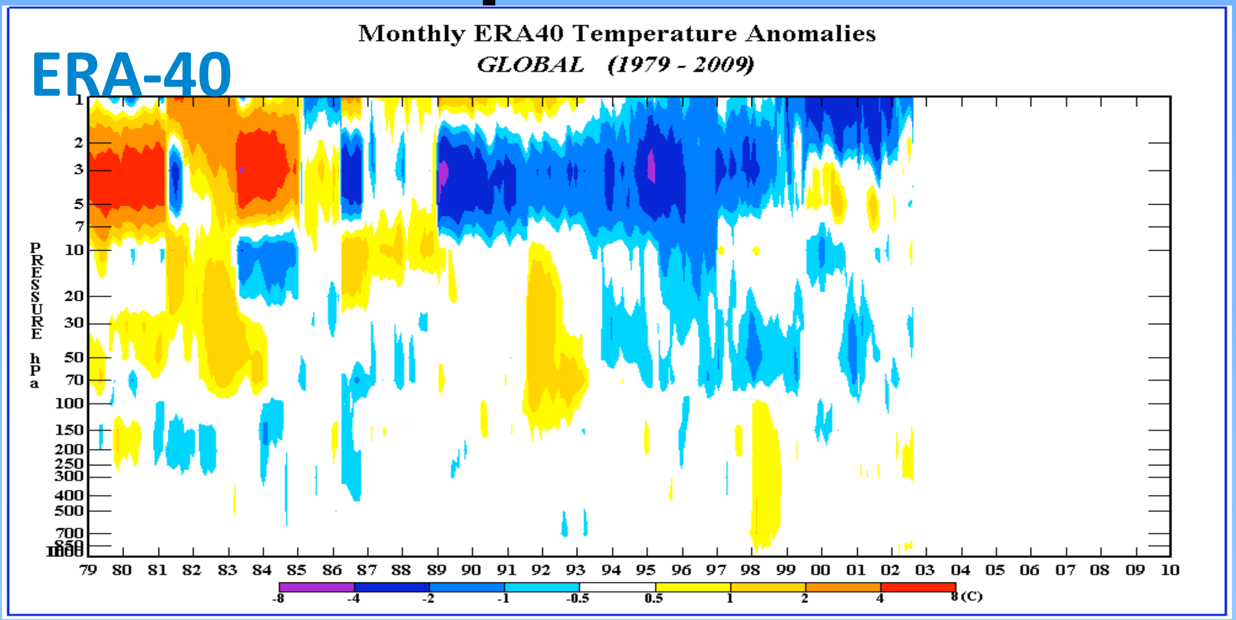



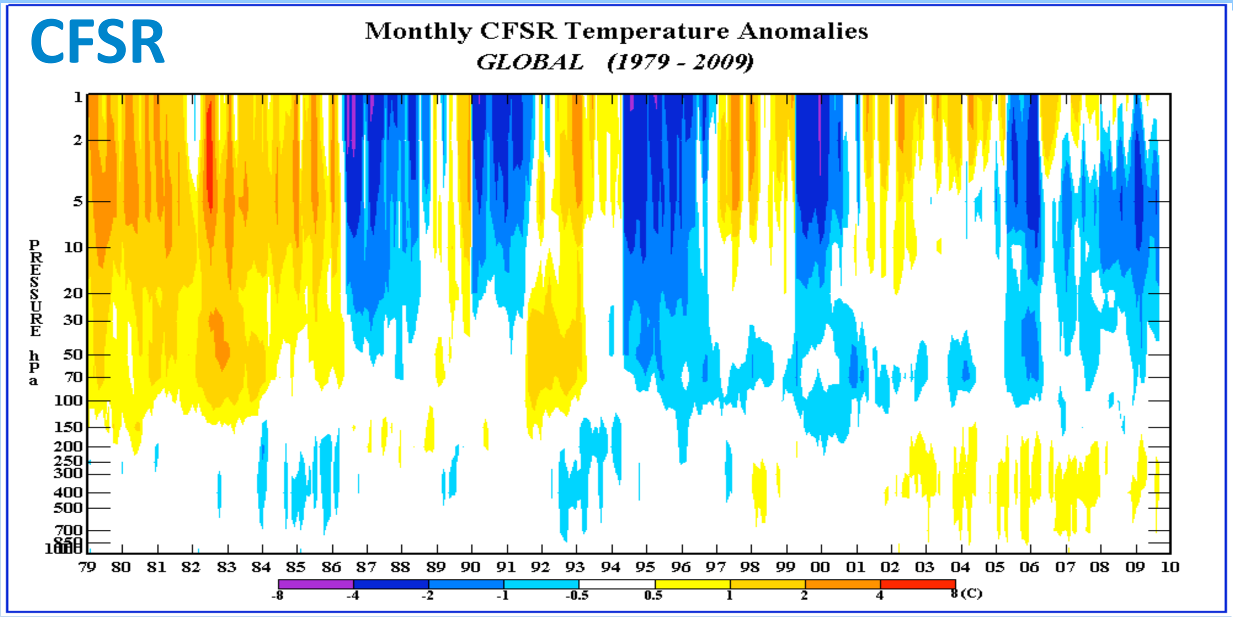



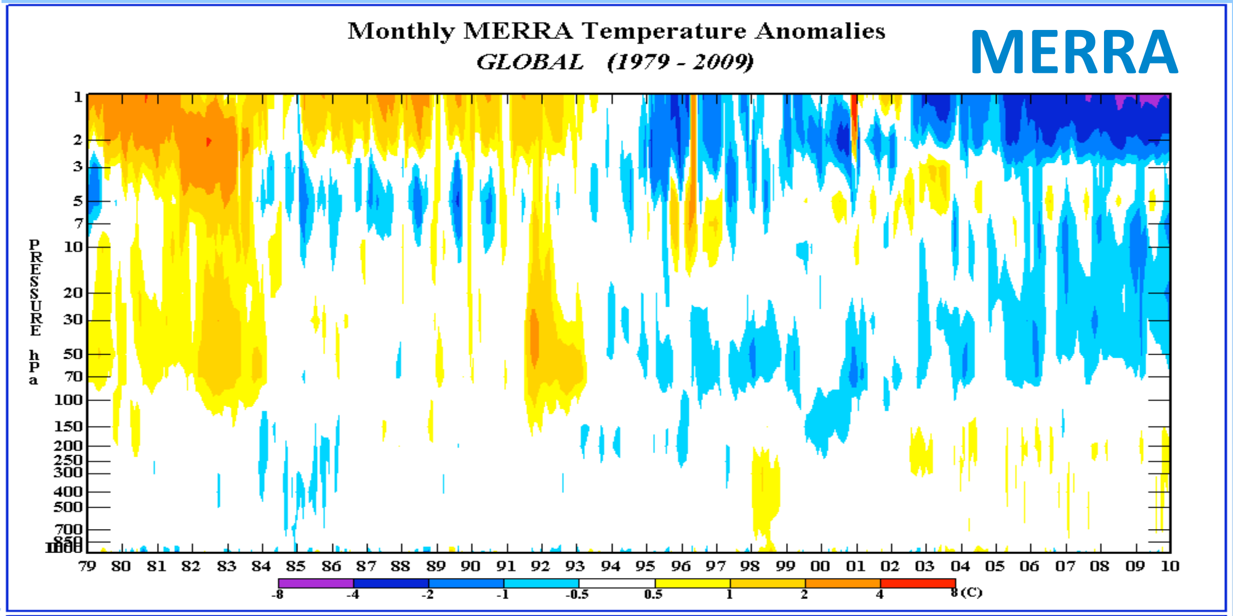



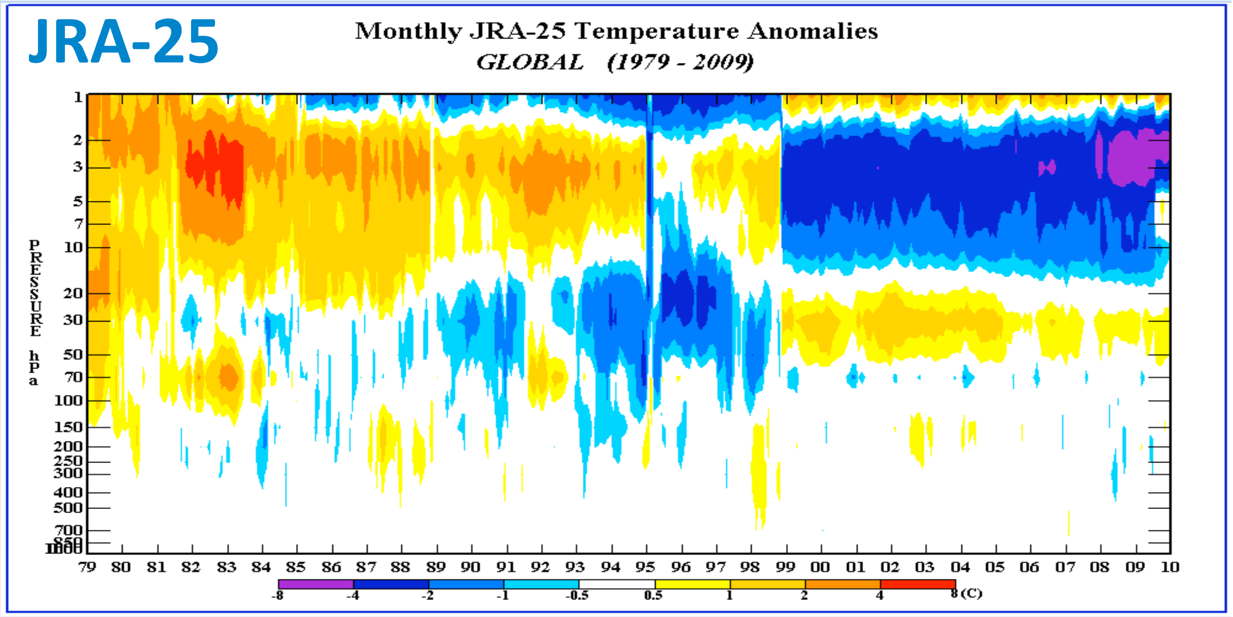
NWP

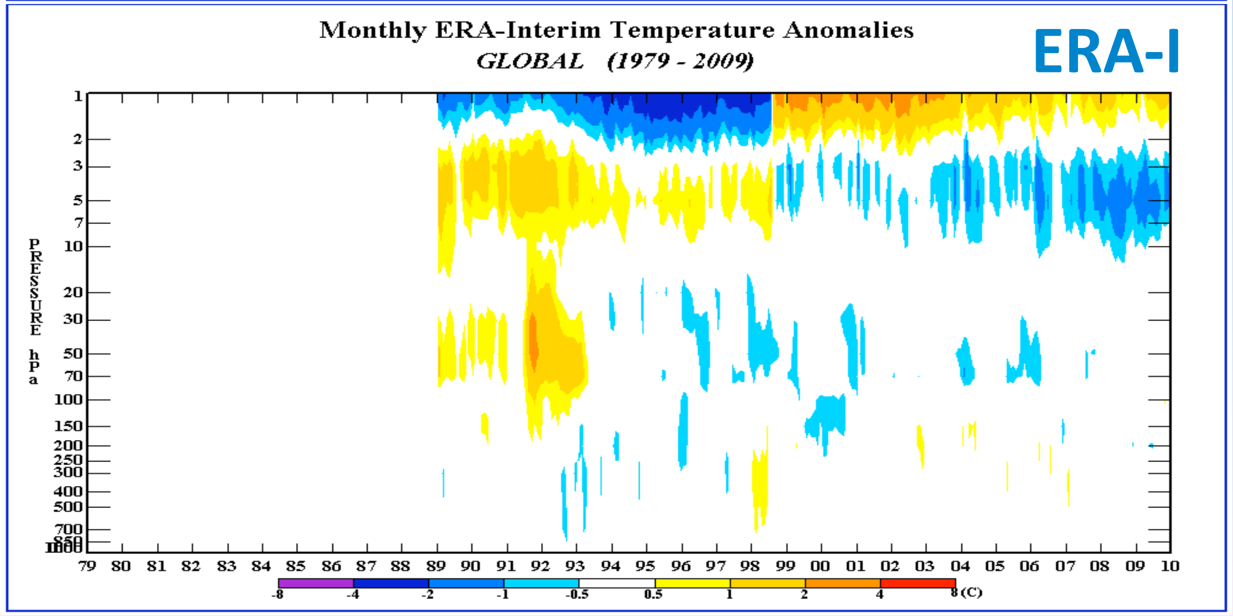
# Global Temperature Anomalies



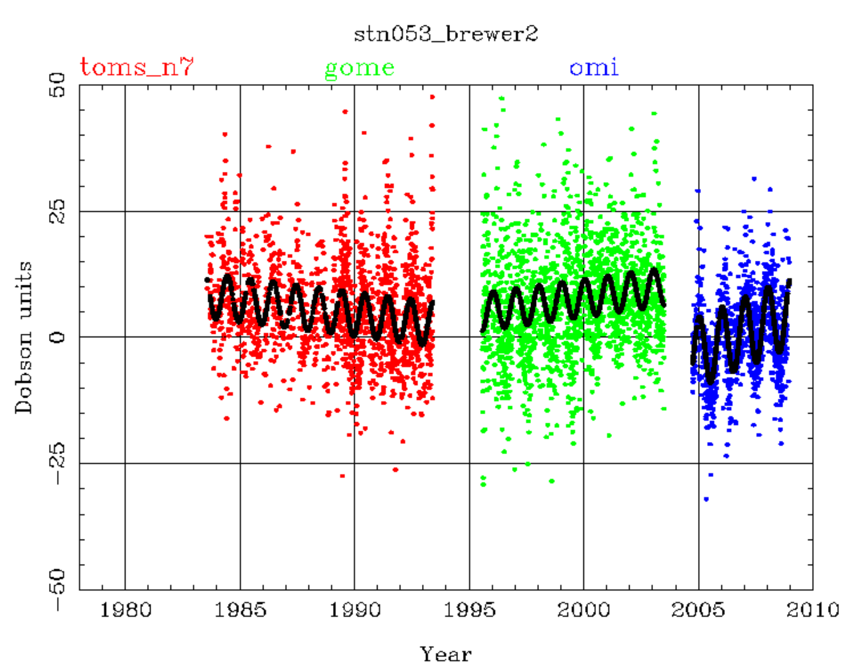



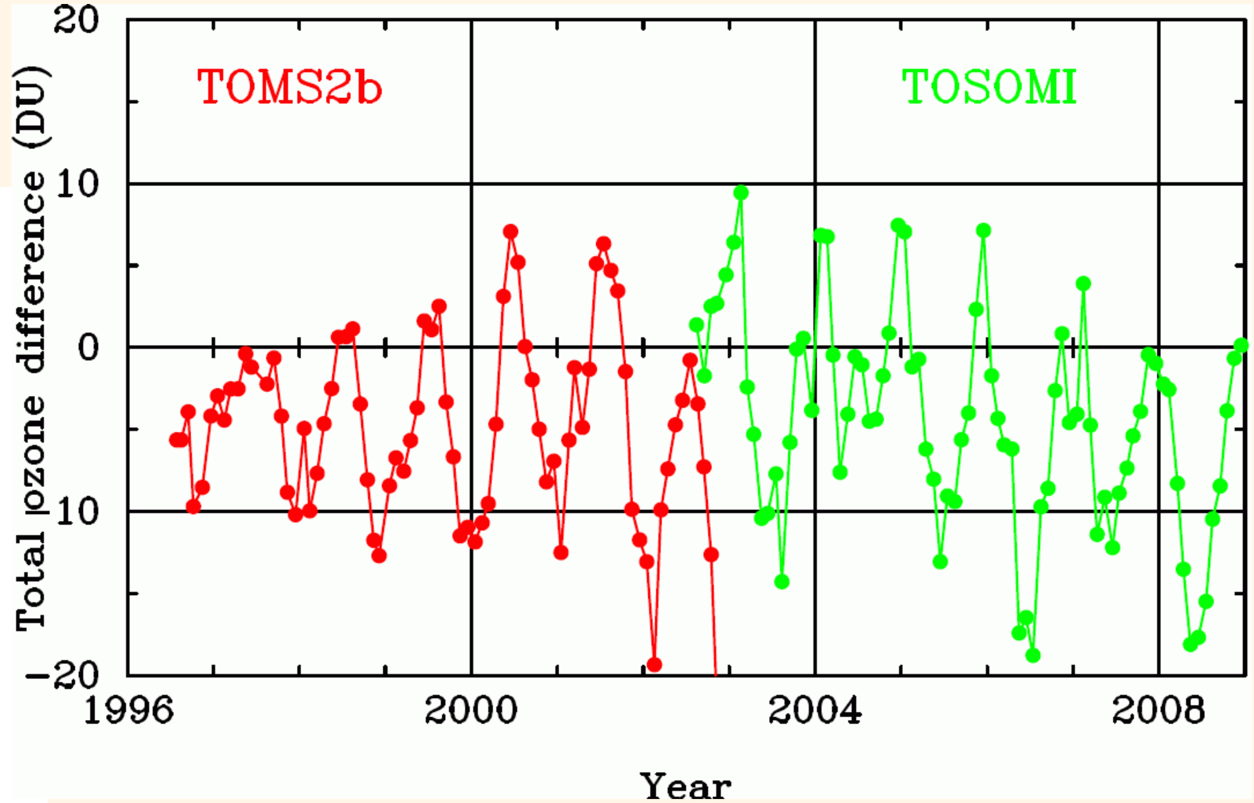



# CTM

- "Satellite minus ground" observation reveals:
  - Out-of-phase seasonal dependencies
  - Trends
  - Offsets




## Available level 2 ozone data (UV-VIS)

| | | | |
|---|---|---|---|
| **TOMS Nimbus 7:** | **1978-1993** | **TOMS v.8** | **NASA** |
| **TOMS EarthProbe:** | **1996-2002** | **TOMS v.8** | **NASA** |
| **SBUV 7, 9a, 9d, 11, 16:** | **1978-2004** | **SBUV v.8** | **NOAA** |
| **GOME :** | **1995-2008** | **GDP v.4** | **ESA/DLR** |
| **GOME :** | **1995-2008** | **TOGOMI v1.2** | **KNMI** |
| **SCIAMACHY :** | **2002-2008** | **SGP v.3** | **ESA/DLR** |
| **SCIAMACHY :** | **2002-2008** | **TOSOMI v.0.43** | **KNMI** |
| **OMI :** | **2004-2008** | **TOMS v.3** | **NASA** |
| **OMI :** | **2004-2008** | **DOAS v.3** | **KNMI** |
| **GOME-2 :** | **2007-2008** | **GDP v.4.2** | **EUMETSAT/DLR** |
| | | | |
| **WOUDC:** | **1978-2008** | **Brewer(3,4), Dobson, Filter** | |

Royal Netherlands Meteorological Institute
*Ministry of Infrastructure and the Environment*

Expected dependencies of satellite data

- Solar zenith angle (DOAS-AMF, O3 cross-section)
- Viewing zenith angle (scan mirror)
- Effective temperature (O3 cross-section)
- Time (instrument degradation)
- Offset (calibration)

# – KNMI 30-year multi sensor reanalysis of total ozone

# Monitoring Atmospheric Composition and Climate – Interim Implementation

**NWP&CTM**

MACC-II is the third in a series of FP6 & 7 EU projects (since 2005), benefiting also from earlier ESA/GSE projects. It is coordinated by ECMWF and the consortium comprises 36 partners from 13 countries. MACC-II runs until end of July 2014, when the operational Copernicus Atmosphere Service starts.

**Weather services**

↕

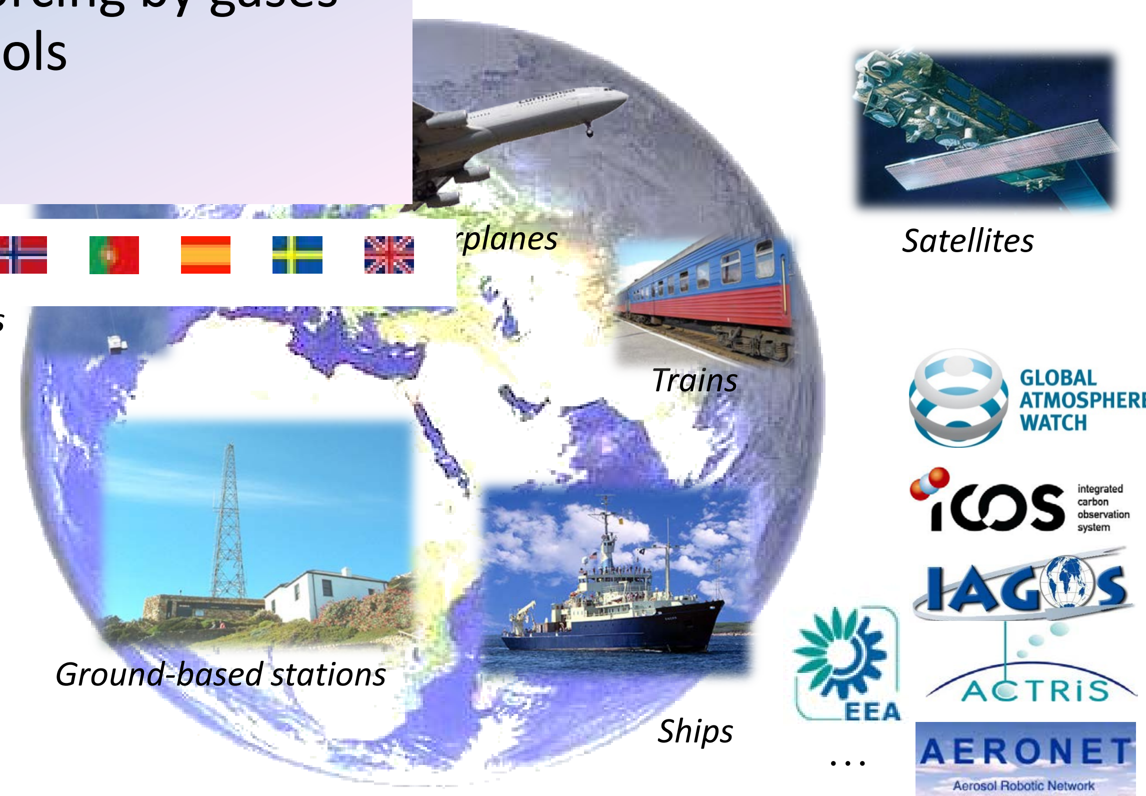
**Atmospheric environmental services** — provide data & information on:

↕

**Environmental agencies**

Copernicus – The European Earth Observation Programme

- Long-range pollutant transport
- European air quality
- Dust outbreaks
- Solar energy
- UV radiation
- Climate forcing by gases and aerosols
- …




大気組成に関するサービス：

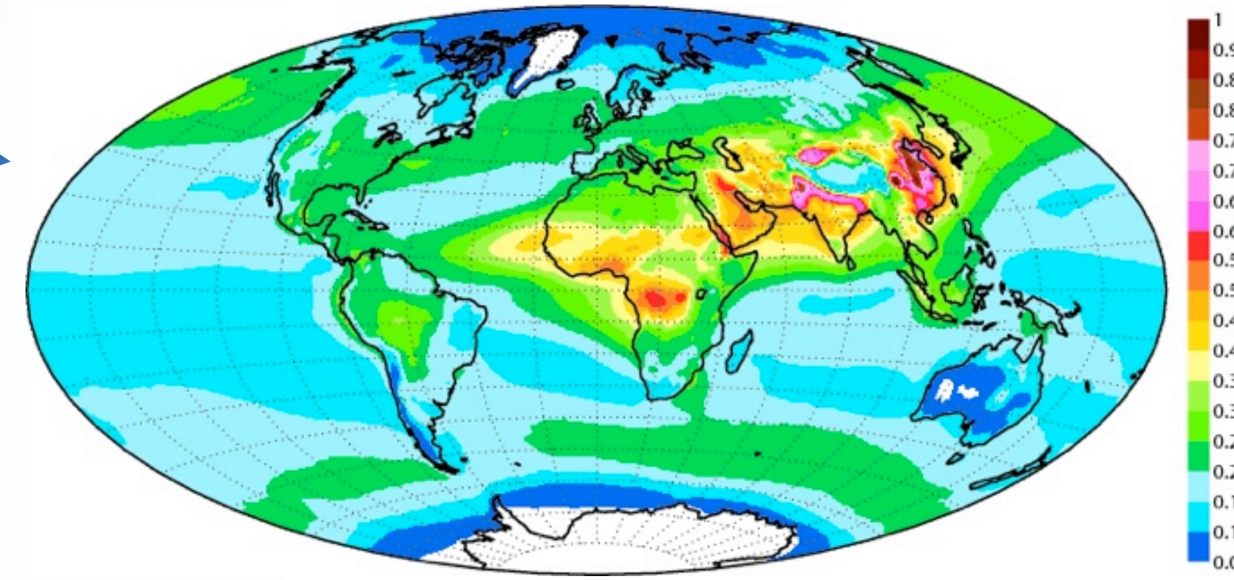
気象予報と環境政策と密接

# NWP&CTM

## http://www.gmes-atmosphere.eu
## Retrospective Service Provision

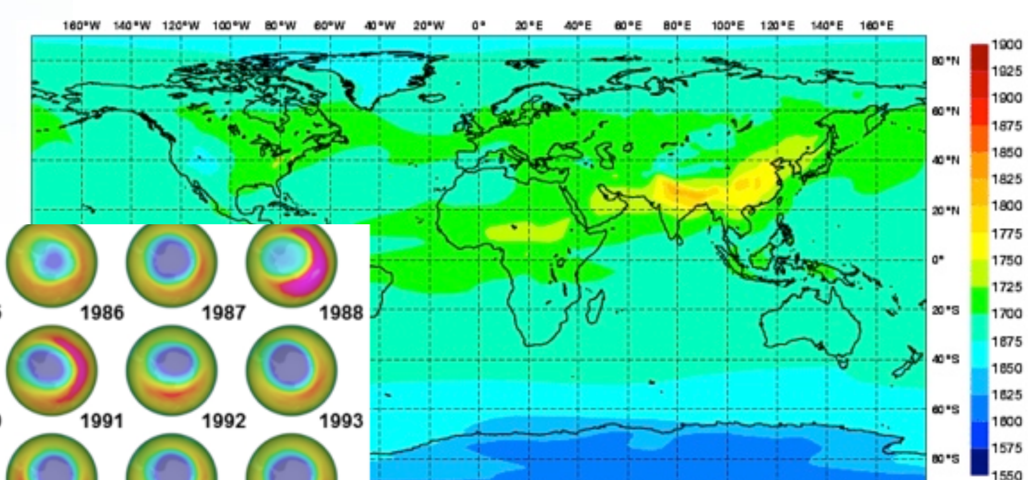

*Reanalysis of Atmospheric Composition (2003-2011)*

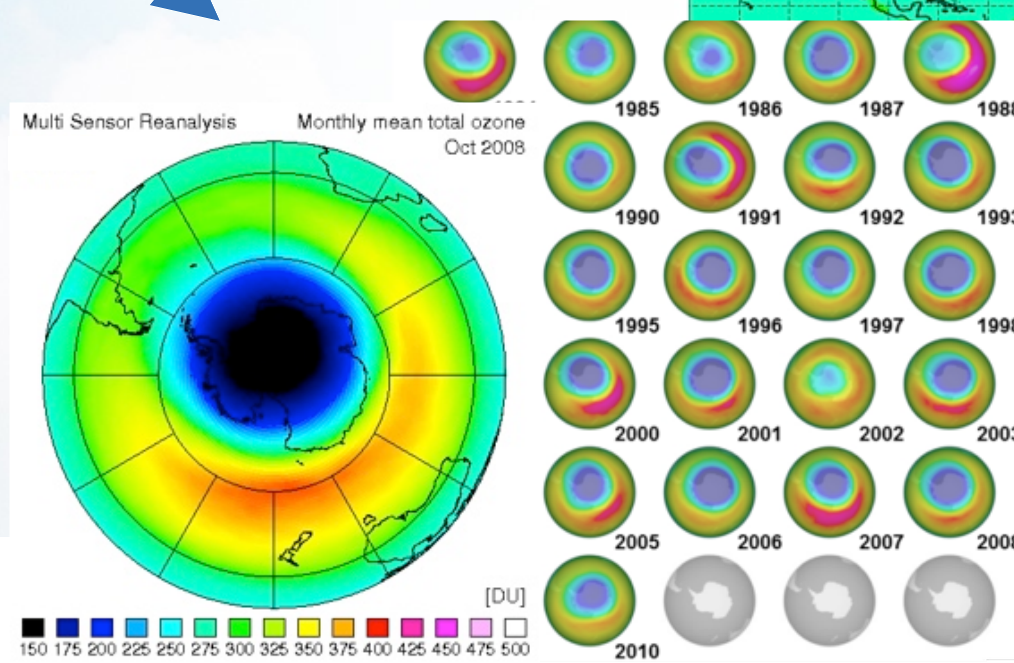
**Aerosol Optical Depth**



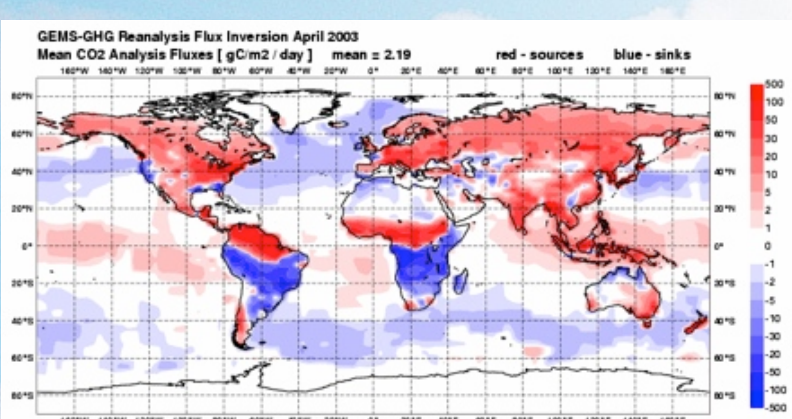
*30 years ozone layer records*

**Methane**






*$CO_2$ and $CH_4$ surface flux inversions*



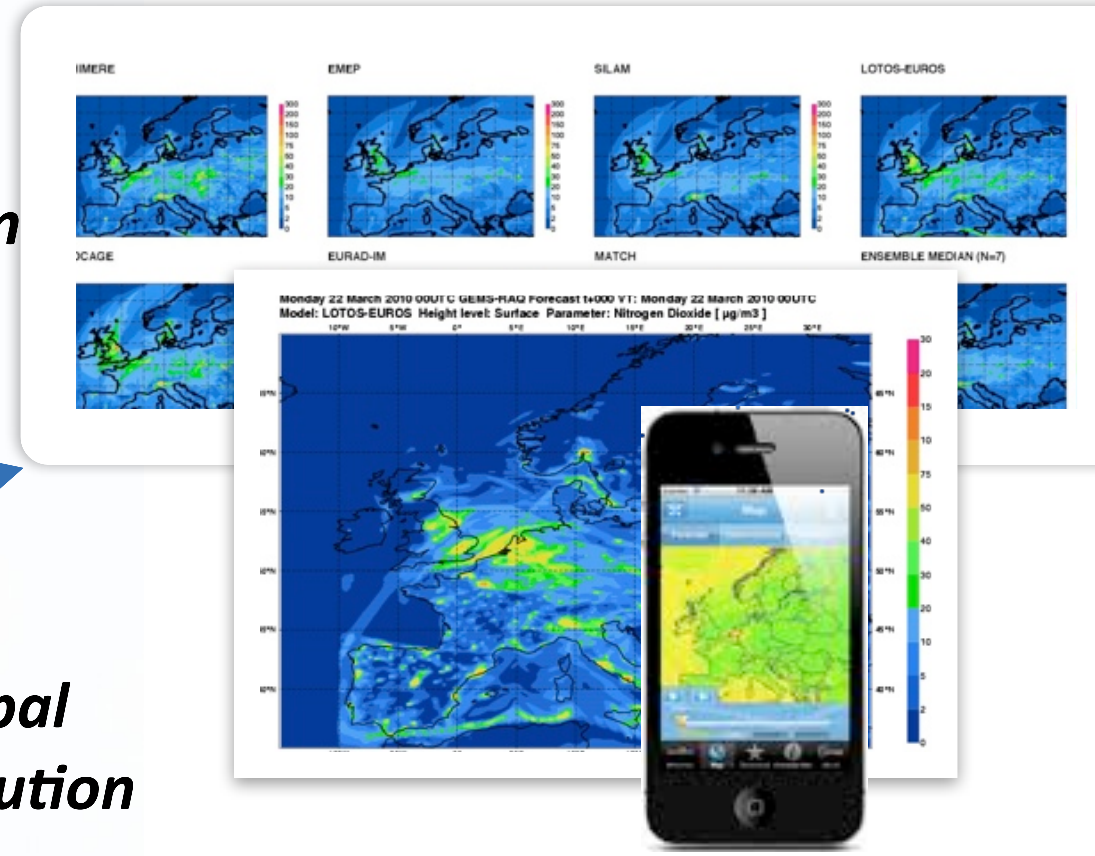

**900+ users**

http://www.gmes-atmosphere.eu

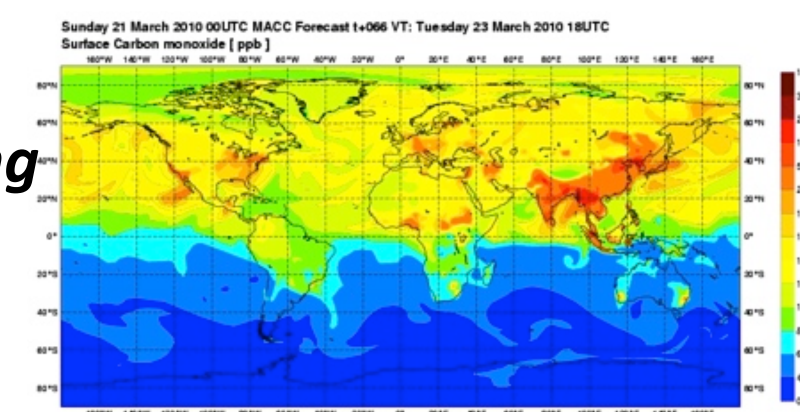
Near-Real-Time Service Provision

100+ users a NWP&CTM

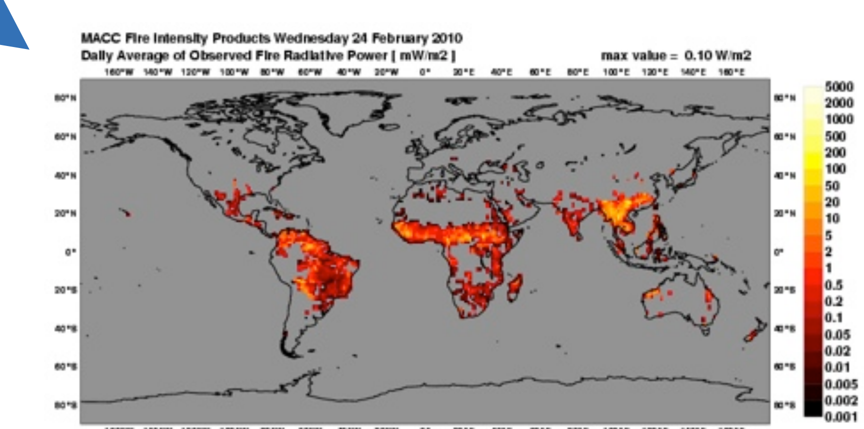

*European Air Quality*



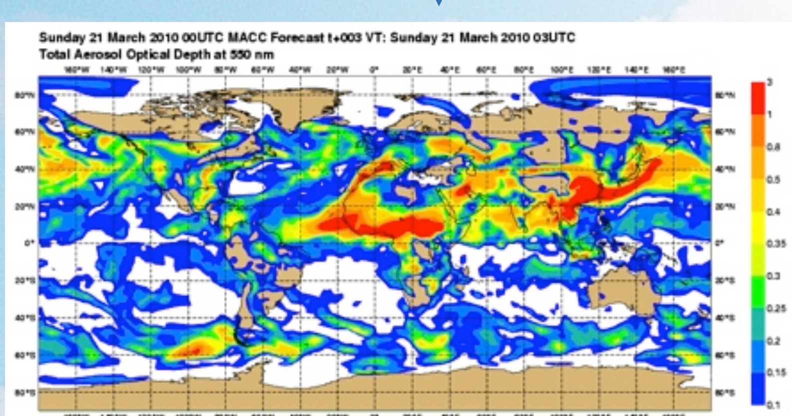

*Global Pollution*



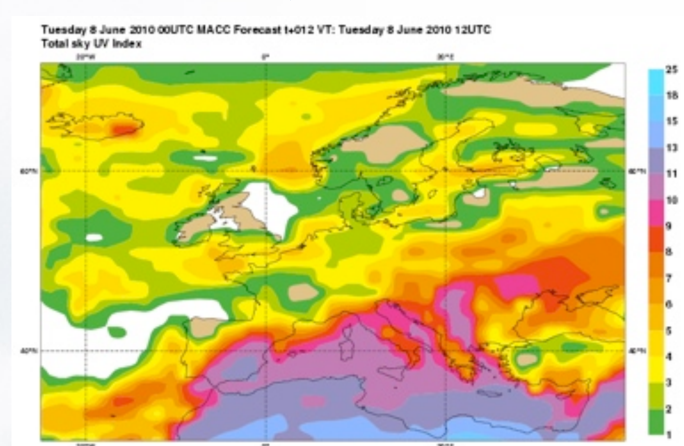

*Biomass burning emissions*




*Aerosol*




*UV index*



NWP&CTM

Monitoring atmospheric composition & climate – II

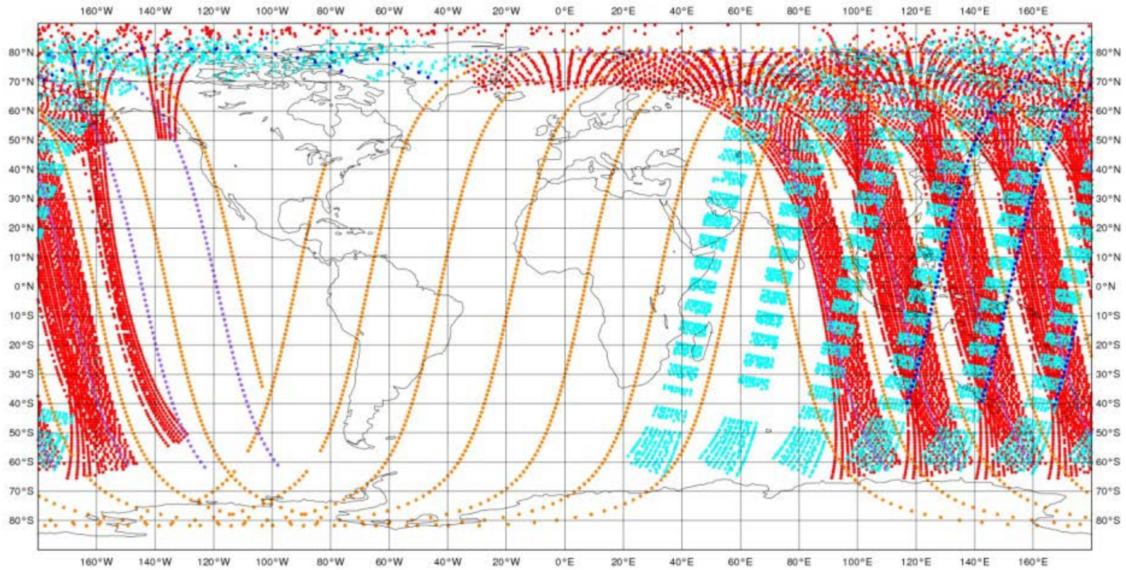
# Combining many observations

**Near-real-time observations for a 12-hour period**

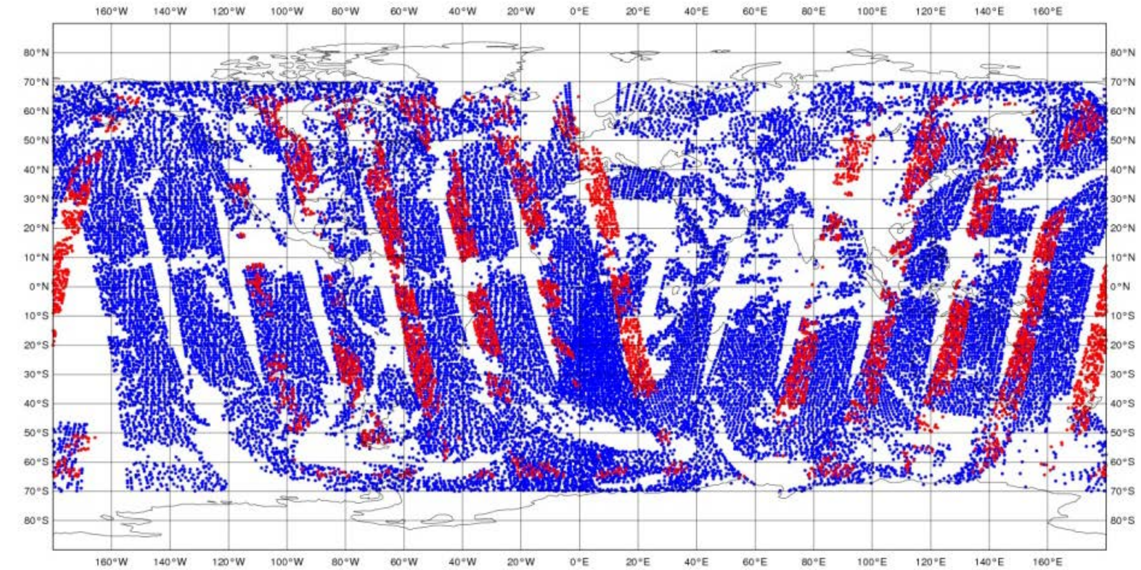
## Ozone

SCIA SBUV/2 SBUV/2

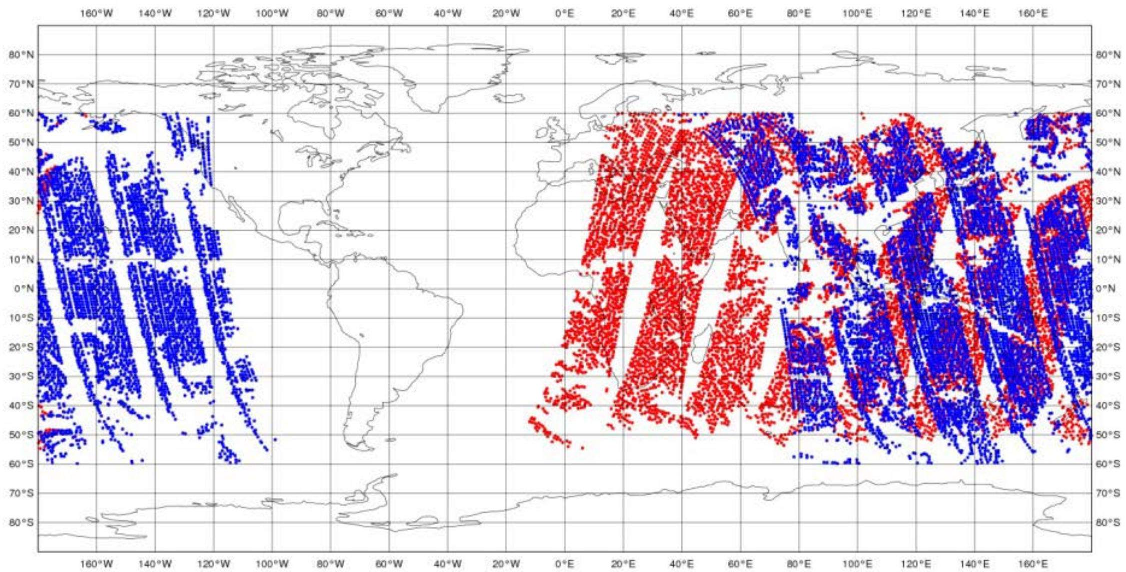
OMI NOAA-17 NOAA-18 MLS



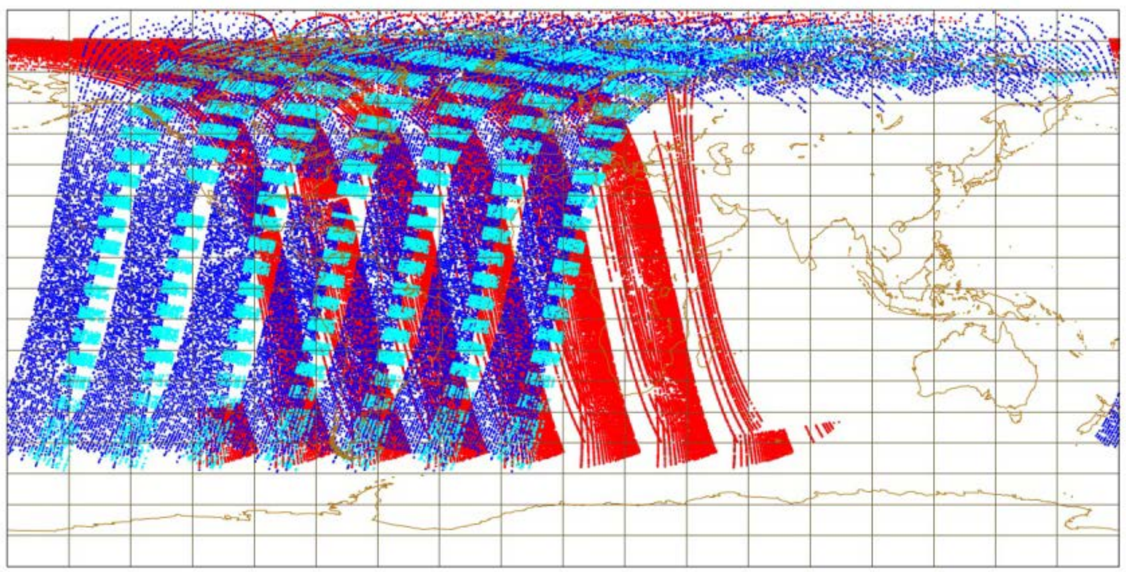
MOPITT **CO** IASI



OMI **NO2** GOME-2

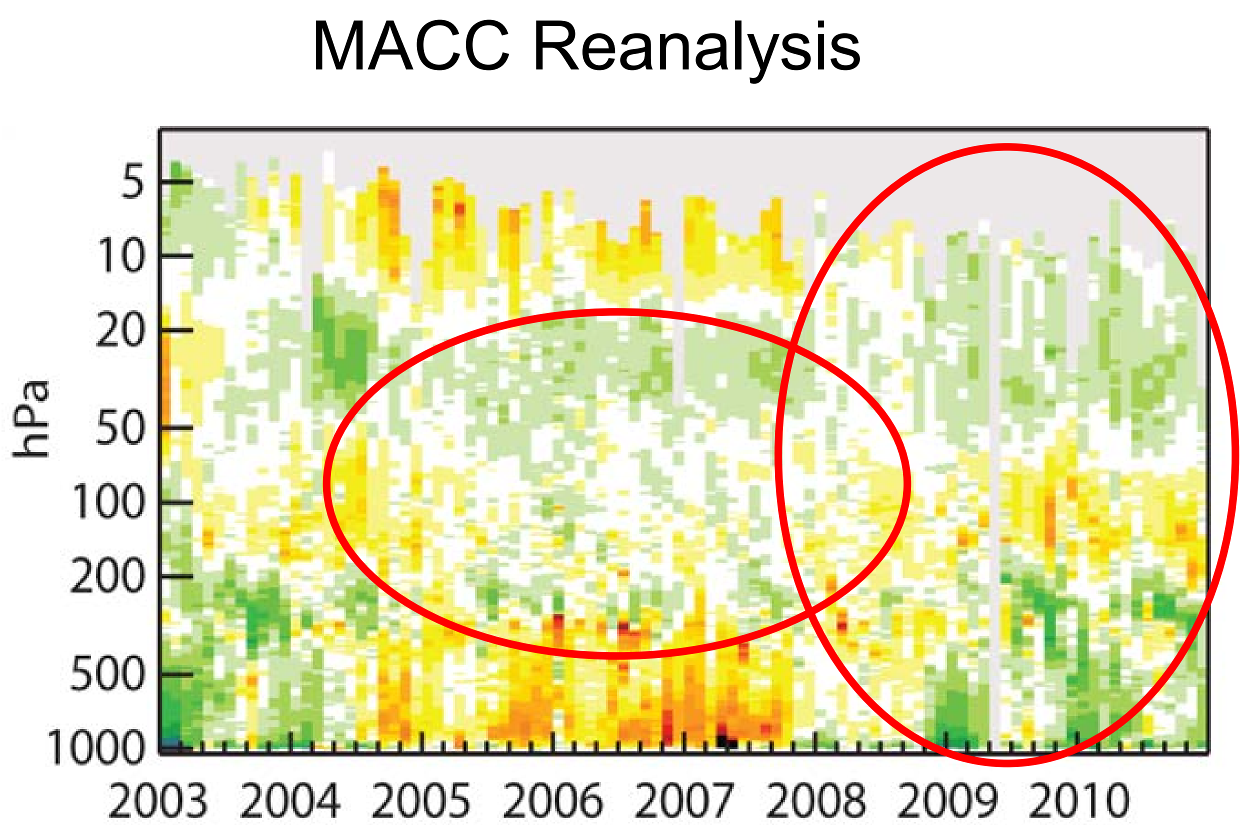


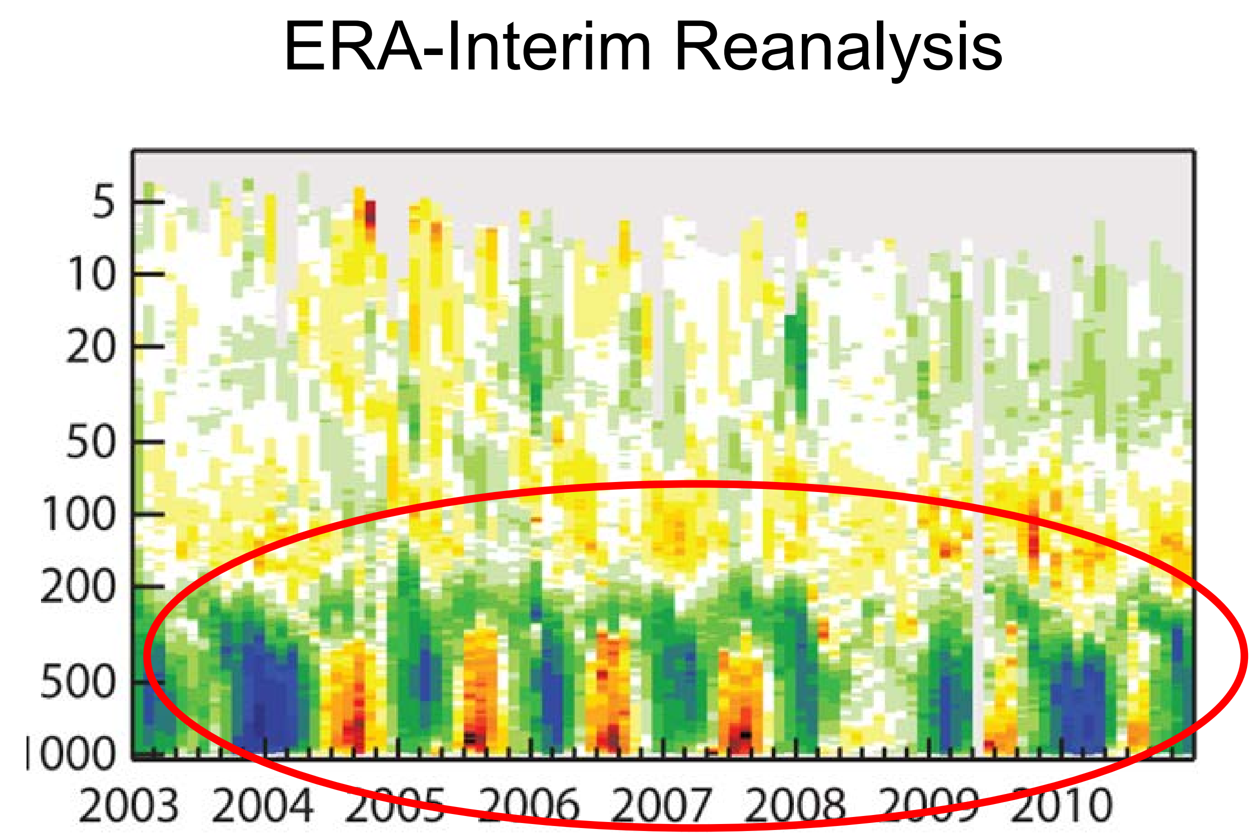
OMI SCIA **SO2** GOME-2



NWP&CTM

# Balance of model and observations




**Limb-sounding ozone data assimilated from August 2004 (MLS) are clearly improving stratospheric ozone.**

**Switch to near-real-time version of MLS observations, which misses lowest layers.**

**Chemical modelling is needed for correct representation of tropospheric ozone.**

## Workshop on Parameter Estimation and Inverse Modelling for Atmospheric Composition

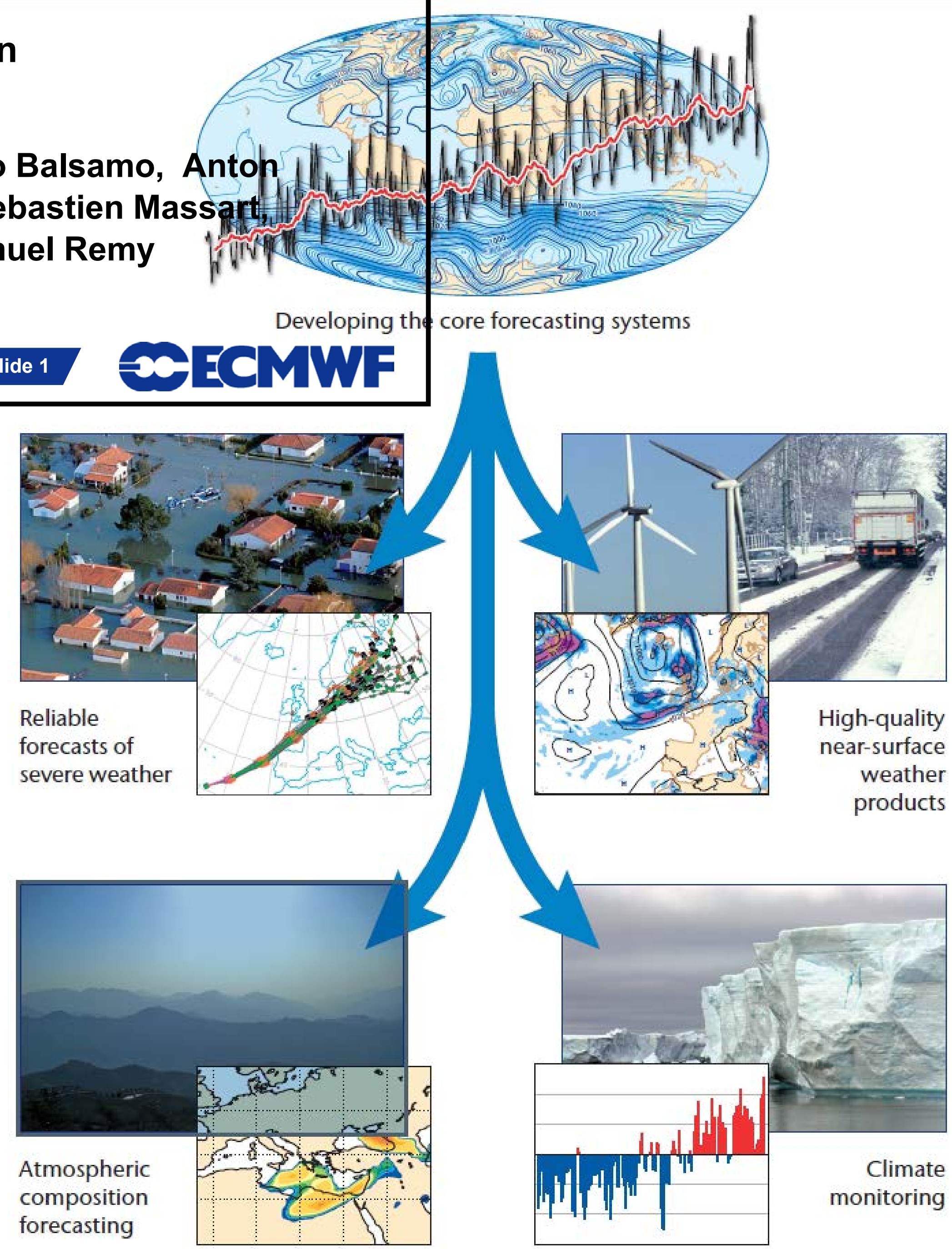
Richard Engelen

Anna Agusti-Panareda, Gianpaolo Balsamo, Anton Beljaars, Johannes Flemming, Sebastien Massart, Vincent-Henri Peuch, Samuel Remy

ECMWF Workshop October 2013 Slide 1

# 更なる発展に向けて

# 2013年10月, ECMWFにて




## ECMWF Strategy 2011 - 2020

The principal goal of ECMWF in the next ten years is to improve its global medium-range weather forecasting systems, at the current rapid rates, in order to:

- Provide Member States' National Meteorological Services with reliable forecasts of severe weather across the medium-range.
- Meet Member States' requirements for high quality near-surface weather forecast products such as precipitation, wind and temperature.

There are also various complementary goals, such as climate monitoring and atmospheric composition forecasting.

# Global chemical data assimilation systems

| Institute/Project | Species | Region | Assimilation | Notes |
|---|---|---|---|---|
| NWP operational centers | $O_3$ | Stratosphere – | mainly 4D-VAR | Simplified chemistry |
| C-IFS (ECMWF MACC) | Various | Troposphere/ Stratosphere – | coupled to IFS 4D-VAR | Multi-models, w/o emission inversion |
| NASA GMAO | Various (EOS-Aura) | Troposphere/ Stratosphere – | Incremental 3D-VAR | Simplified chemistry |
| NASA JPL/Harvard Univ. | Mainly $O_3$, CO | Troposphere/ Stratosphere – | 3D-VAR | |
| NCAR | Mainly CO | Troposphere | Ensemble Kalman filter | w/ emission inversion |
| KNMI | $O_3$ | Troposphere/ Stratosphere – | Sub-optimal Kalman filter | 30 years, Simplified chemistry |
| DARC/Reading | Mainly $O_3$ (MIPAS) | Stratosphere – | 3D-VAR | |
| BASCOE (BIRA-IASB) | Various | Stratosphere – | 4D-VAR | |
| JAMSTEC | Various | Troposphere/LS | Ensemble Kalman filter | w/ emission inversion |

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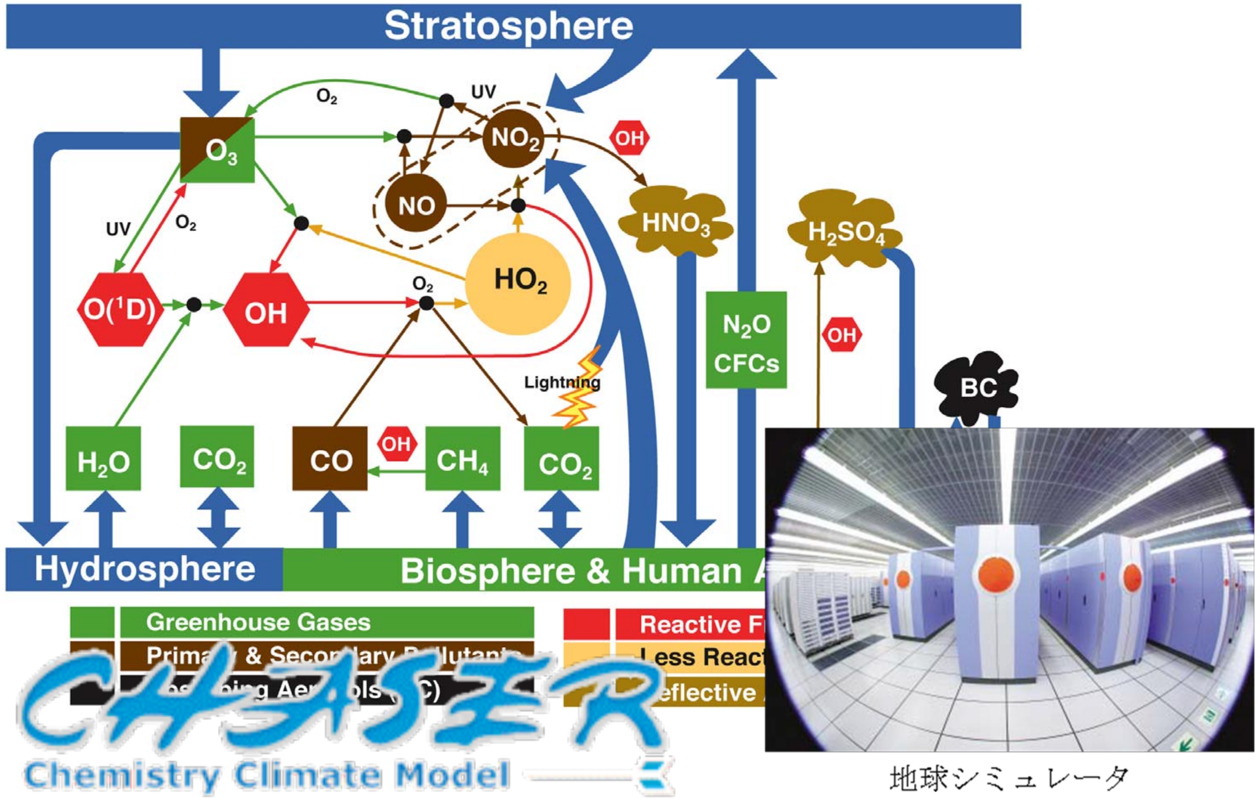
# Tropospheric chemistry data assimilation

✓ The use of data assimilation for atmospheric chemistry, especially for short-lived chemical species, is still challenging (e.g., MACC).

✓ A large part of the chemical system is not sensitive to initial conditions, but is sensitive to the model parameters (e.g., reaction rates, emissions).

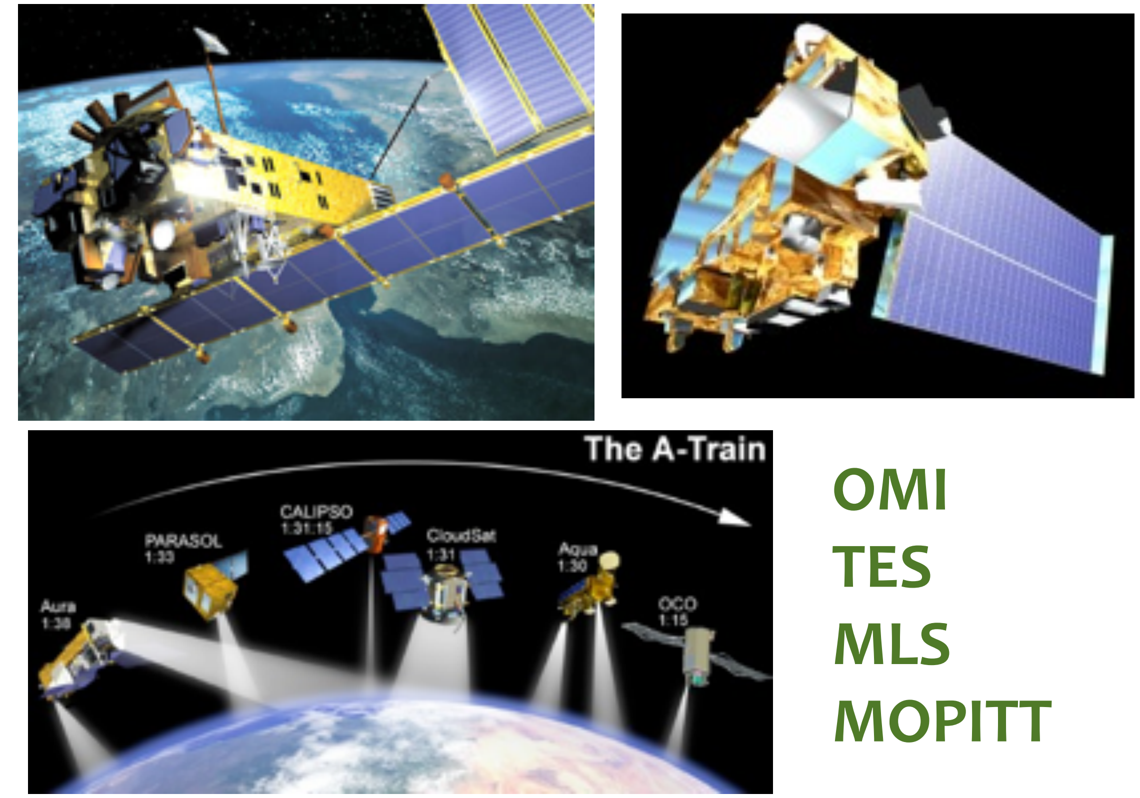
✓→ Simultaneous adjustment of model parameters and concentrations is a powerful framework.

✓ The advantage of Ensemble Kalman filter (EnKF) is its easy implementation for complicated systems and parameter estimations.



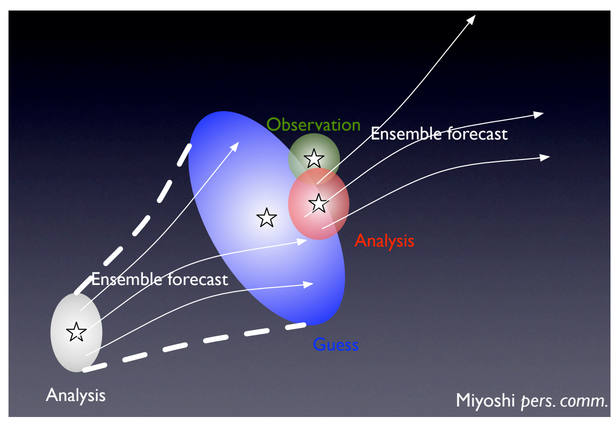

Global CTM "CHASER"

+



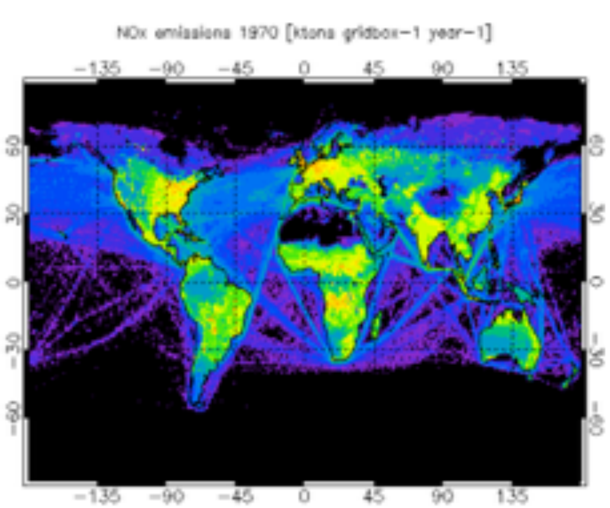

OMI
TES
MLS
MOPITT

Observations

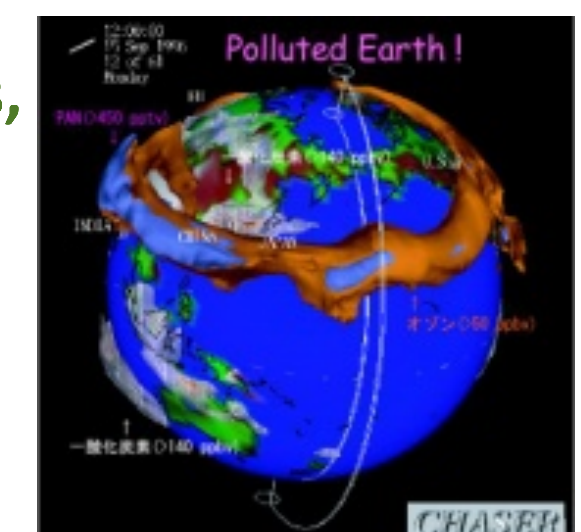



## Ensemble Kalman Filter Data Assimilation

(Miyazaki et al., 2012a, 2012b)



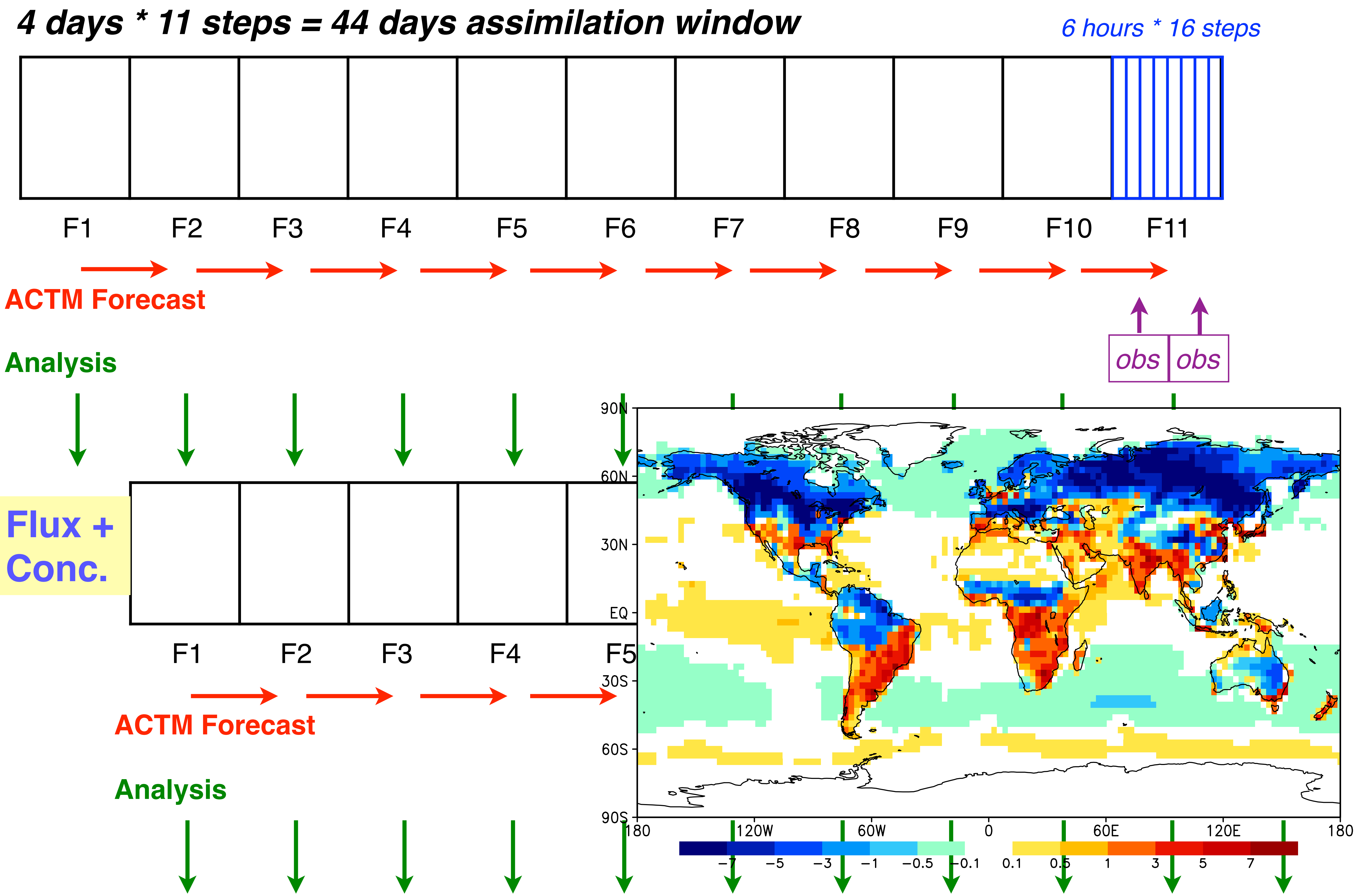

**Chemical concentrations, surface emissions, lightning sources**

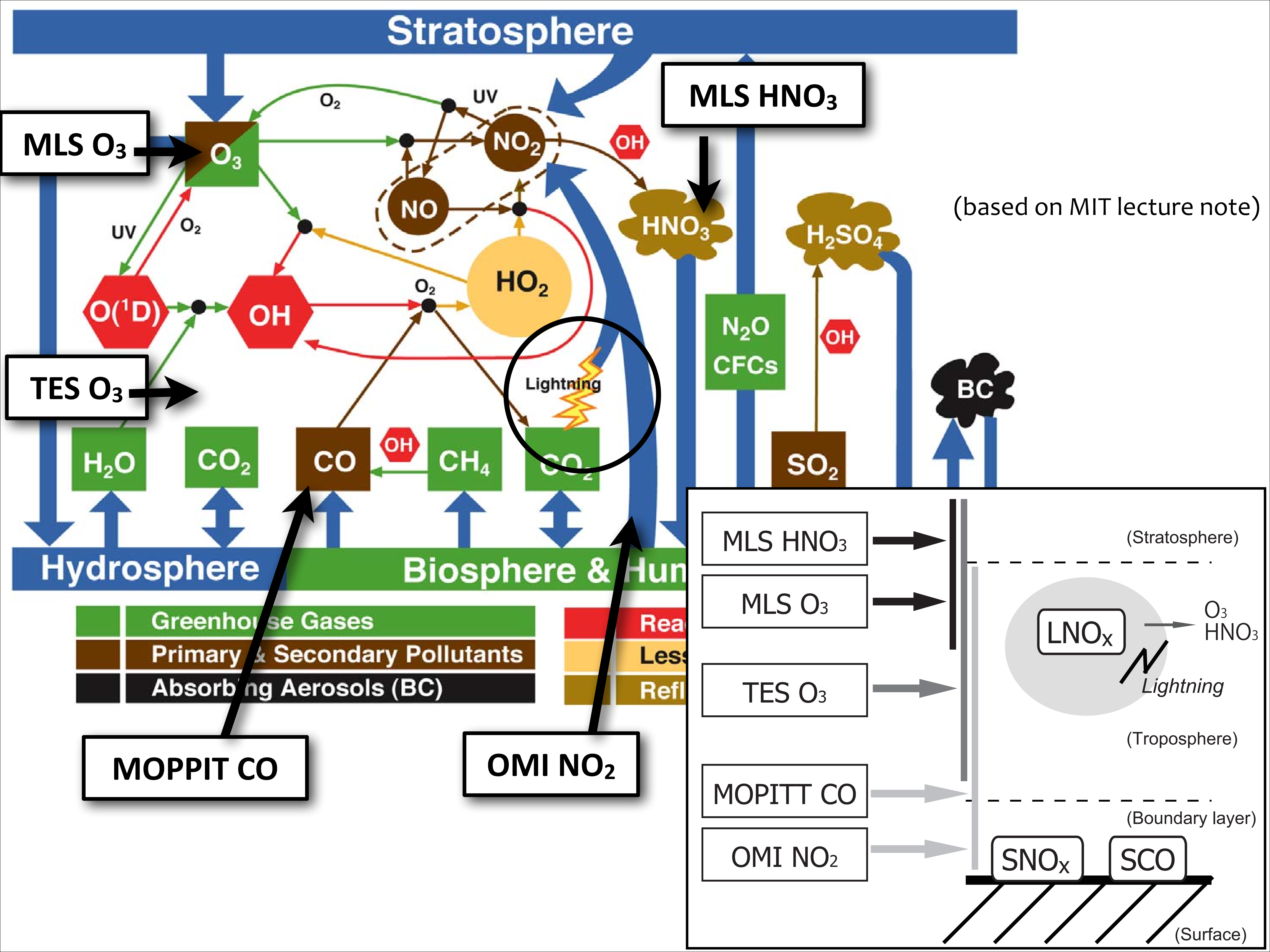


# CHASER-DAS (Miyazaki et al., 2012a, 2012b, 2013a, 2013b)

| | |
|---|---|
| *Assimilation scheme* | LETKF (Hunt et. al., 2007), 48 members |
| *Forecast model* | CHASER (Sudo et al., 2002), 47 species & 88 reactions, T42L32 |
| *A priori emissions* | EDGAR4.2 + GFED3.1 + GEIA |
| *State vector* | NOx & CO emissions, lightning NOx, 35 chemical species |
| *Obs operator* | Averaging kernel and a priori information |
| *Super Obs* | applied for OMI $NO_2$ and MOPPIT CO data |
| *Cycle* | 100 min. |
| *Techniques* | Spatial & variable covariance localization, covariance inflation |
| *Assimilated data* | OMI $NO_2$ (DOMINO2), TES $O_3$ (ver. 4), MOPITT CO (ver. 5), MLS $O_3$ & $HNO_3$ (ver. 3.3) |
| *Validation data* | SCIAMACHY $NO_2$, GOME-2 $NO_2$, TES CO,<br>Ozonesonde, Aircraft (IAGOS, NASA, HIPPO) etc |

# JAMSTEC carbon DA system ver.2

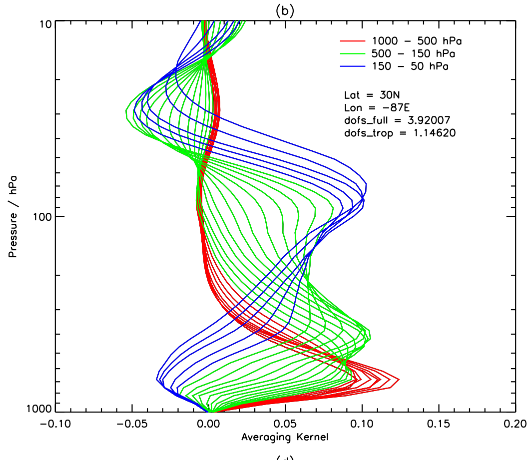




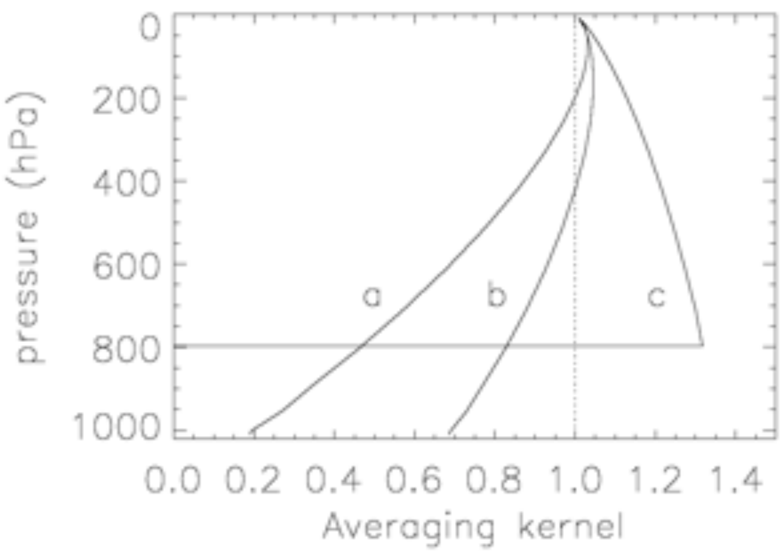

(based on MIT lecture note)

# Observation operators

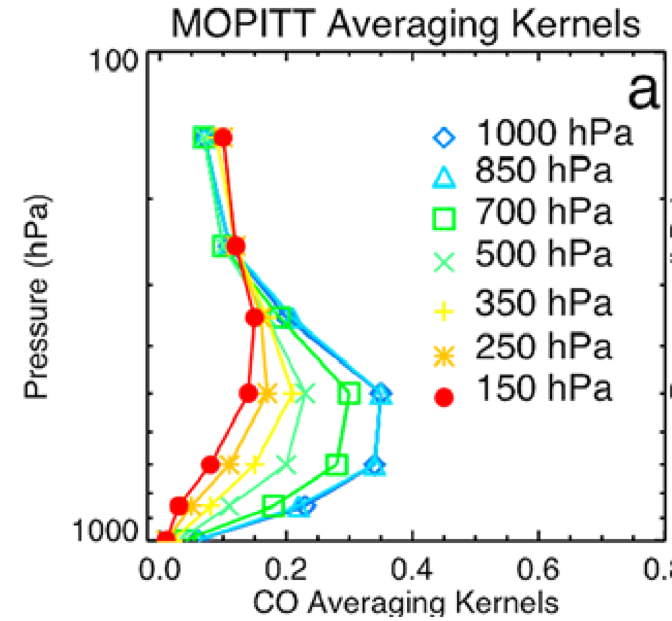
TES O3



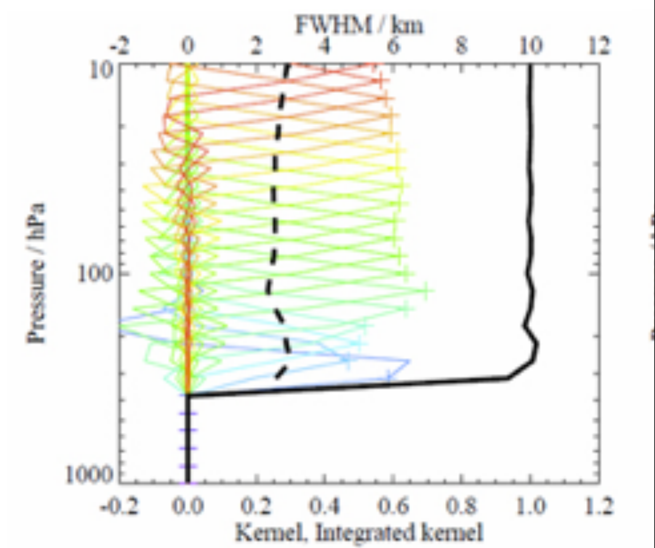

OMI NO2




MOPITT CO




MLS O3,HNO3




• The observation operator (H) converts the model profiles to the profile that would be retrieved from satellite measurements.

$$y^b = H(x) = x_a + \mathbf{A}(S(x) - x_a).$$

• The model-satellite difference (the innovation) is not biased by the a priori profile

$$y^o - y^b = \mathbf{A}(x_{true} - S(x)) + \epsilon,$$

(Rodgers, 2000;
Eskes and Boersma, 2003)

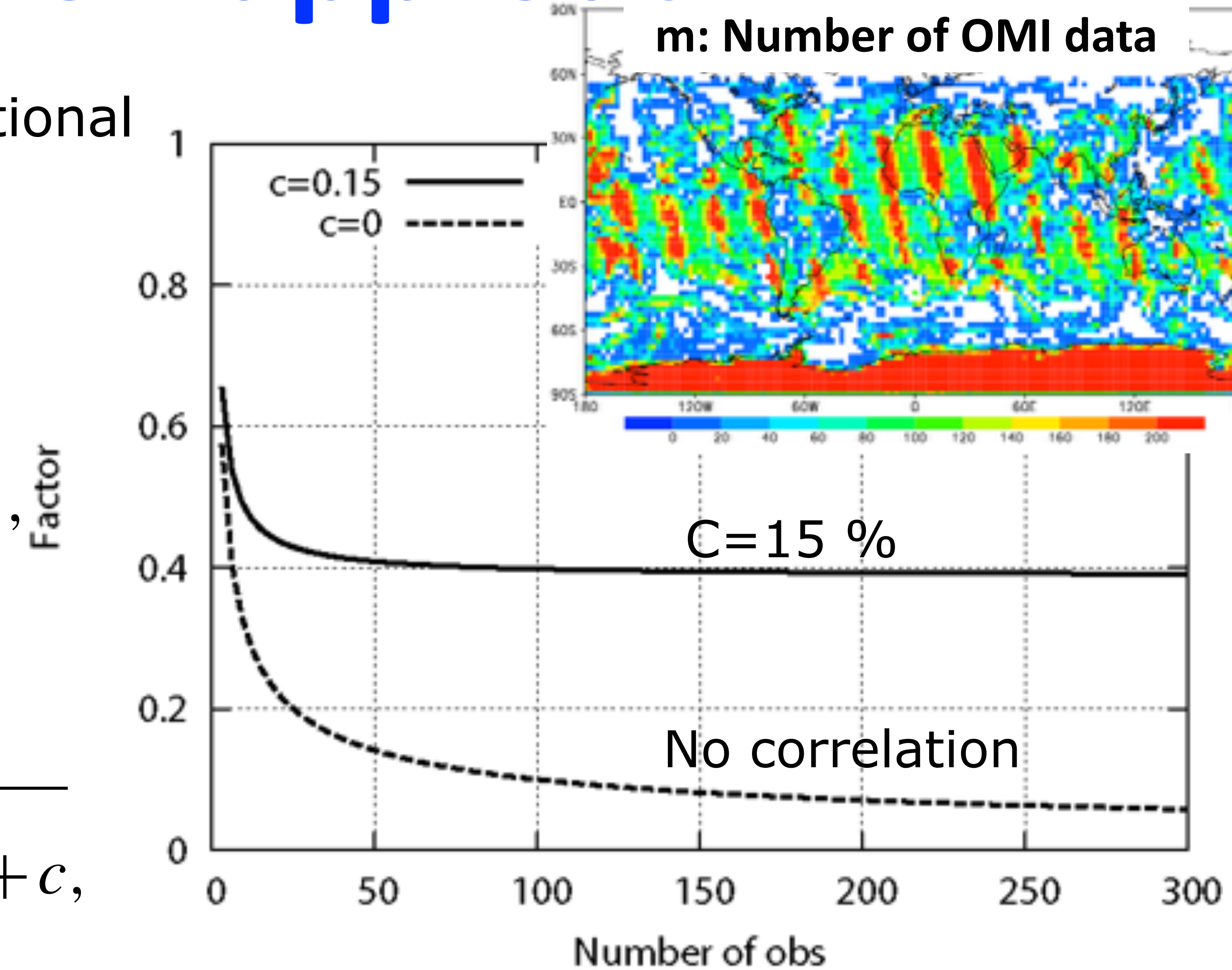
• The observational error matrix (R) in each retrieval includes smoothing error, systematic error, measurement error, and representativeness error.

# Super-observation approach

to fill spatiotemporal gaps, reduce the computational cost, produce more representative data

## Super-observation

$$\overline{y} = \left(\sum_{l=1}^{m} w_l y_l\right) \Big/ \left(\sum_{l=1}^{m} w_l\right),$$




## Measurement error

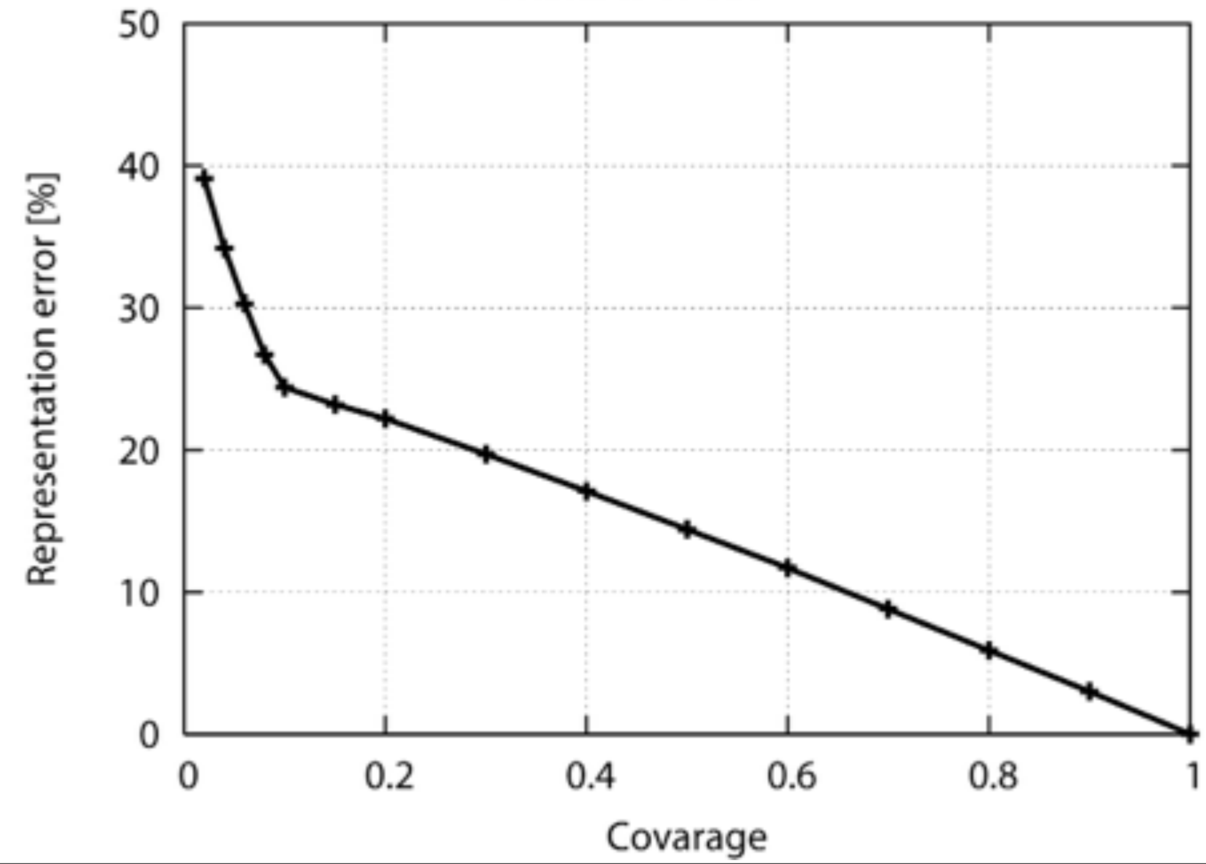
$$\sigma_{\text{super,mean}} = \left(\left(\sum_{l=1}^{m} w_l \sigma_l\right) \Big/ \left(\sum_{l=1}^{m} w_l\right)\right) \sqrt{\frac{1-c}{m} + c},$$

## Representation error

$$f_{\text{rep}}(\alpha) = \left| \left(\frac{1}{m}\sum_{l=1}^{m} y_l - \frac{1}{\alpha \times m}\sum_{l=1}^{\alpha \times m} y_l\right) \Big/ \left(\frac{1}{m}\sum_{l=1}^{m} y_l\right) \right|$$

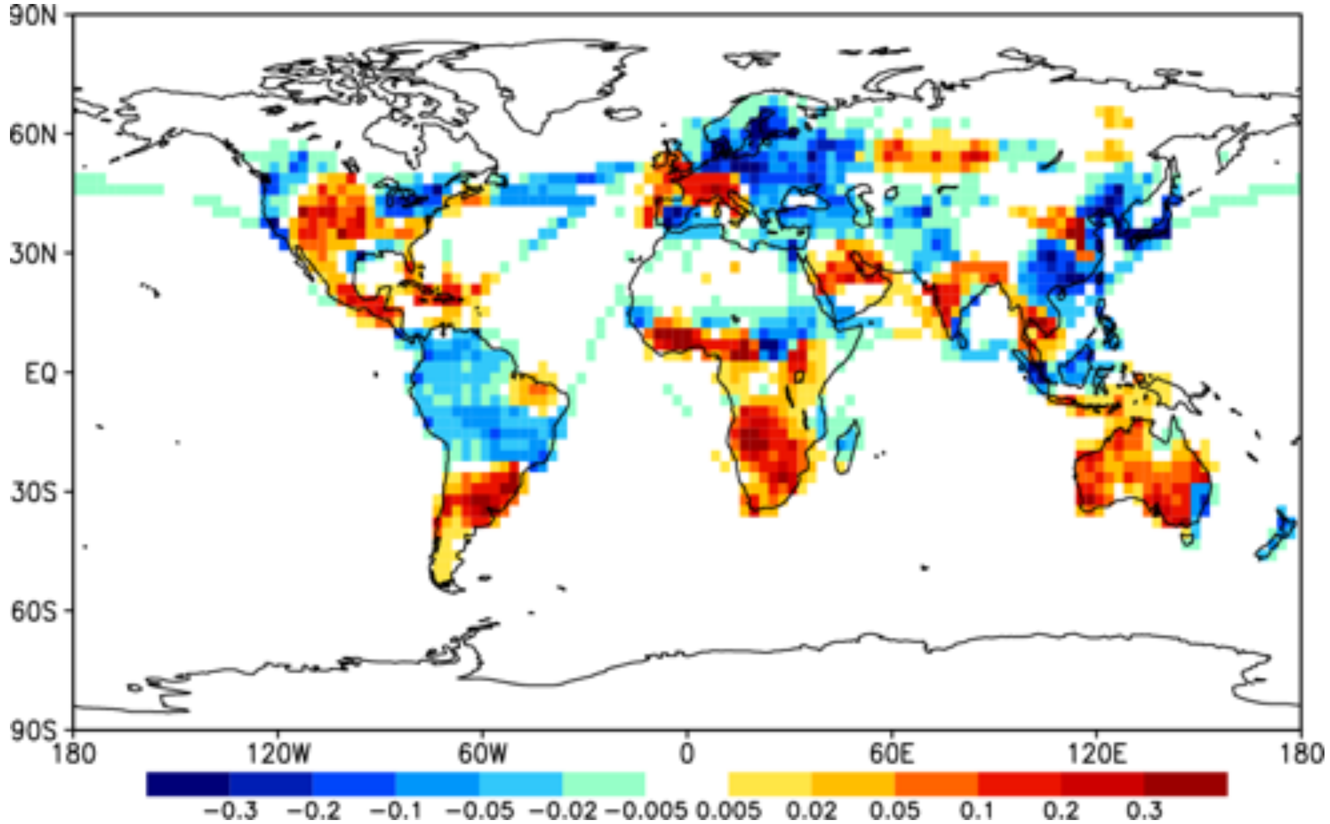
$$\sigma_{\text{super,rep}} = f_{\text{rep}}(\alpha) \times \overline{y}$$

$$\sqrt{\sigma_{\text{super,mean}}^2 + \sigma_{\text{super,rep}}^2}.$$

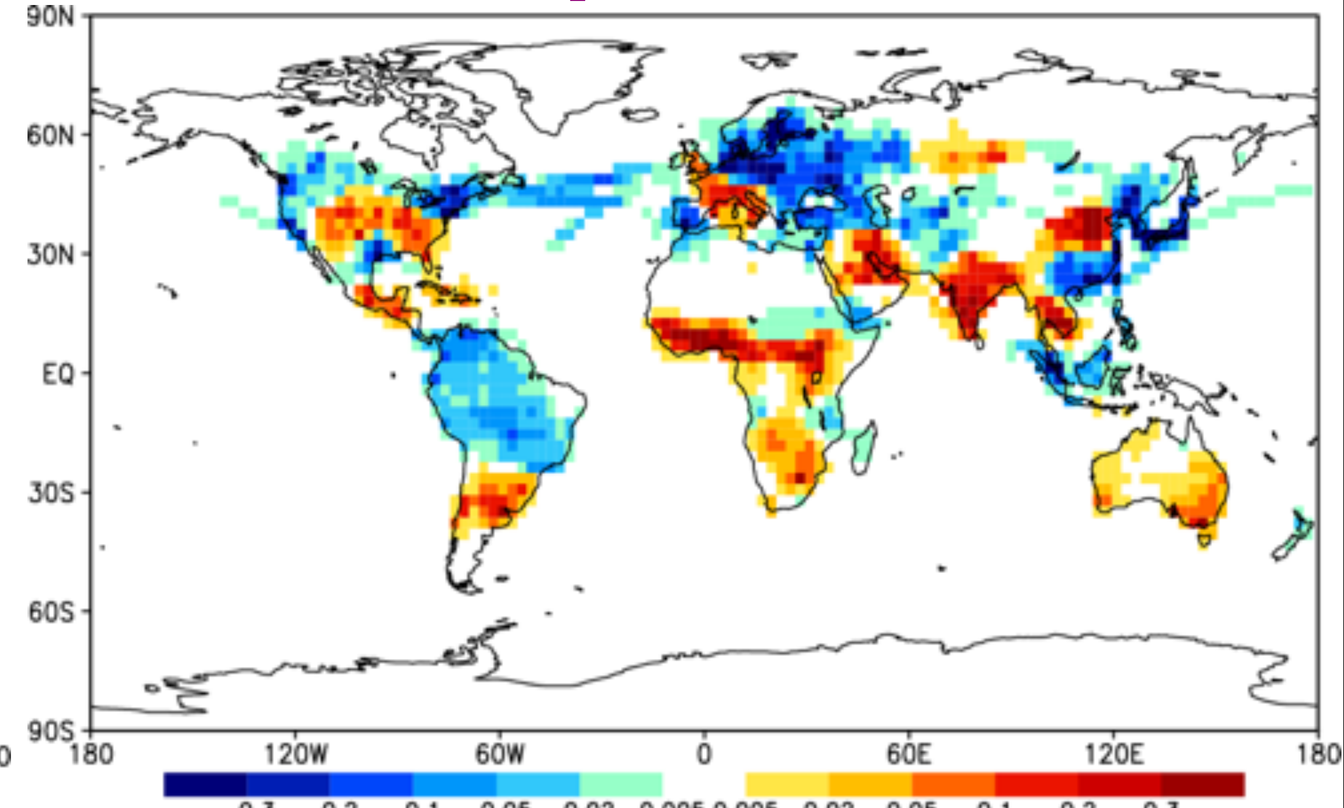


# NOx emission increments: 11 January 2005

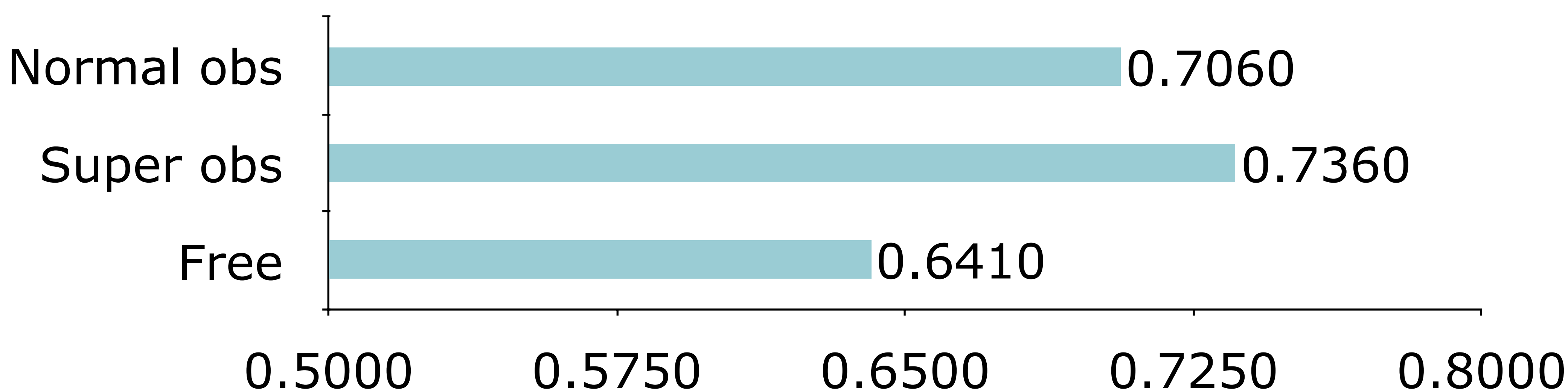
**Normal obs**



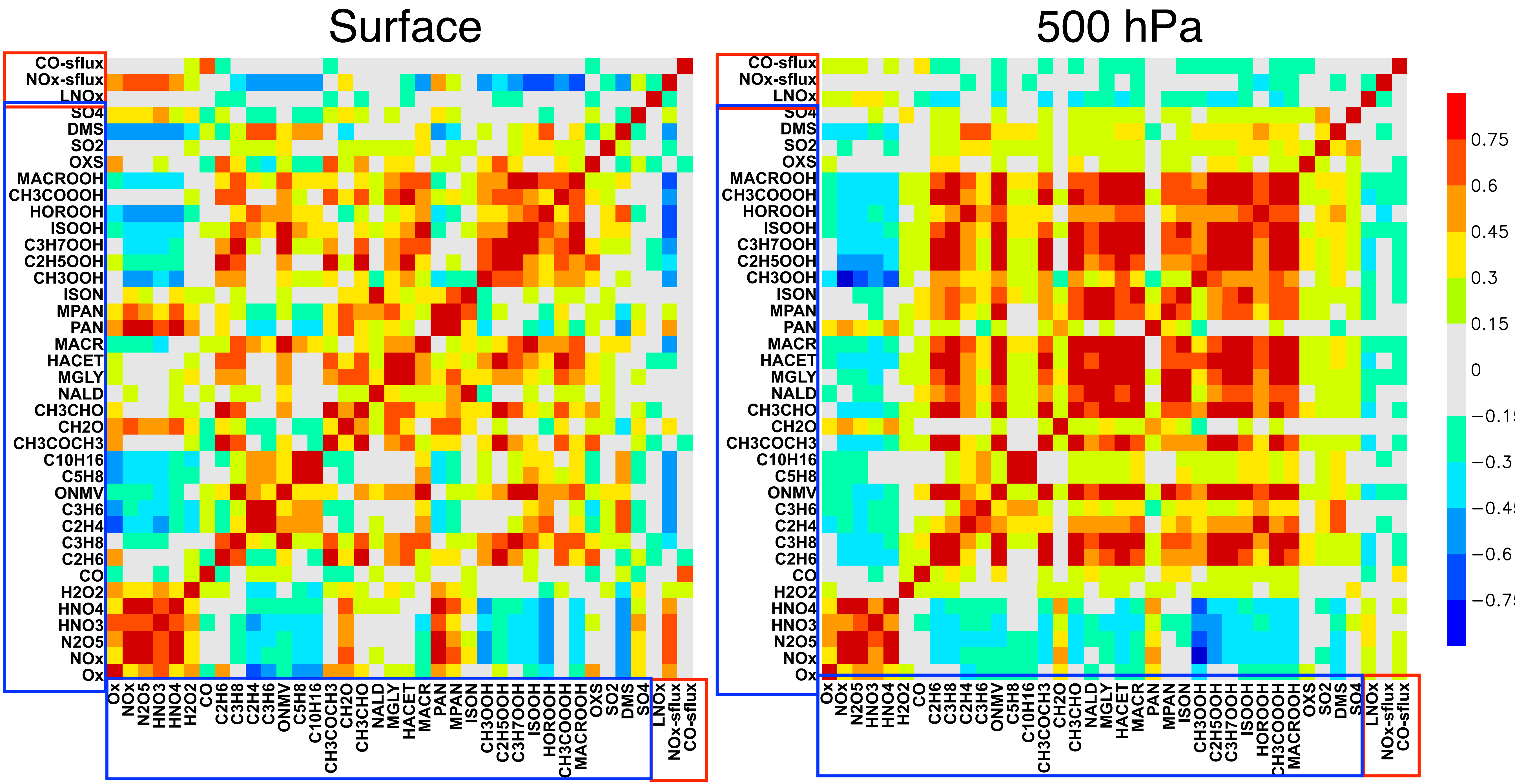

**Super obs**




**Spatial correlation**



# Background error covariance structure in CHASER-DAS



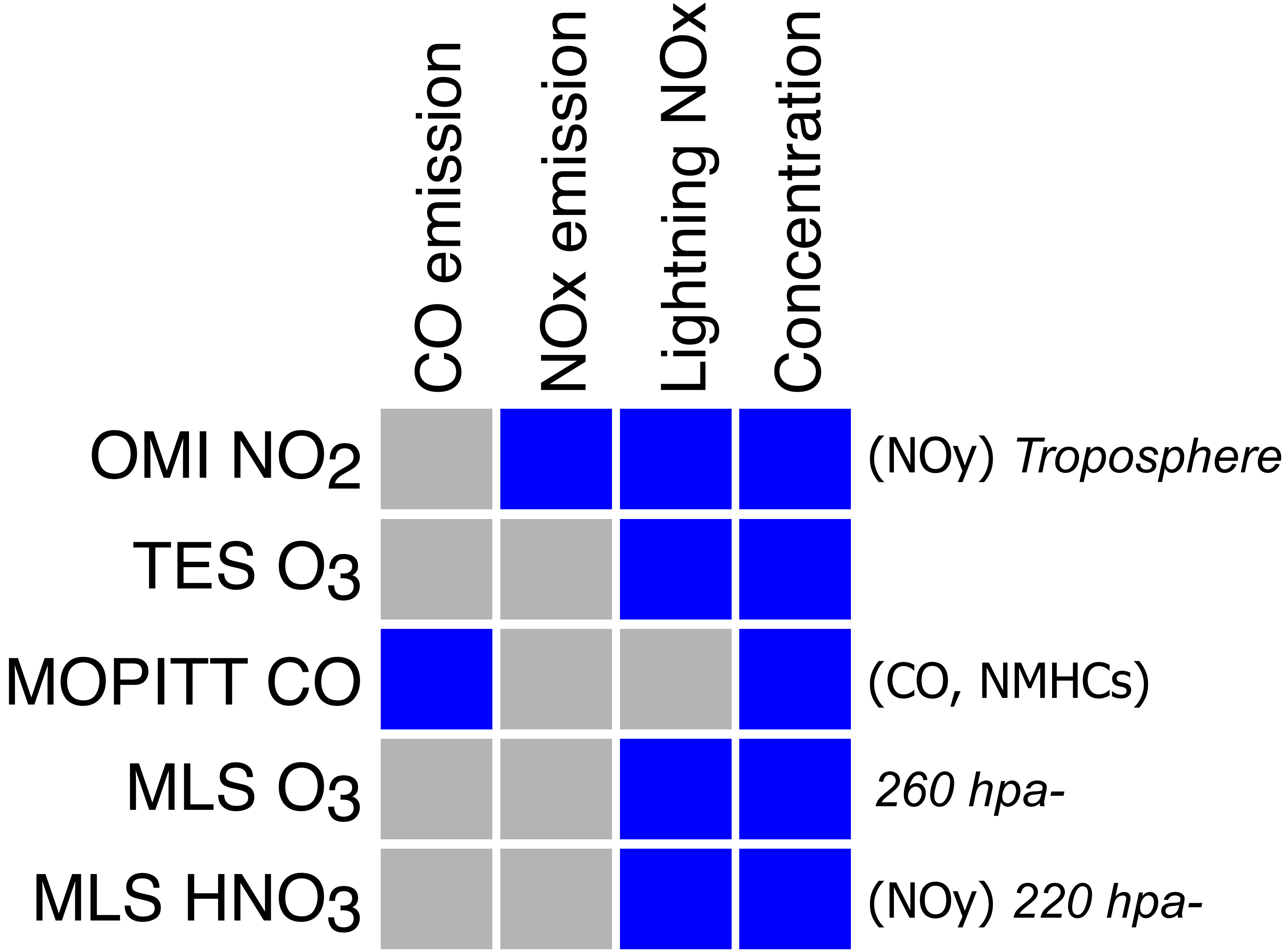

- Emission estimation based on state augmentation.
- Covariance among very weakly-related species is neglected (i.e., variable localization.

$$\mathbf{x}_i^b = \begin{bmatrix} \mathbf{c}_i^b \\ \mathbf{e}(\mathrm{NO_x})_i^b \\ \mathbf{e}(\mathrm{CO})_i^b \\ \mathbf{e}(\mathrm{LNO_x})_i^b \end{bmatrix}$$

Concentration

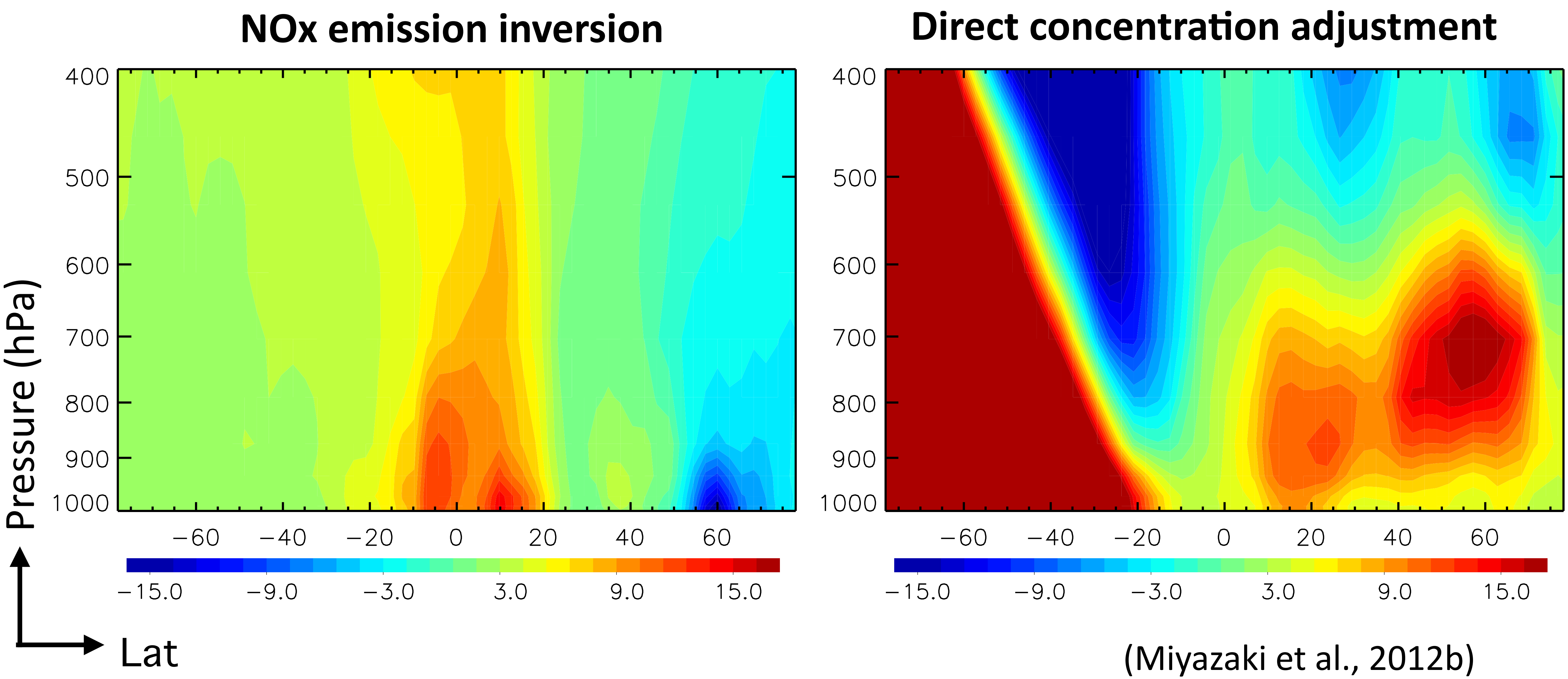
Emissions

# Background error covariance structure in CHASER-DAS




The variable localization (Kang et al., 2011)

## The relative impact (in %) of the NOx emission inversion (left) and the direct concentration adjustment (right) through assimilation on the vertical $O_3$ profile




(Miyazaki et al., 2012b)

**The simultaneous adjustment of the emissions and the concentrations is a powerful approach to optimize the whole tropospheric profiles**

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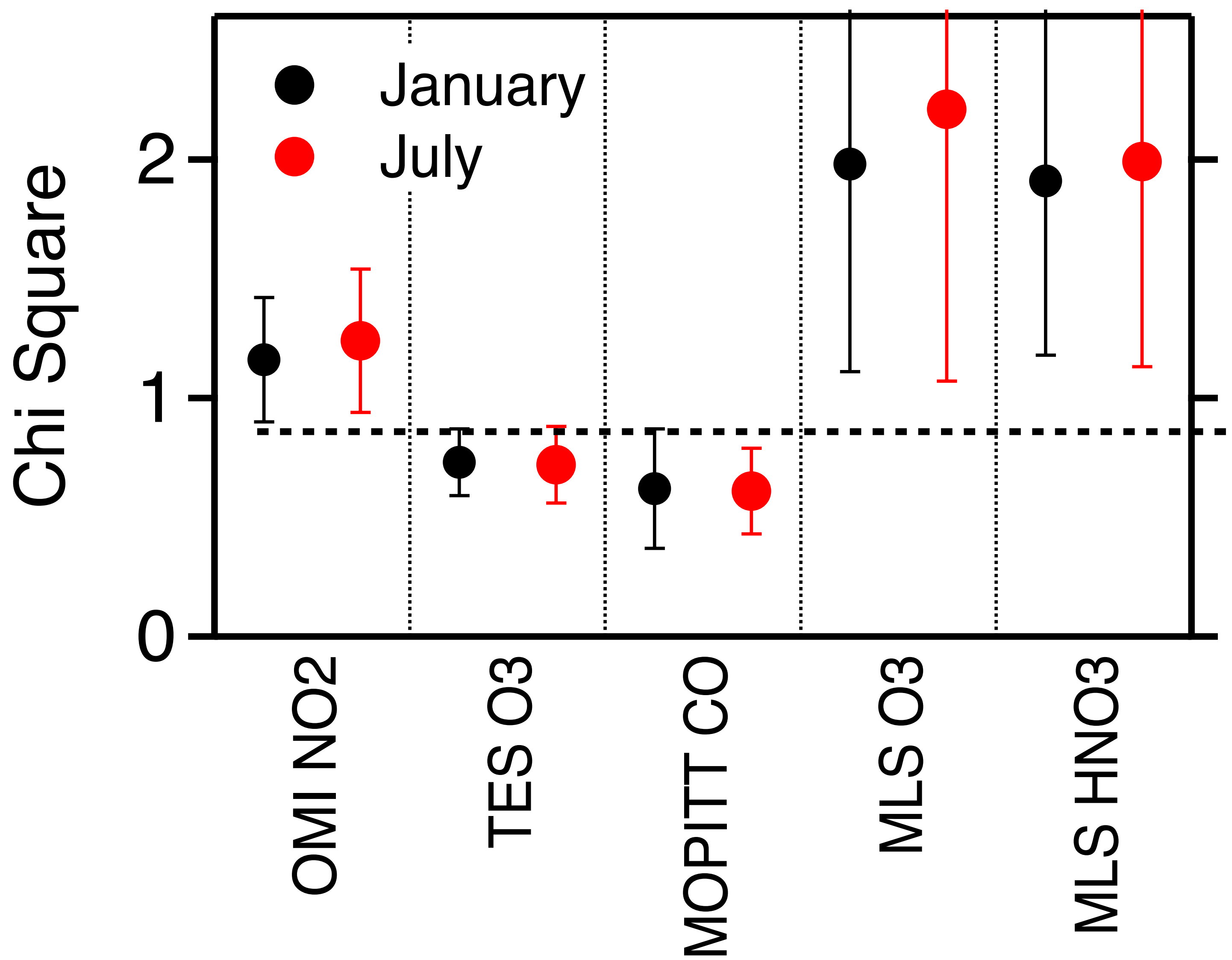
# Self-consistency check: Chi-square test

**An important test for the quality of data assimilation is whether the differences between the innovations are consistent with the covariance matrices for the model forecast and observations.**

$$\mathbf{Y} = \frac{1}{\sqrt{m}} \left( \mathbf{H}\mathbf{P}^b\mathbf{H}^T + \mathbf{R} \right)^{-1/2} \left( \mathbf{y}^o - H\left(\mathbf{x}^b\right) \right). \qquad \chi^2 = \mathrm{trace}\,\mathbf{Y}\mathbf{Y}^T$$




(Miyazaki et al., 2012b)



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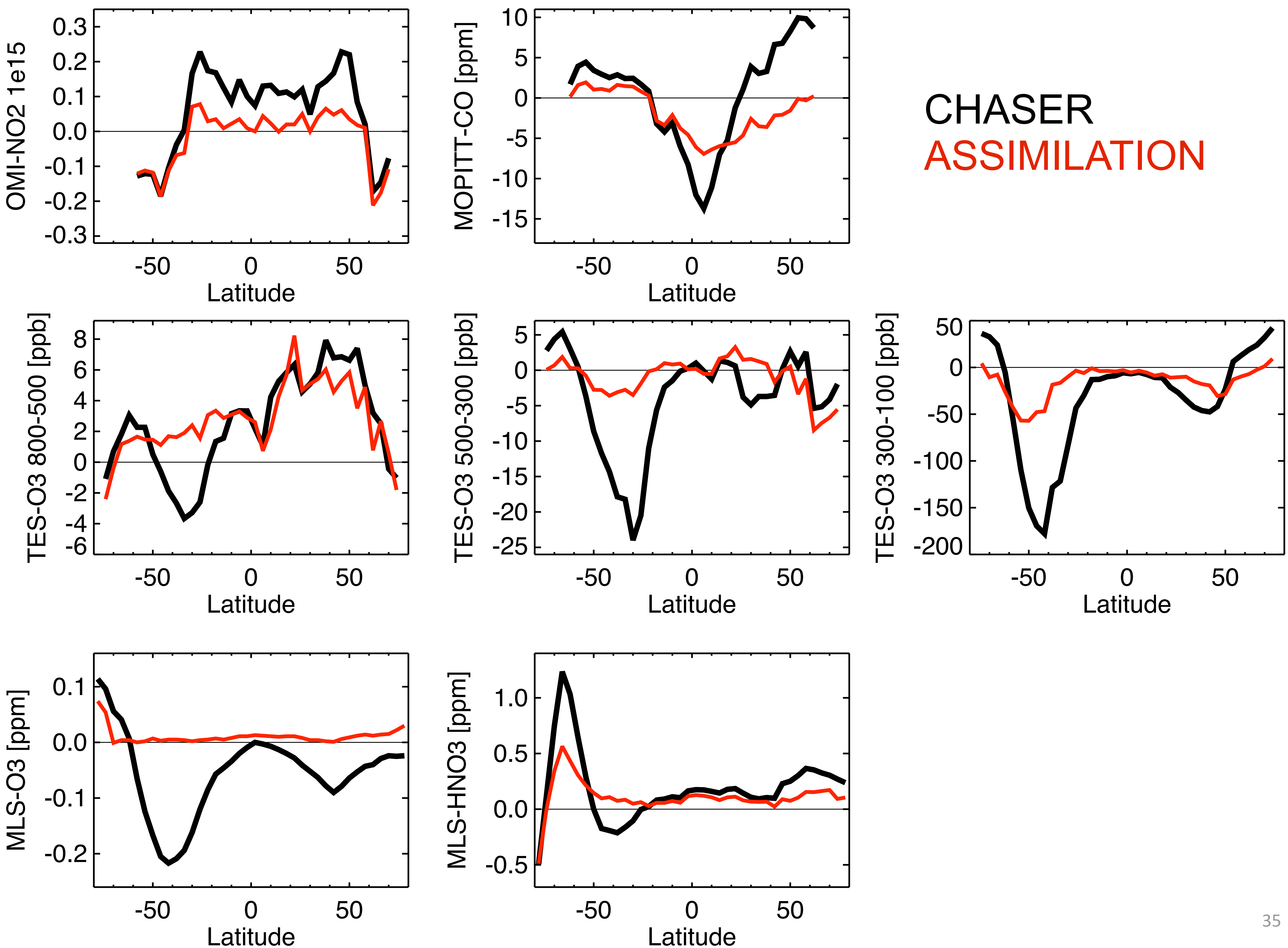
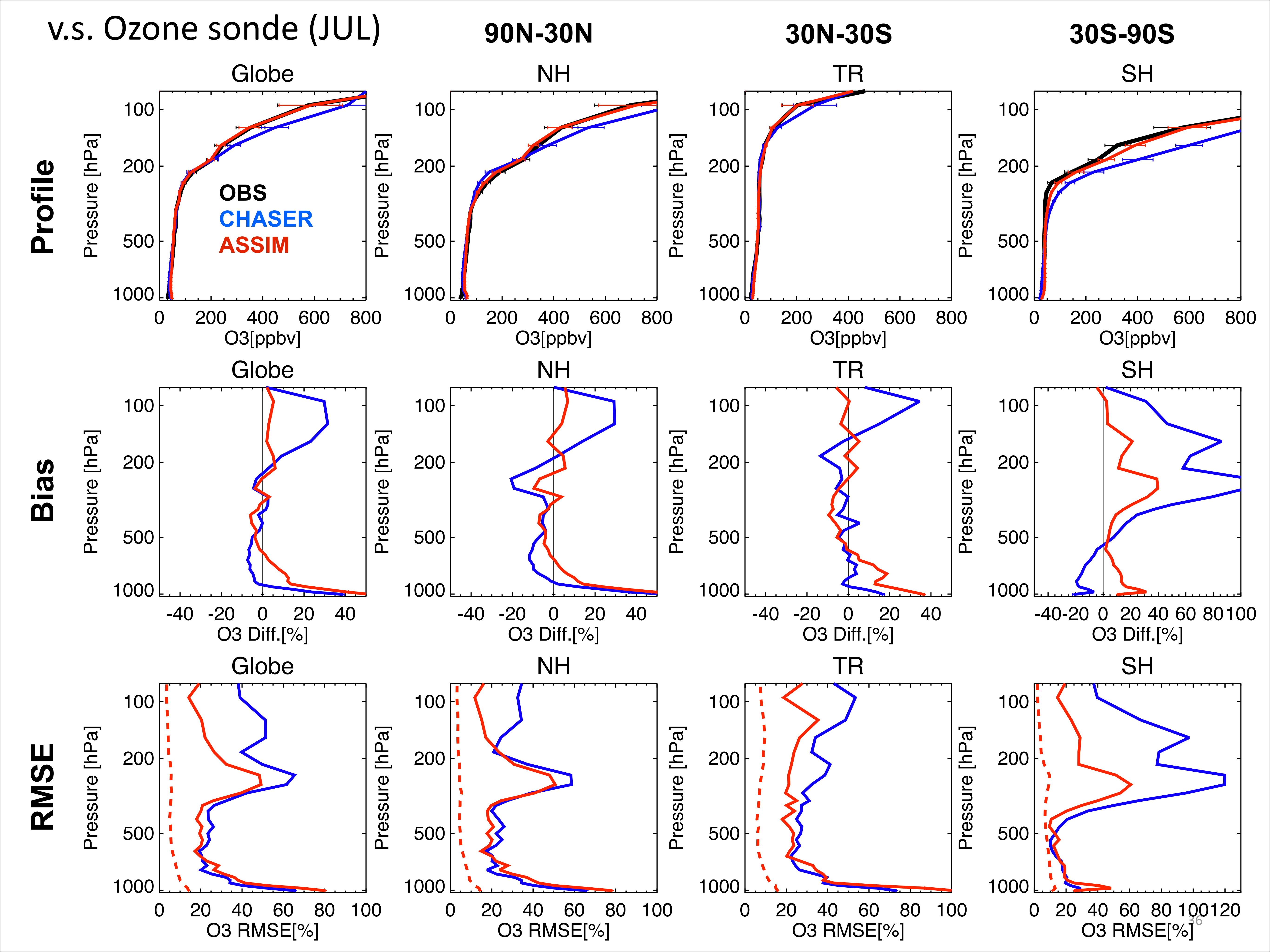
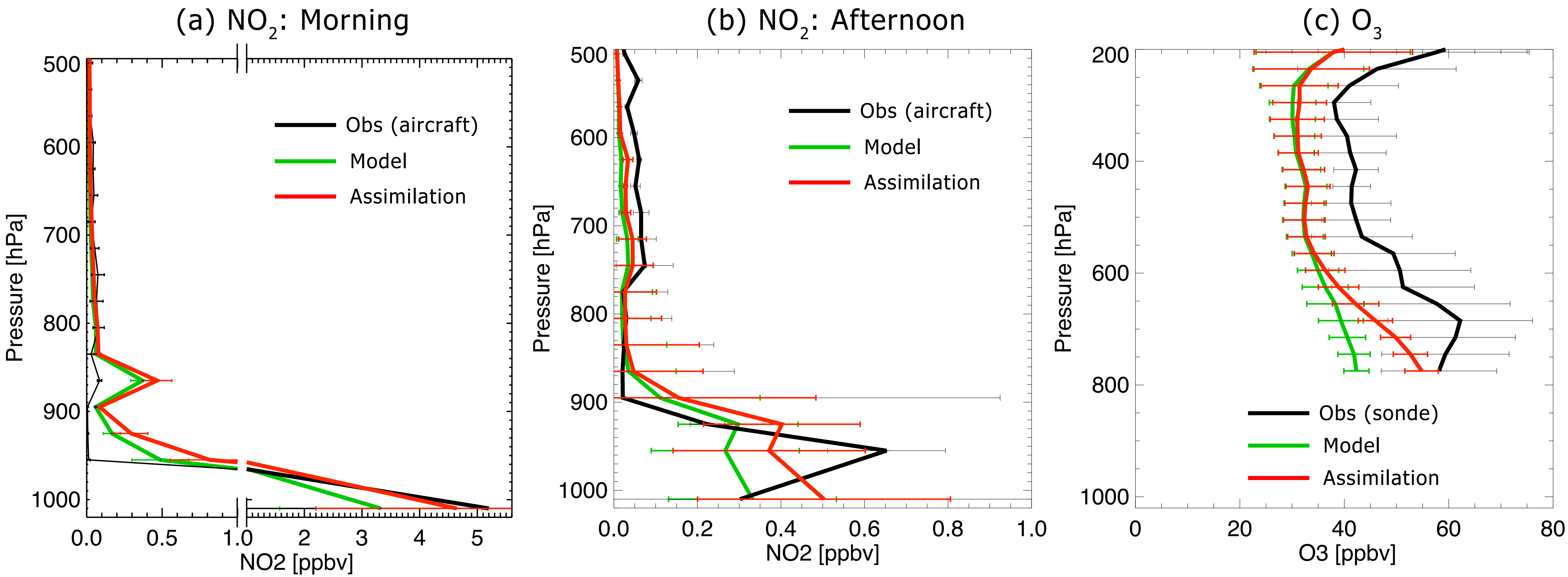
# Self-consistency check: Observation-minus-Forecast (OmF) Mean





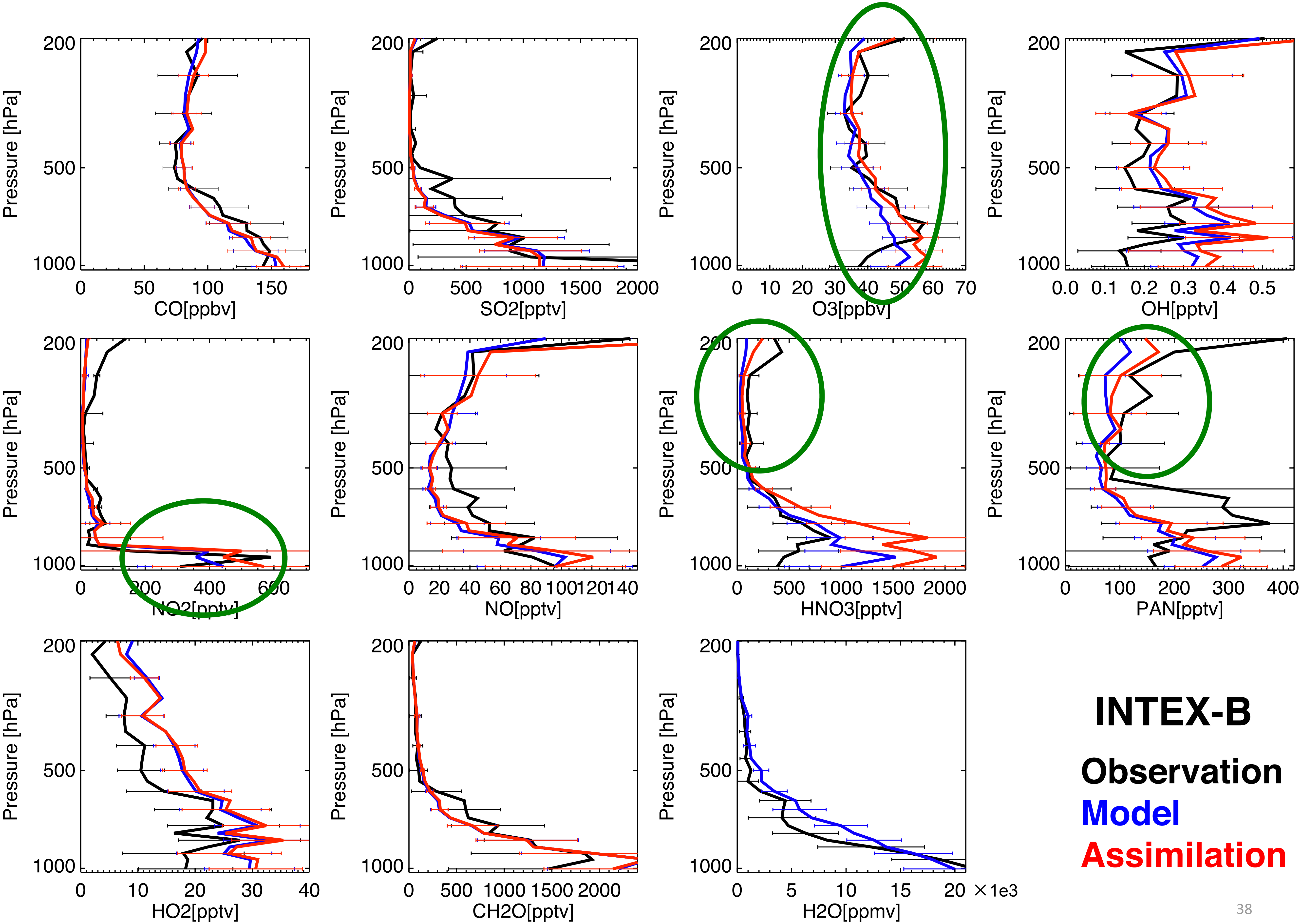
v.s. Ozone sonde (JUL)
90N-30N
30N-30S
30S-90S
Profile
Bias
RMSE
Globe
NH
TR
SH
OBS
CHASER
ASSIM
Pressure [hPa]
O3[ppbv]
O3 Diff.[%]
O3 RMSE[%]

# INTEX-B

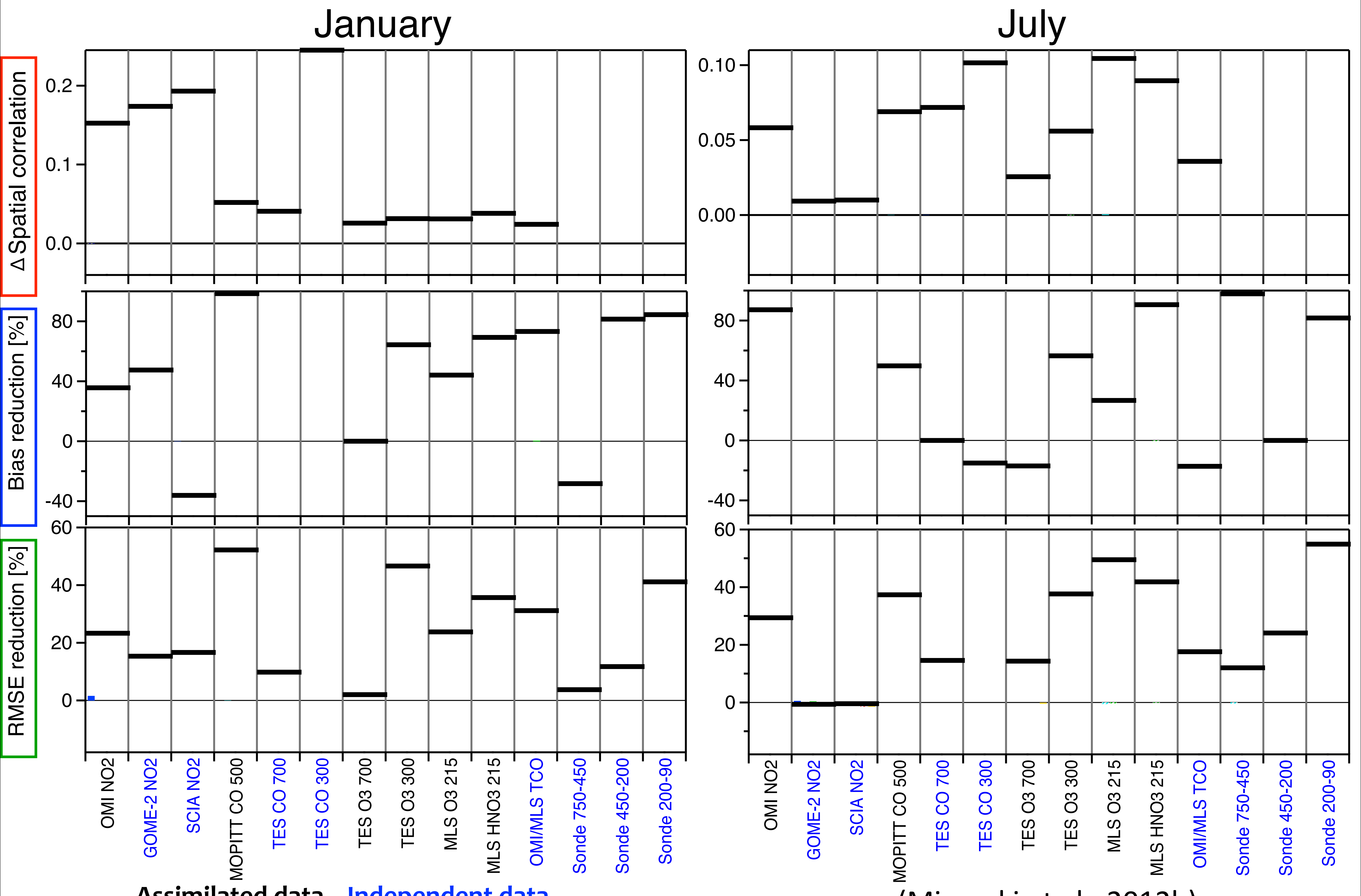


(a) $NO_2$: Morning
(b) $NO_2$: Afternoon
(c) $O_3$
Obs (aircraft)
Model
Assimilation
Obs (sonde)
Pressure [hPa]
NO2 [ppbv]
O3 [ppbv]
500
600
700
800
900
1000
200
400
0.0
0.5
1.0
2
3
4
5
0.2
0.4
0.6
0.8
0
20
40
60
80

# v.s. aircraft during INTEX-B

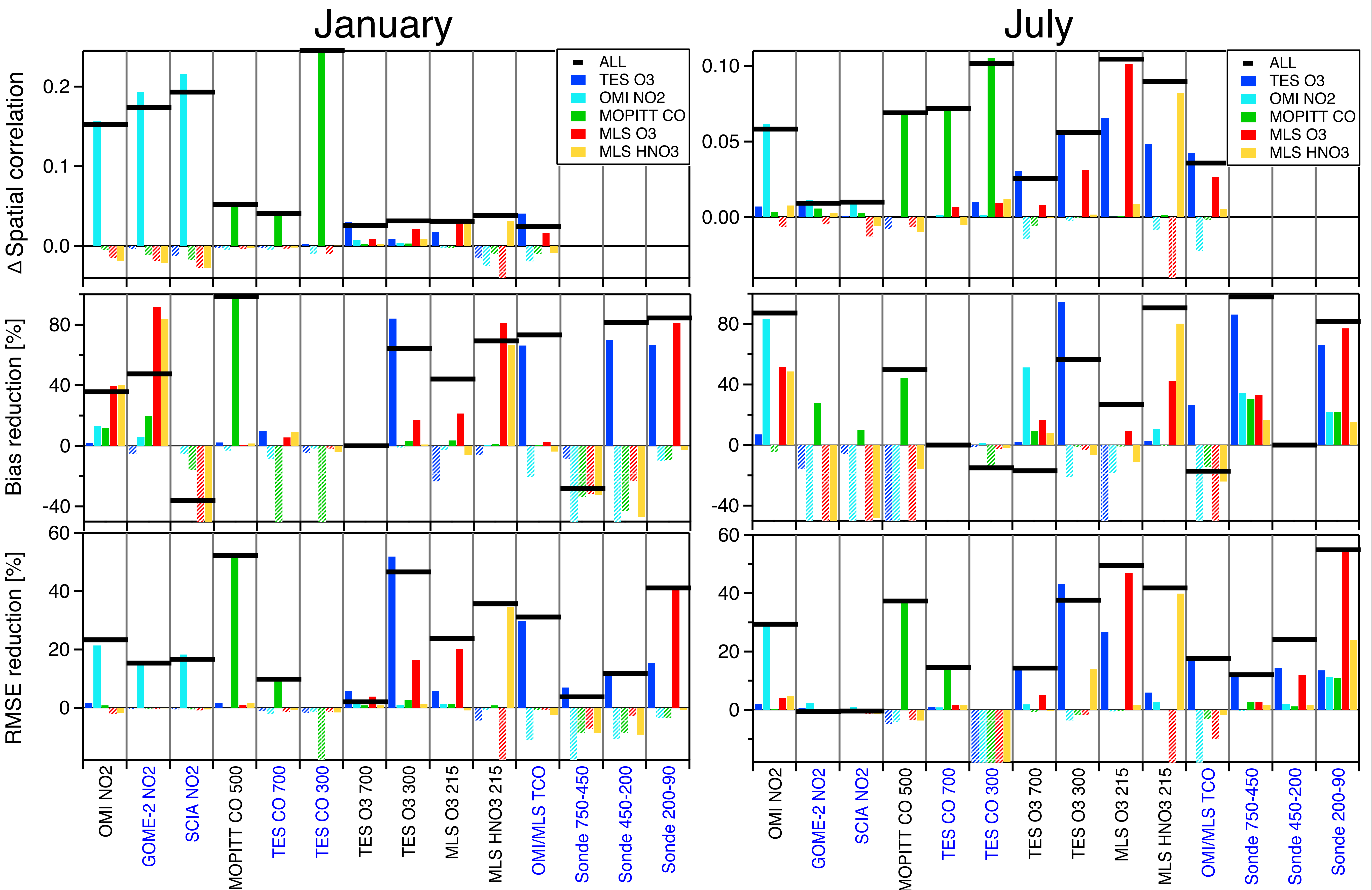


Spatial correlation increment BIAS reduction rate RMSE reduction rate




(Miyazaki et al., 2012b)

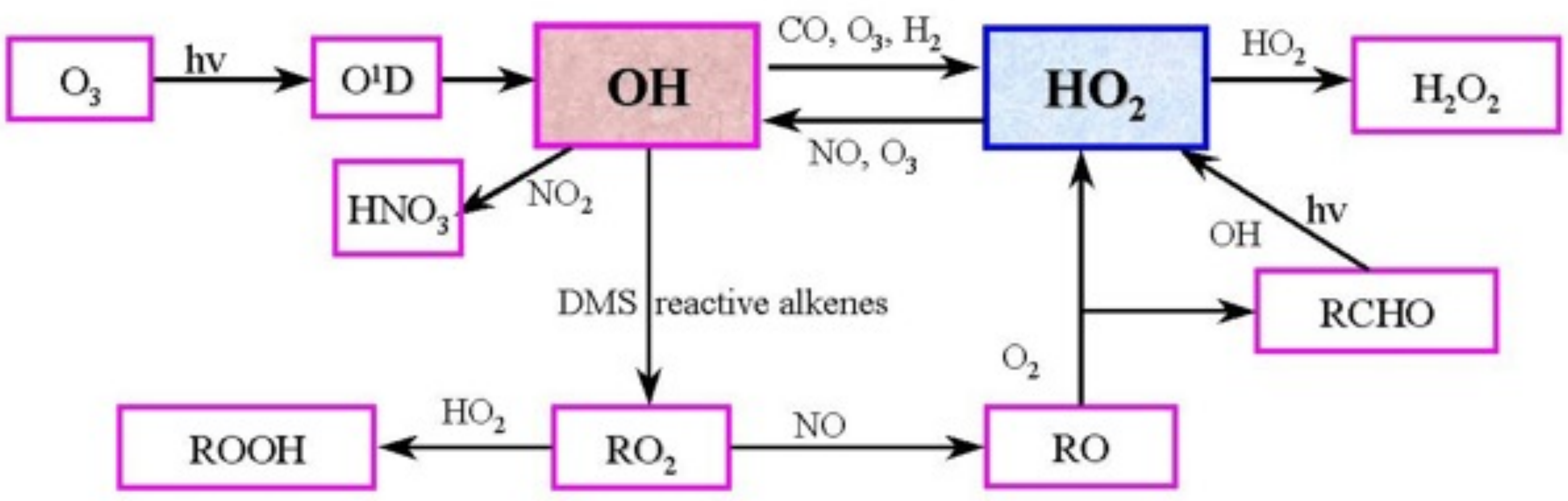
# Observing System Experiments (OSEs)

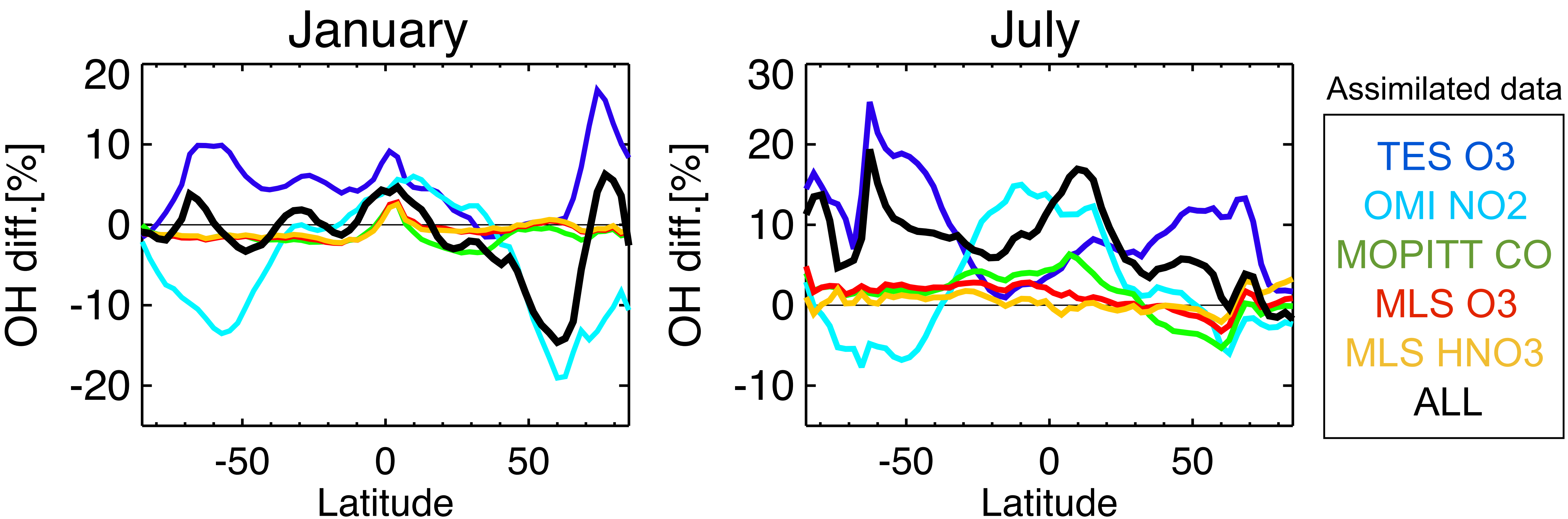



(Miyazaki et al., 2012b)

# Influences on the oxidation capacity

- Assimilation of each species data set has a strong influence on both assimilated/non-assimilated species.
- The inter-species influences are tightly associated with the changes in OH because of the chemical interactions in the CO-OH-Ox-NOx system.



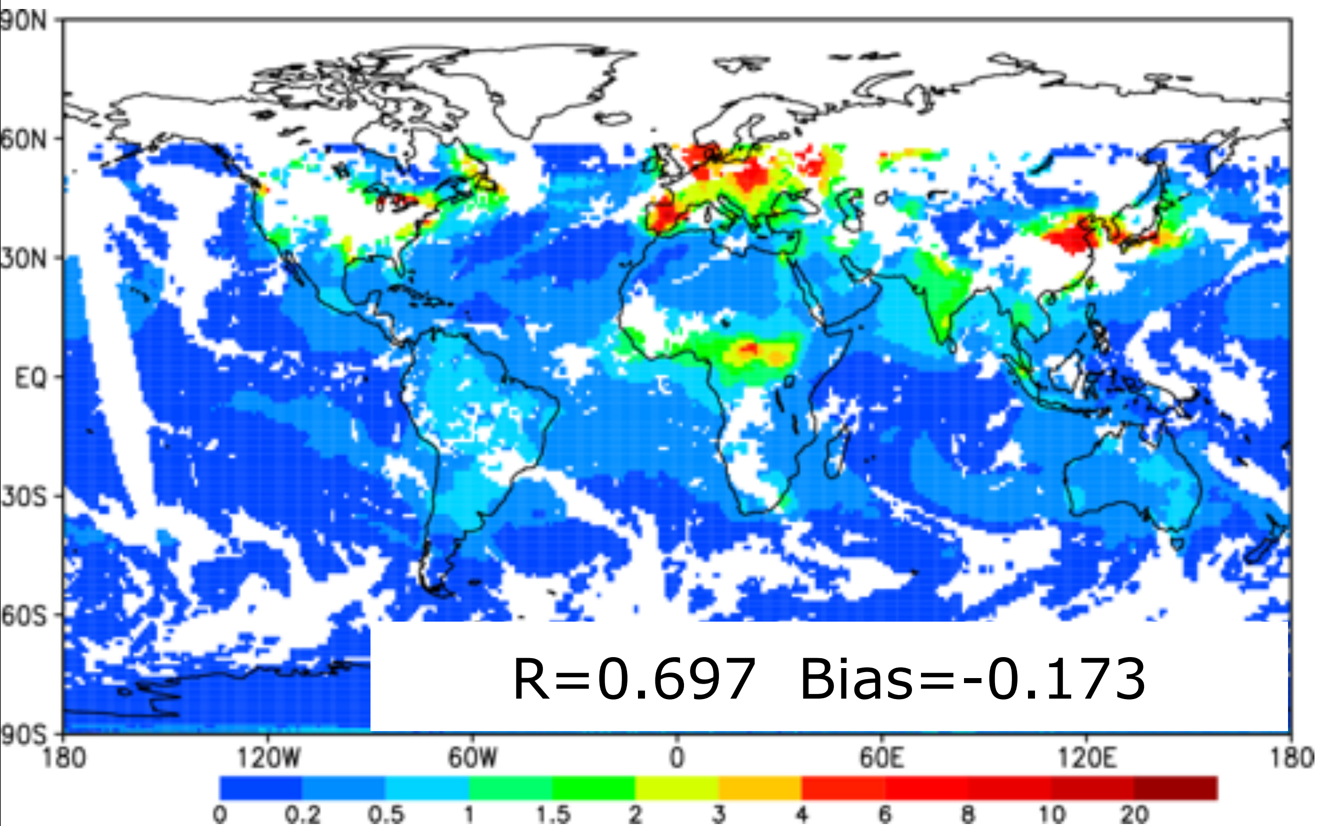




**The obvious changes in the OH fields reveal the great potential of the multiple species assimilation to influence the NOx emission inversion etc.**

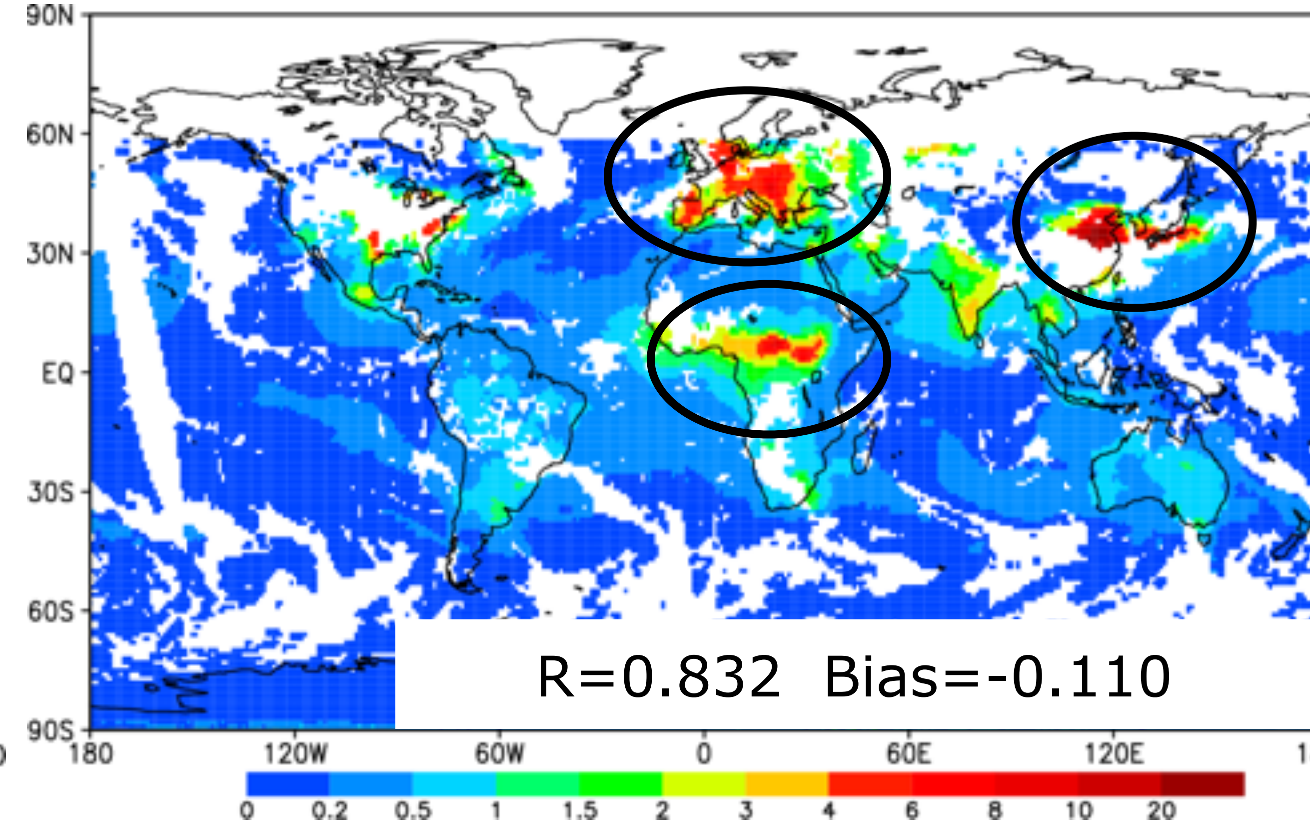
(Miyazaki et al., 2012b)

# $NO_2$

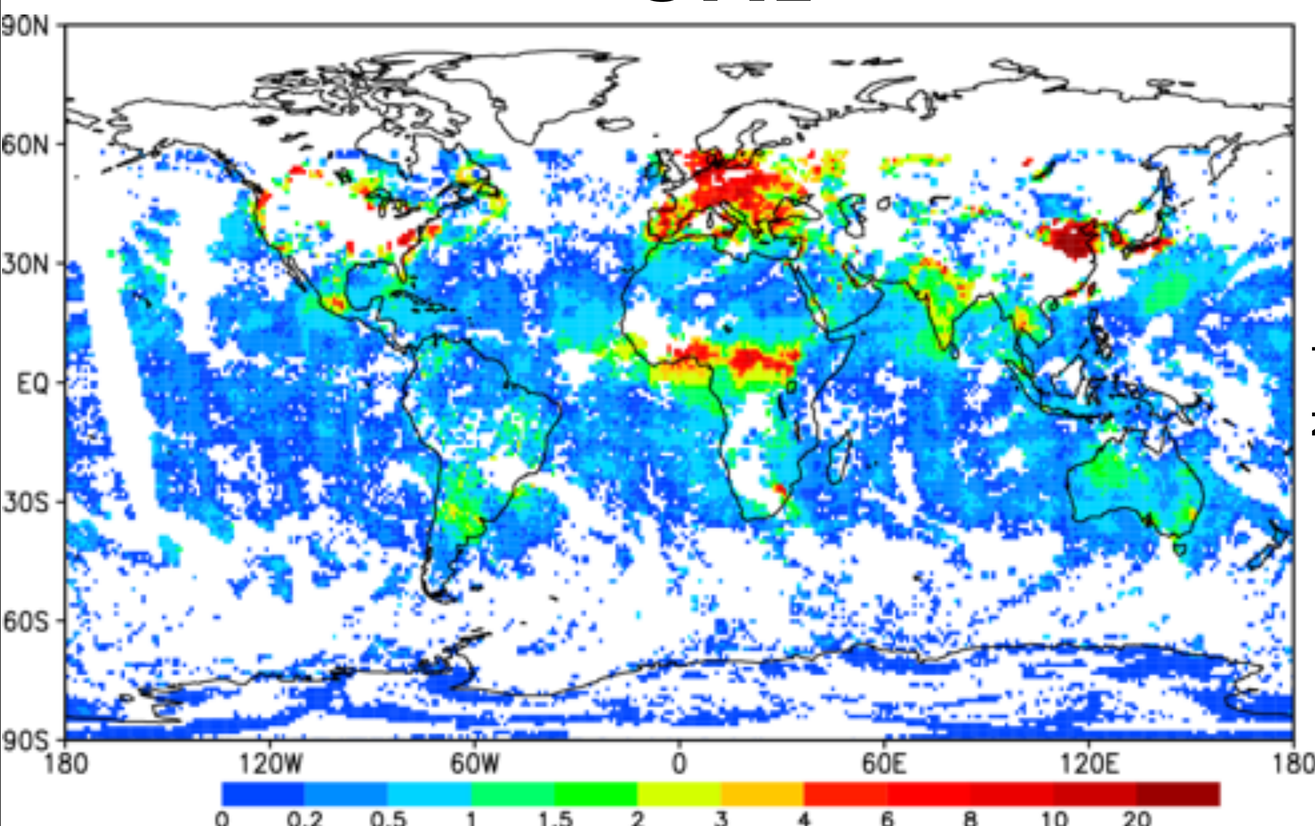
## Simulation

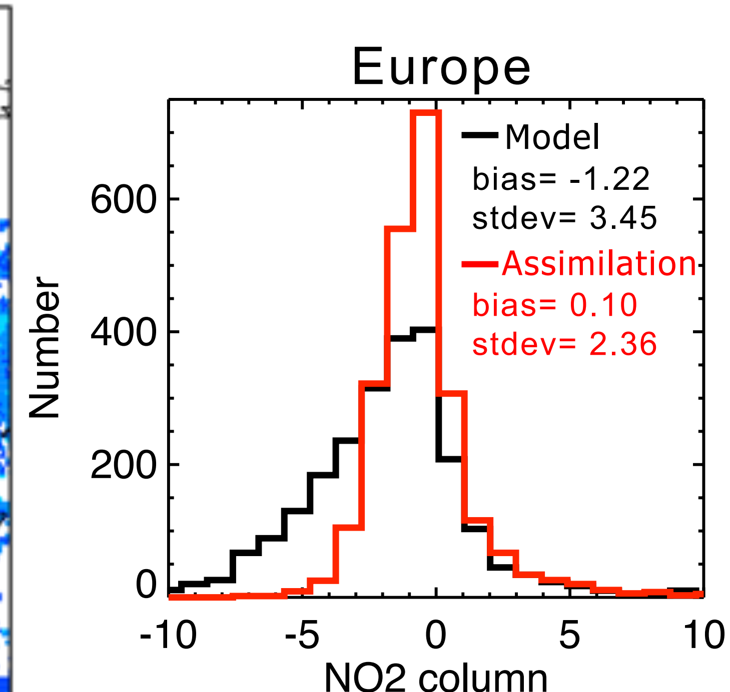


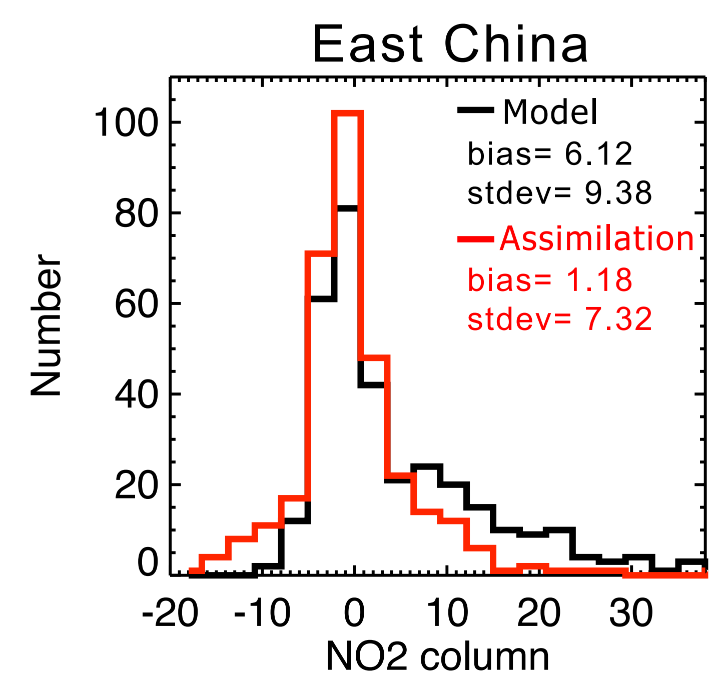

## Assimilation




## OMI

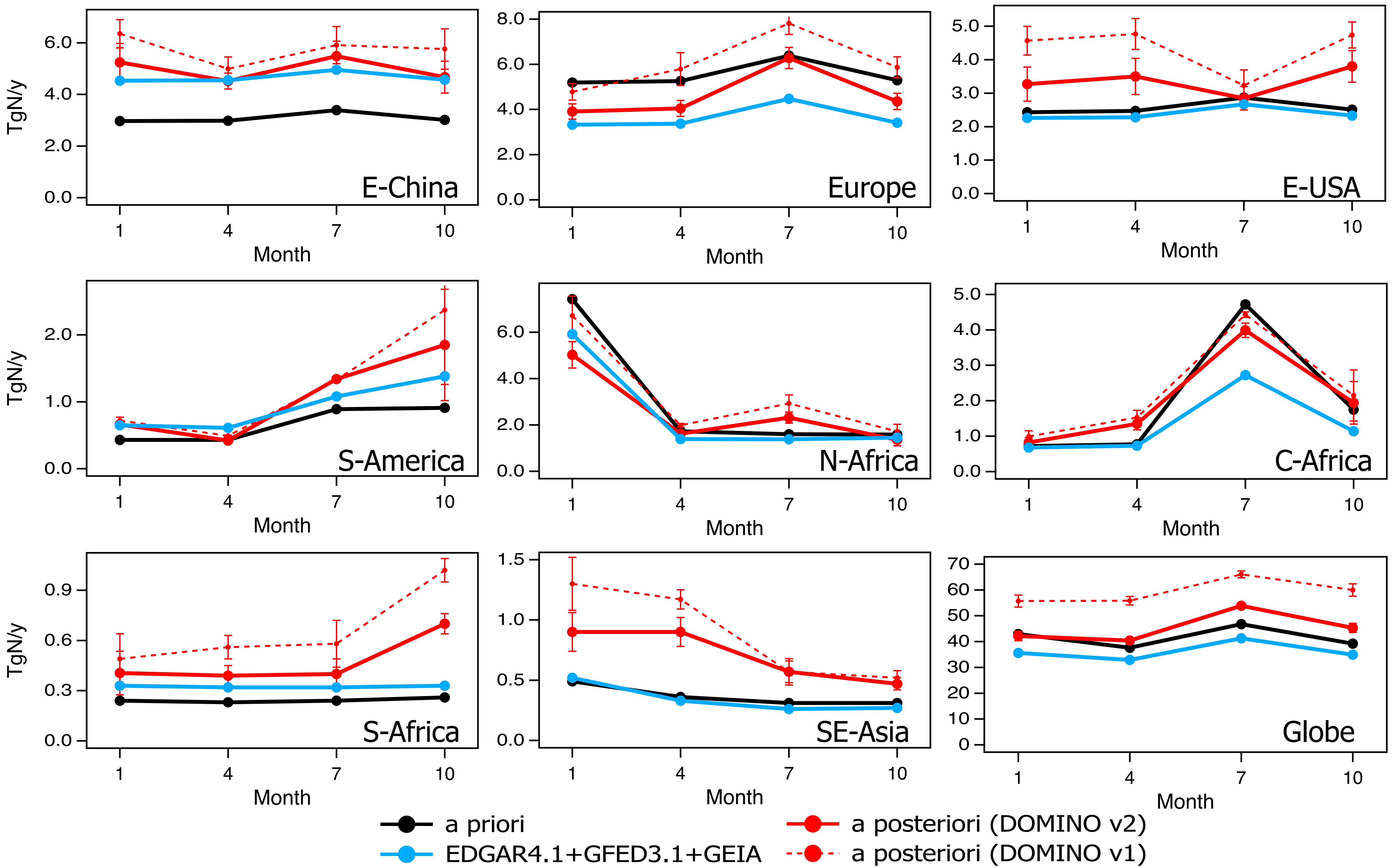



**11 January 2005**

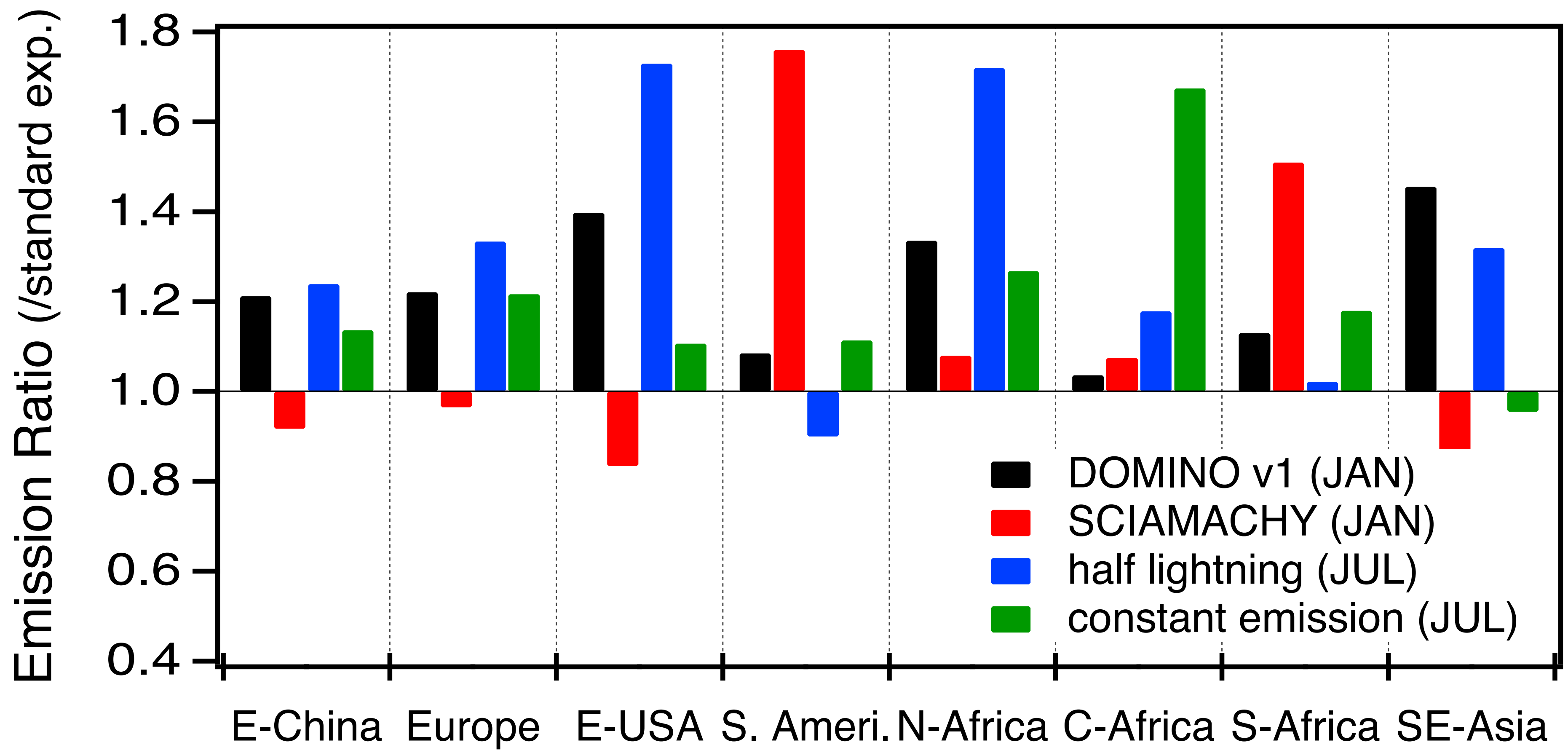
# Surface NOx emissions

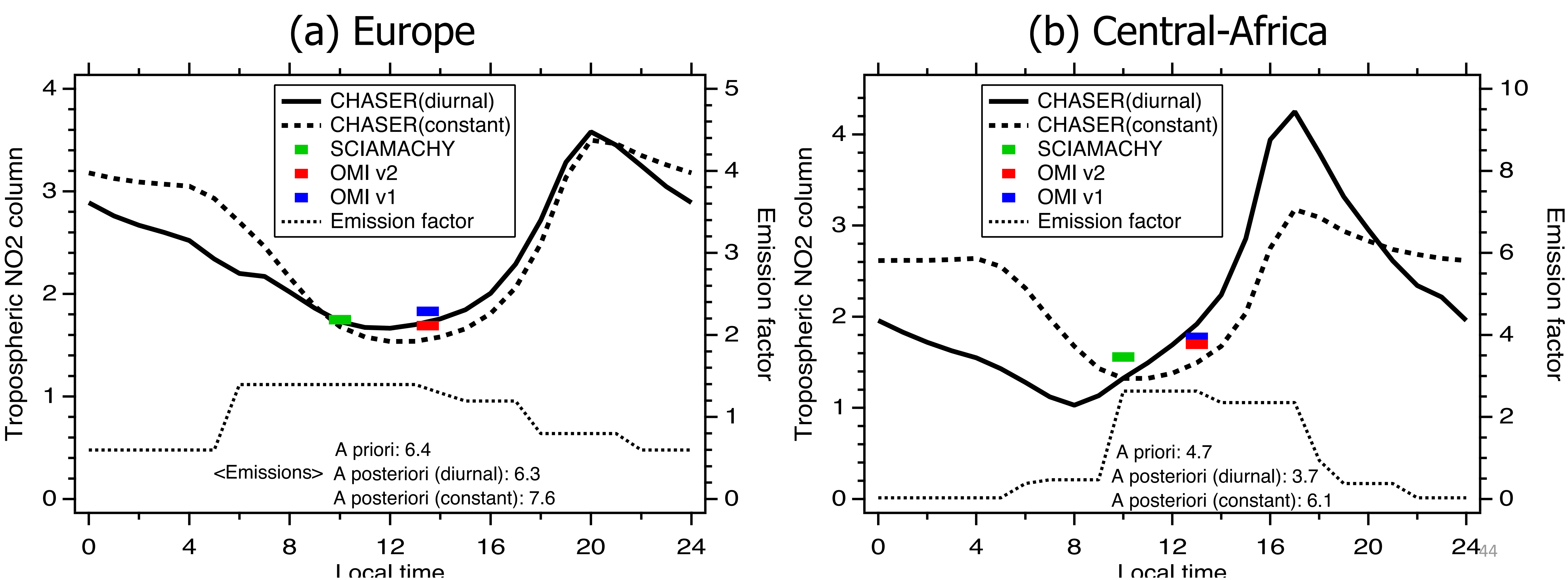


# Surface NOx emissions

推定への大きな影響

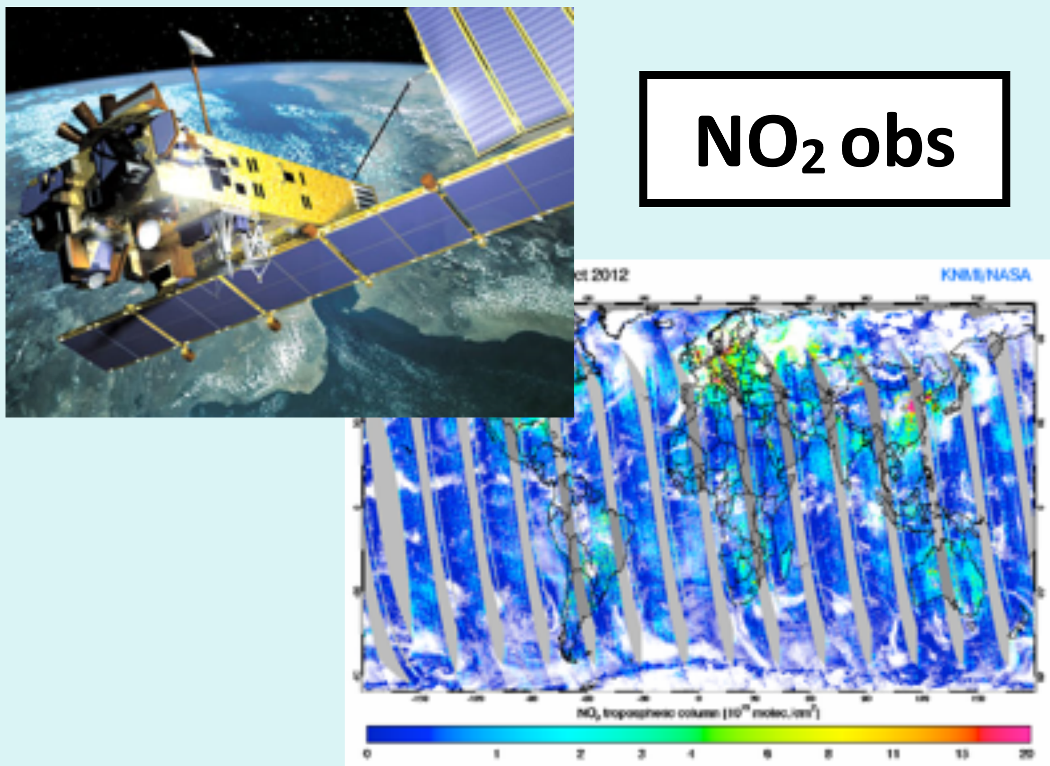
- データの品質
- モデルの性能



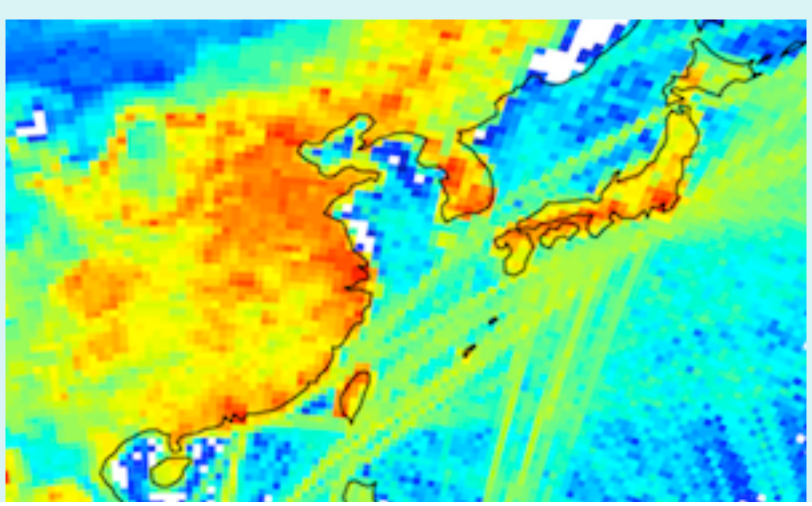
# Top-down NOx emission estimates from satellite

## Previous studies (only $NO_2$ obs used)



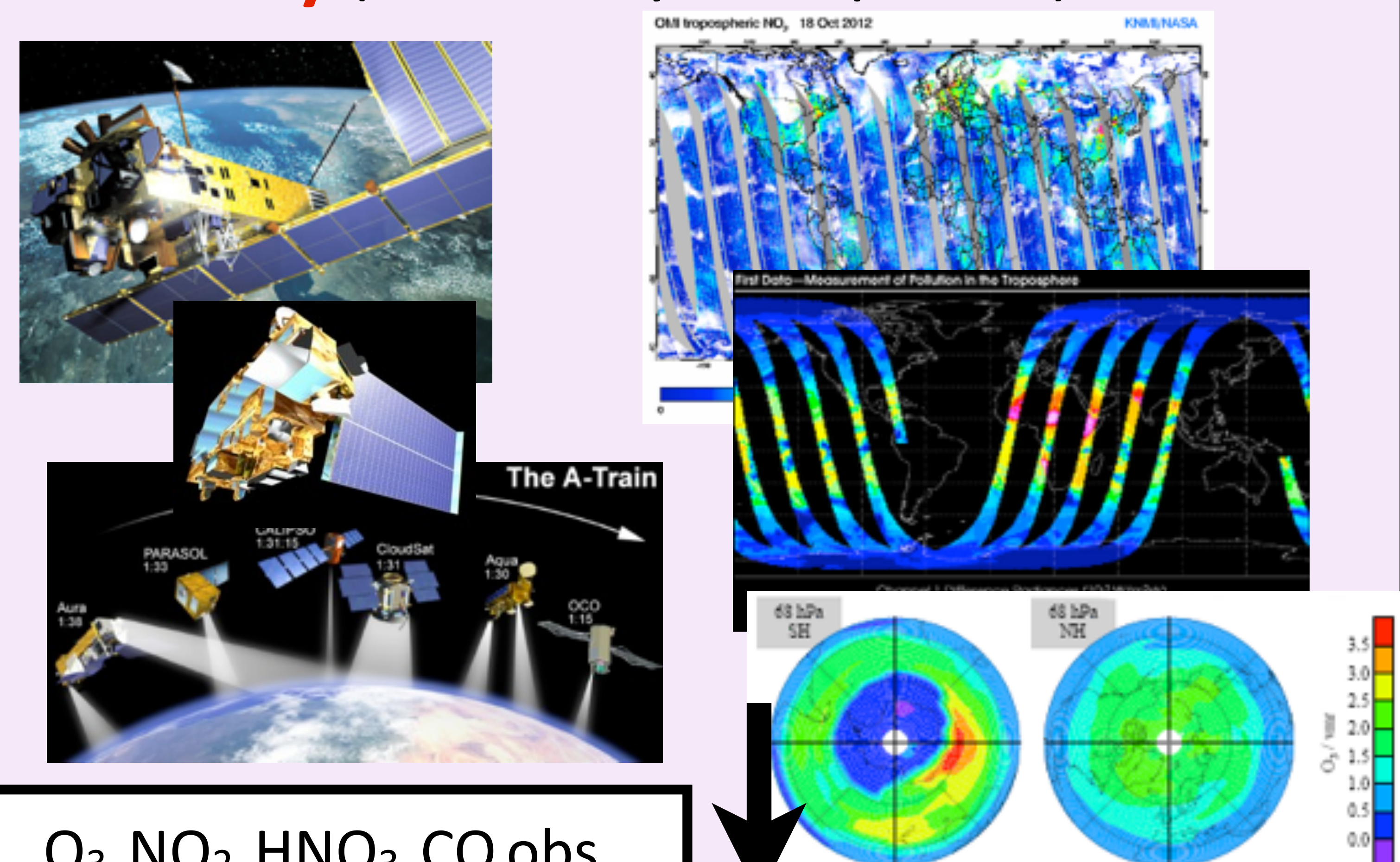

**$NO_2$ obs**

Obvious influences of model errors



(e.g., Martin et al., 2003; Jaeglé et al., 2005)

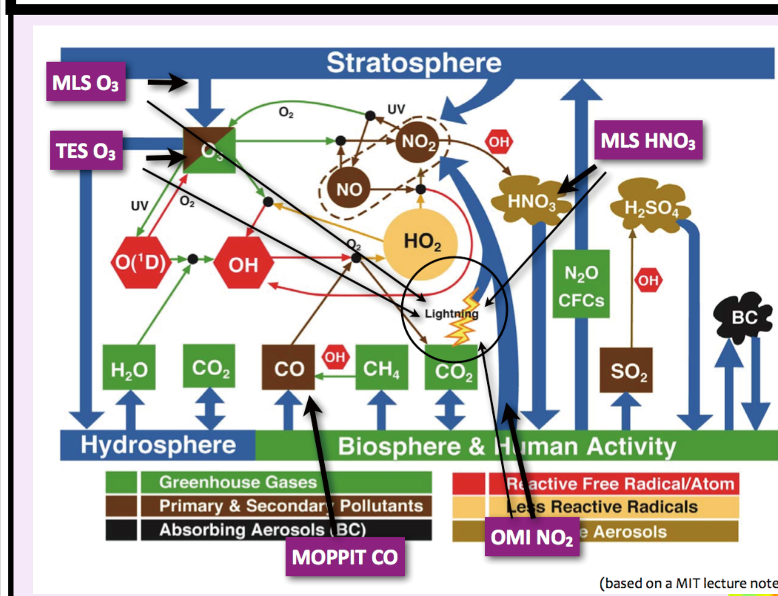
## This study (uses chemically-related species obs)

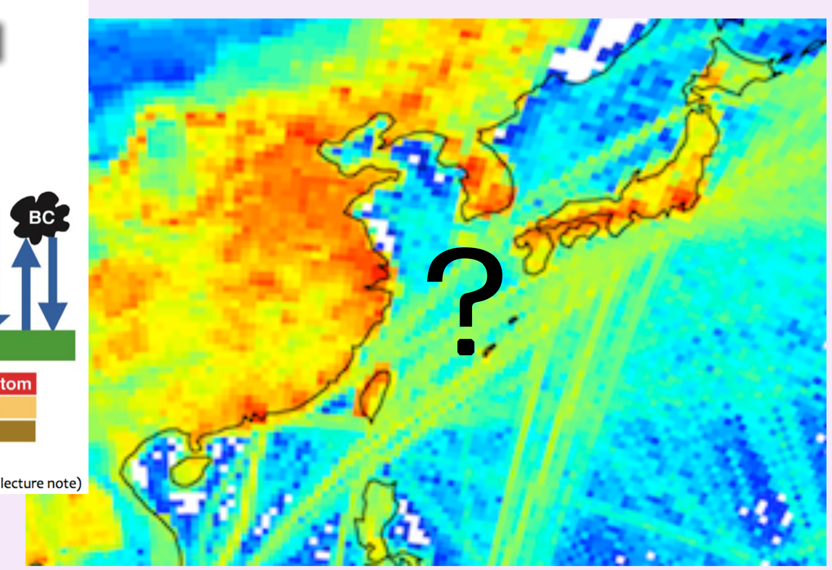


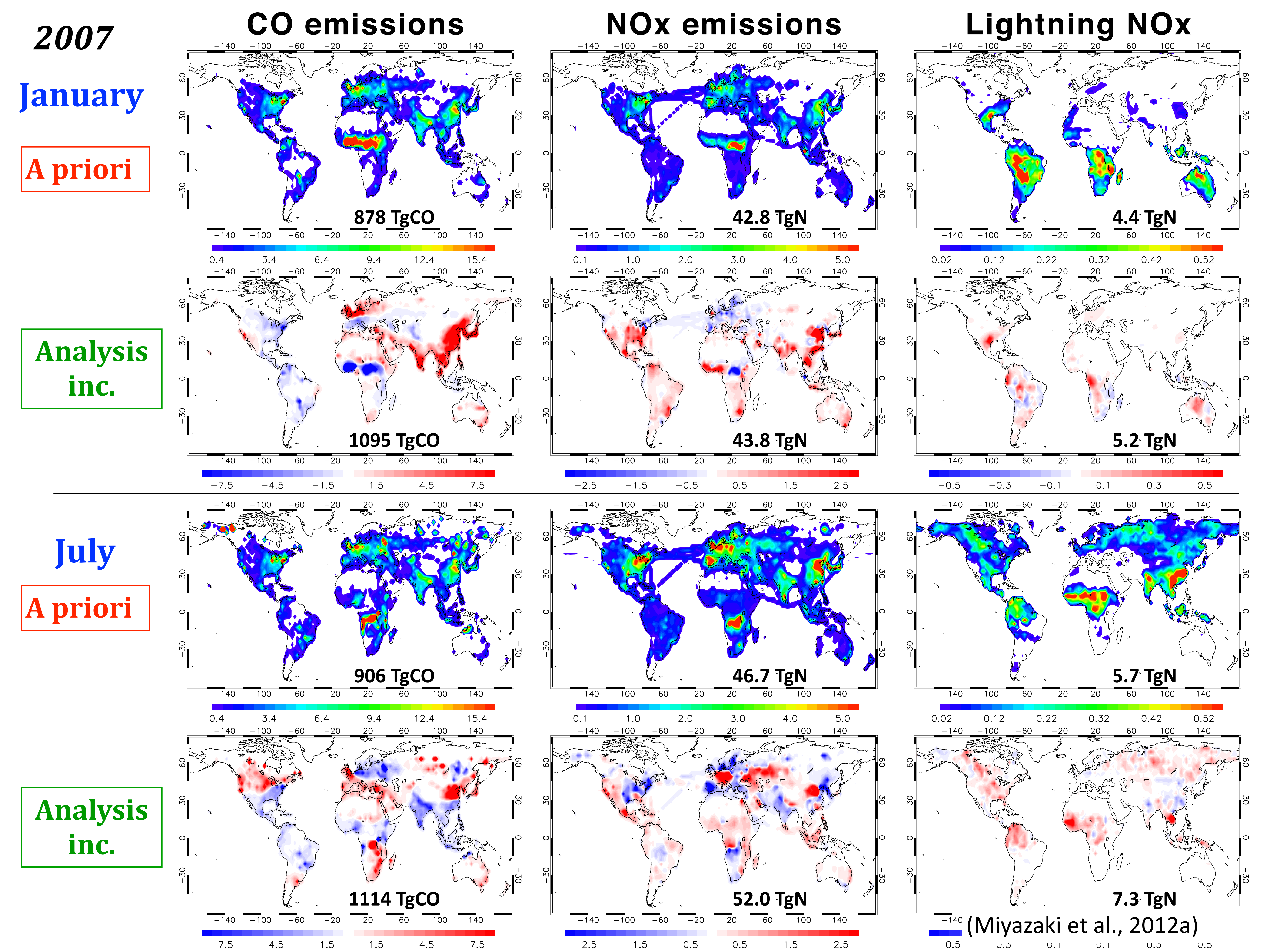

$O_3$, $NO_2$, $HNO_3$, CO obs

Constrain the chemical system

Reduce model errors and improve the emission analysis

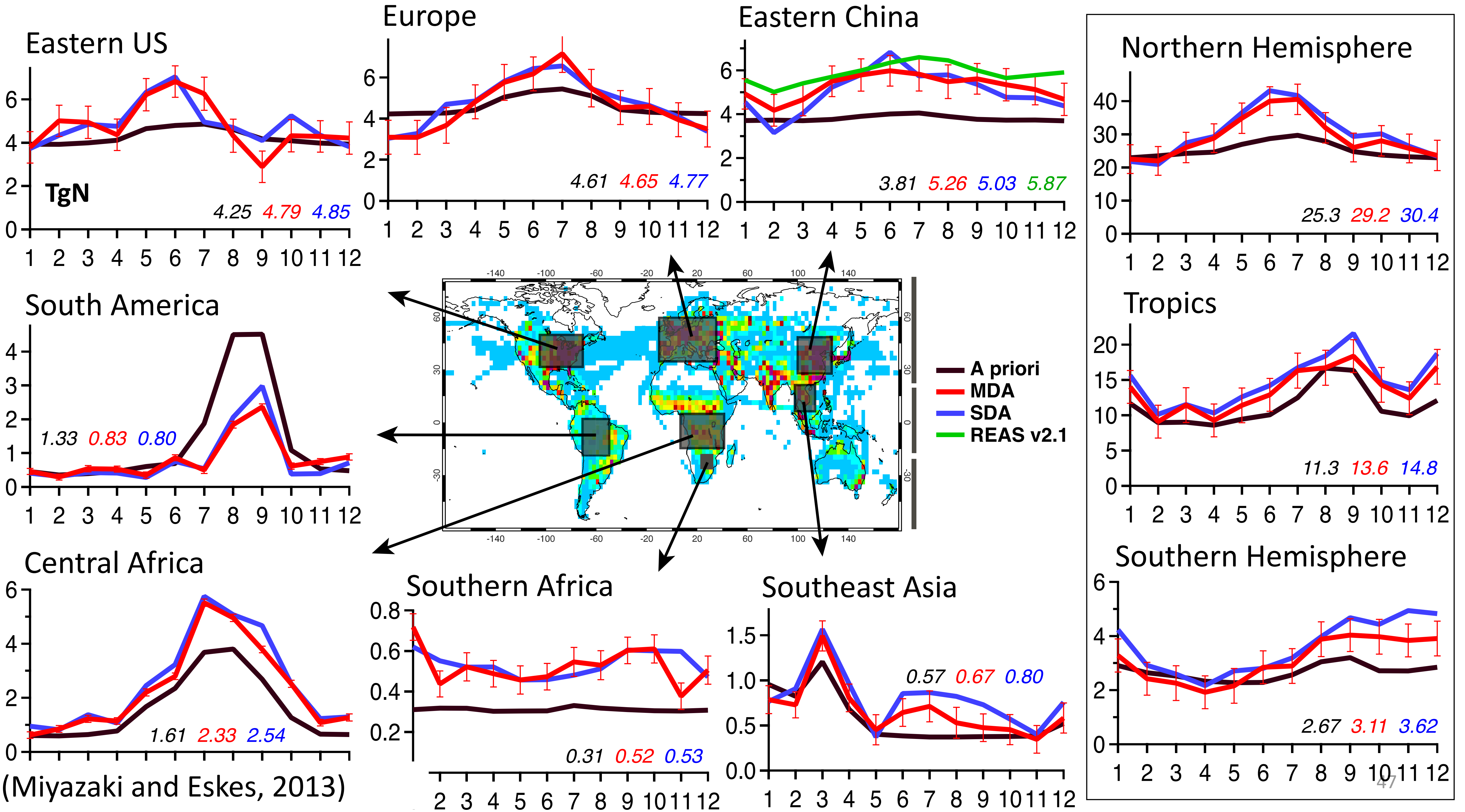


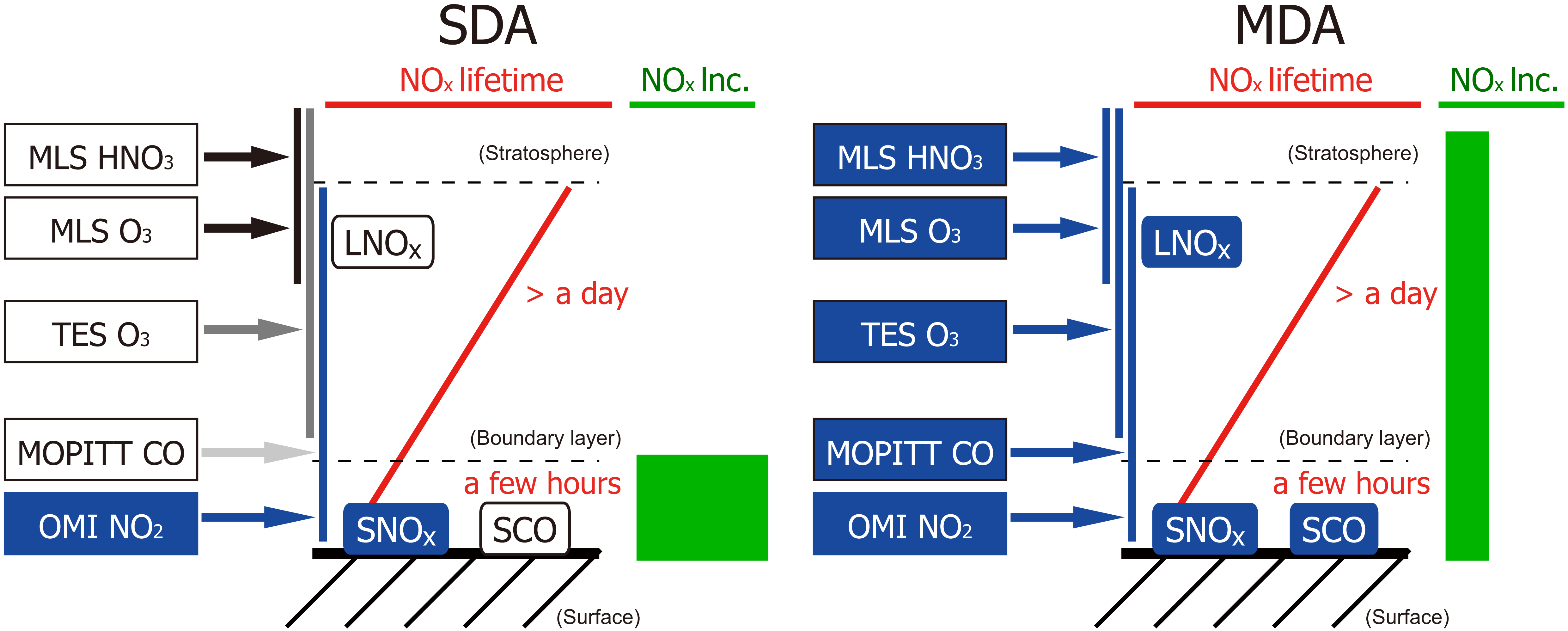

2007
CO emissions
NOx emissions
Lightning NOx
January
A priori
Analysis inc.
July
A priori
Analysis inc.
878 TgCO
42.8 TgN
4.4 TgN
1095 TgCO
43.8 TgN
5.2 TgN
906 TgCO
46.7 TgN
5.7 TgN
1114 TgCO
52.0 TgN
7.3 TgN
(Miyazaki et al., 2012a)

# Multiple species constraints on surface NOx emissions

- The **multiple datasets assimilation (MDA)** provides additional constraints, as a consequence of the $NO_2$ profiles being modified by the non-$NO_2$ observations.
- The large influences of non-$NO_2$ data highlight the large uncertainty (by 58% on regional scale) in the NOx emissions inverted from **$NO_2$ observations only (SDA: single dataset assimilation)**.




(Miyazaki and Eskes, 2013)

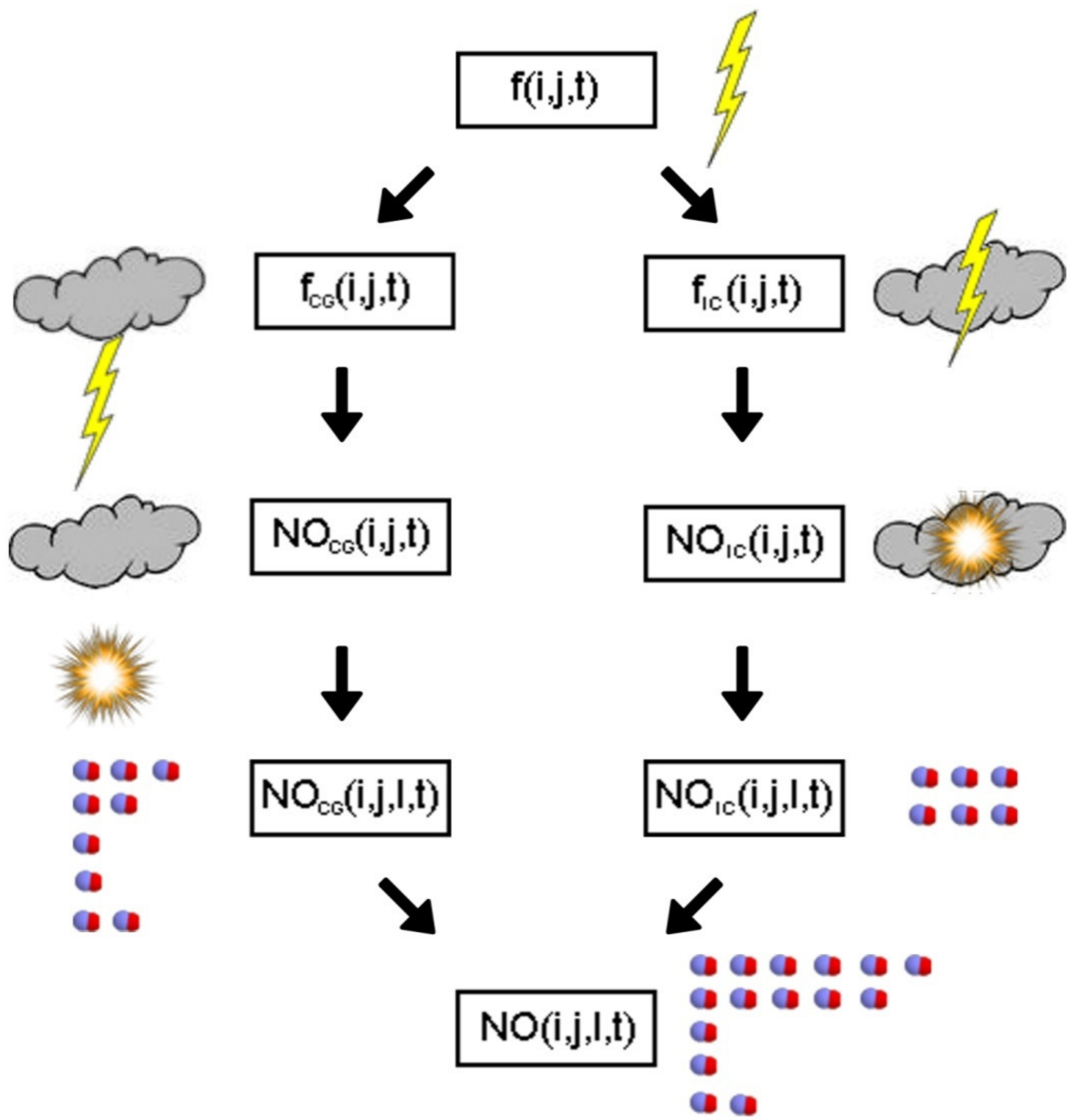


SDA
NOx lifetime
NOx Inc.
MLS HNO3
MLS O3
TES O3
MOPITT CO
OMI NO2
(Stratosphere)
LNOx
> a day
(Boundary layer)
a few hours
SNOx
SCO
(Surface)
MDA
NOx lifetime
NOx Inc.
MLS HNO3
MLS O3
TES O3
MOPITT CO
OMI NO2
(Stratosphere)
LNOx
> a day
(Boundary layer)
a few hours
SNOx
SCO
(Surface)

**Accurate estimates of LNOx are important to understand variations in NOx, the oxidizing capacity, and several greenhouse gases ($O_3$, $CH_4$).**

***Larger uncertainly in the estimated total amount of NOx globally produced by lightning, i.e. ranging from 2 to 8 TgN/yr.***

**Bottom-up:** The lightning and subsequent NOx formation are determined with the help of empirical parameterizations.




Spatial (2-D) and temporal distribution of lightning flashes

**(Price and RInd, 1992)**

Ratio of IC to CG flashes

NO production per IC & CG flash

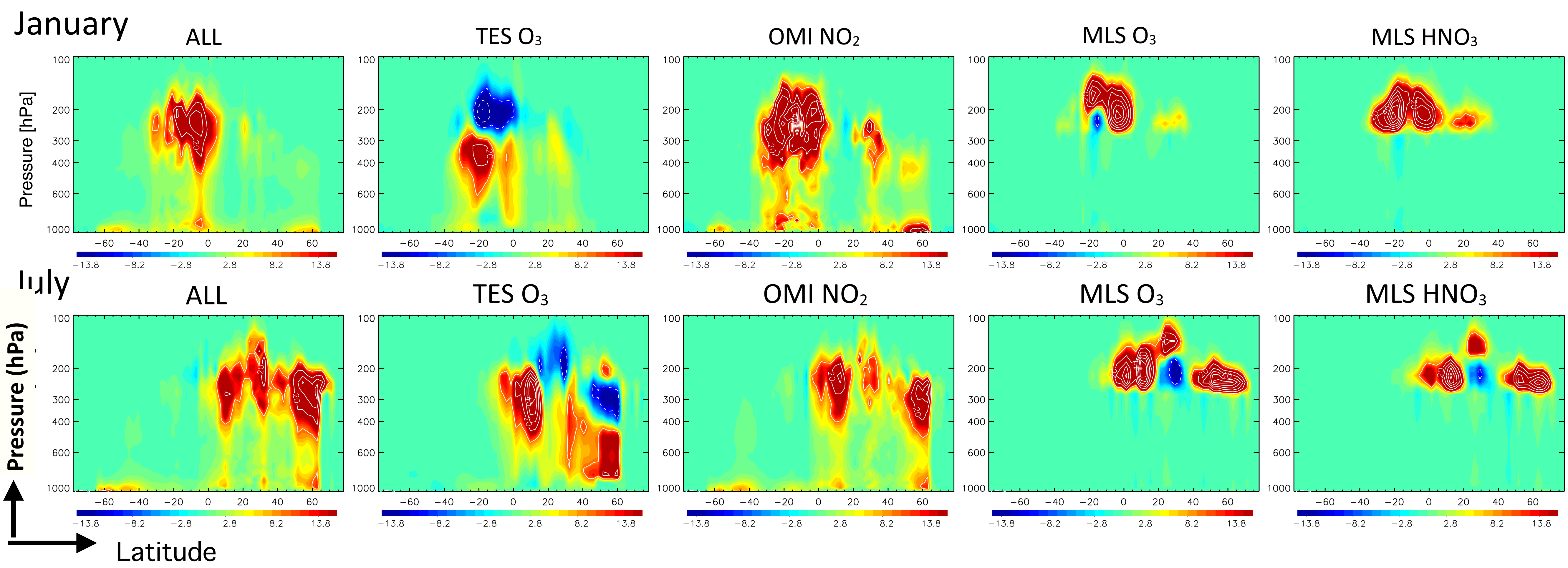
Vertical NO distribution for IC & CG flashes

Total lightning NO profile

(From Folkert Boersma)

# LNOx source increments from OSEs

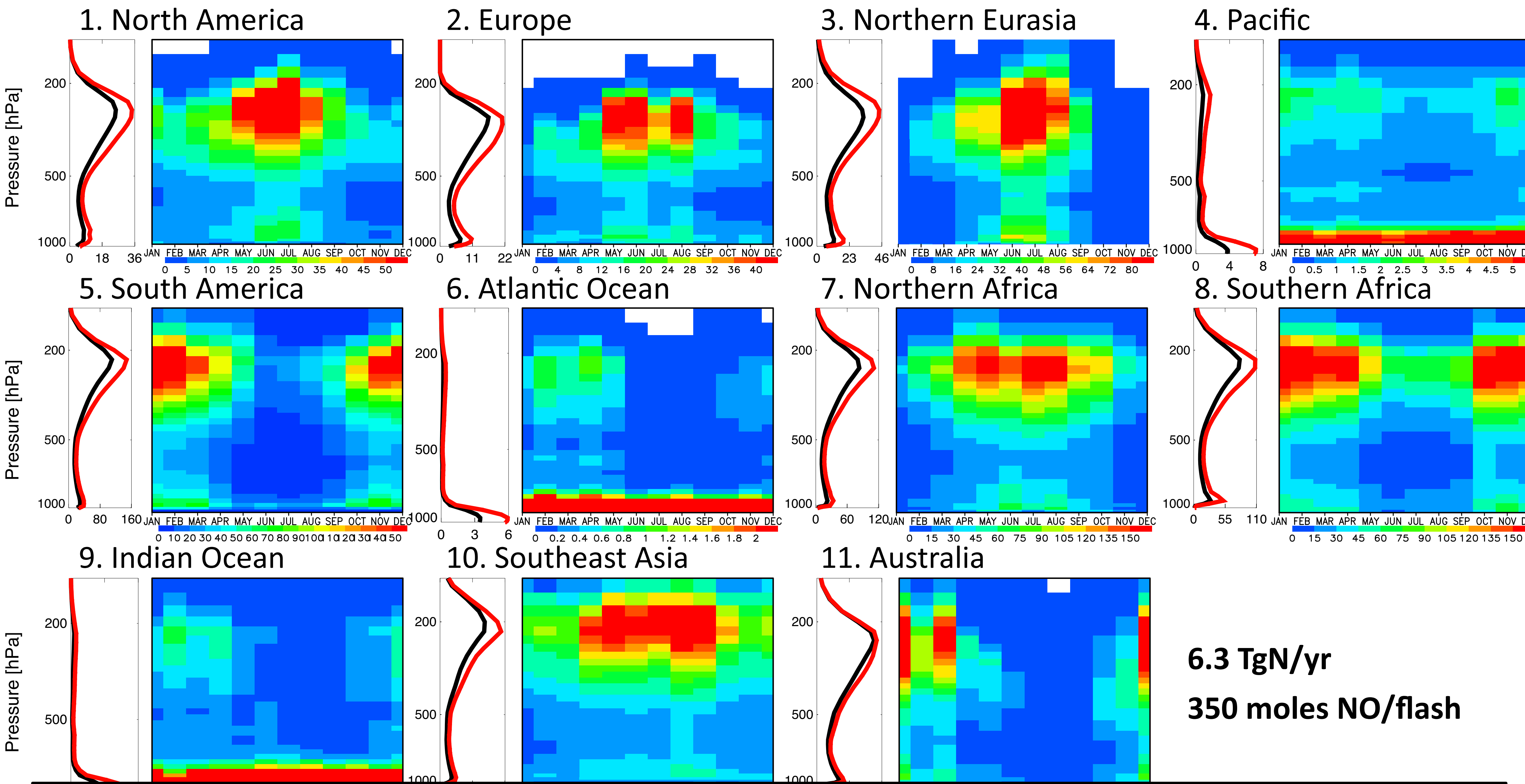
90S-90N & 1000-100hPa cross-section




The combined use of the multiple datasets with different vertical sensitivities etc facilitates the estimation of the vertical LNOx profile and to distinguish between the surface NOx emissions and LNOx sources.

# Seasonal variation of the LNOx sources

(**Bottom-up** and **Top-down**)




**6.3 TgN/yr**

**350 moles NO/flash**

The widely used lightning parameterisation based on the C-shape assumption underestimates the source amounts in the upper troposphere and overestimates the peak source height in the upper troposphere by up to 1 km over land.

# Error estimation

| | January | | | | July | | | |
|---|---|---|---|---|---|---|---|---|
| | NH | TR | SH | GL | NH | TR | SH | GL |
| Control | 0.78 | 3.99 | 1.39 | 6.15 | 4.69 | 2.99 | 0.50 | 8.18 |
| w/ OMI bias | 0.87 | 3.97 | 1.46 | 6.31 | 4.61 | 3.08 | 0.50 | 8.18 |
| TES bias corr. | 0.68 | 3.79 | 1.36 | 5.83 | 4.19 | 2.74 | 0.29 | 7.21 |
| w/o cloud OMI | 0.76 | 4.04 | 1.31 | 6.09 | 4.13 | 2.89 | 0.29 | 7.33 |
| year 1997 SST | 0.76 | 3.89 | 1.37 | 6.03 | 4.71 | 3.06 | 0.51 | 8.26 |
| +20% convection | 0.80 | 3.76 | 1.37 | 5.89 | 4.27 | 2.99 | 0.50 | 8.09 |
| +20% LNOx err. | 0.83 | 3.75 | 1.32 | 5.90 | 4.59 | 2.93 | 0.51 | 8.03 |
| +20% SNOx err. | 0.81 | 3.77 | 1.27 | 5.85 | 4.58 | 2.83 | 0.50 | 7.90 |
| +15% LNOx prior | 0.83 | 4.10 | 1.48 | 6.41 | 5.29 | 3.16 | 0.57 | 9.02 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Total bias | 0.16 | 0.47 | 0.20 | 0.66 | 1.06 | 0.38 | 0.31 | 1.58 |

( and more error sources in the chemical schemes etc (e.g., Stavrakou et al. 2013)

**6.3 ± 1.4 TgN**

c.f. Schumann and Huntrieser (2007) have provided a best estimate of 5±3 TgN

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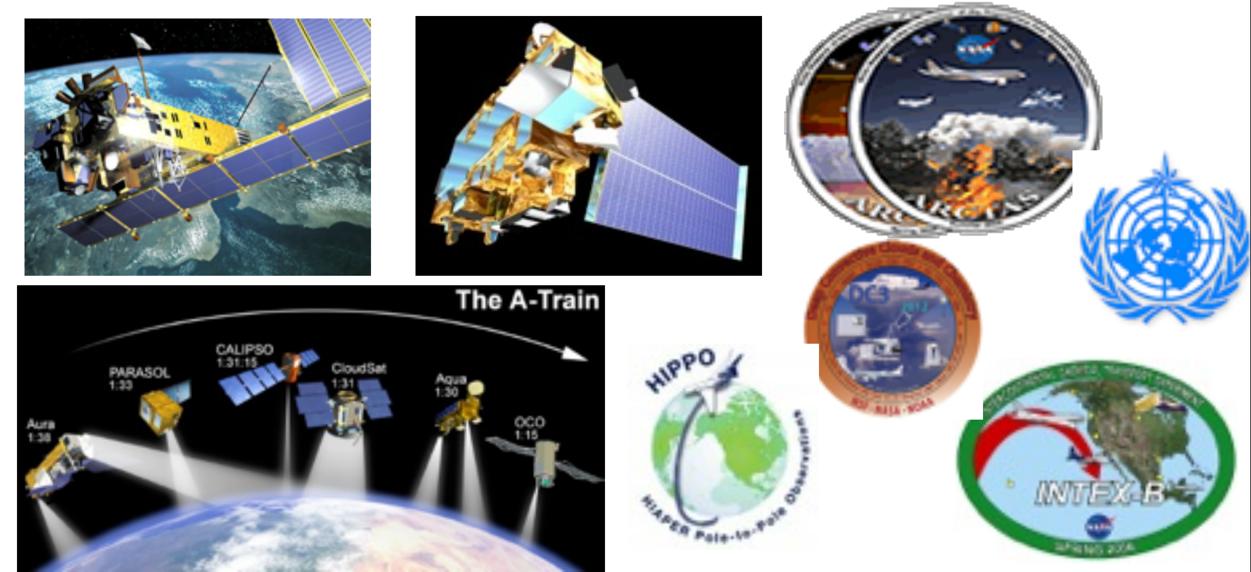
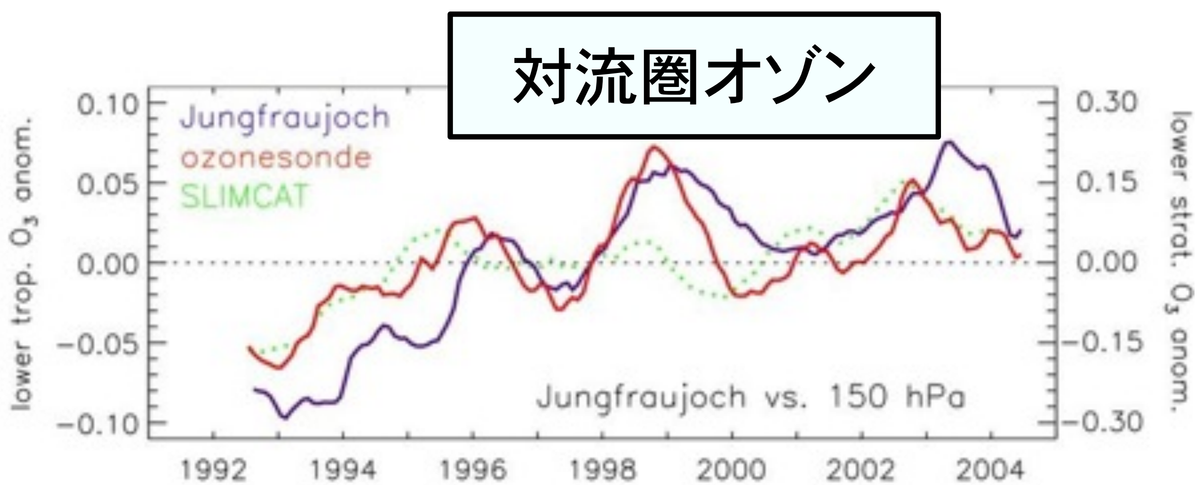
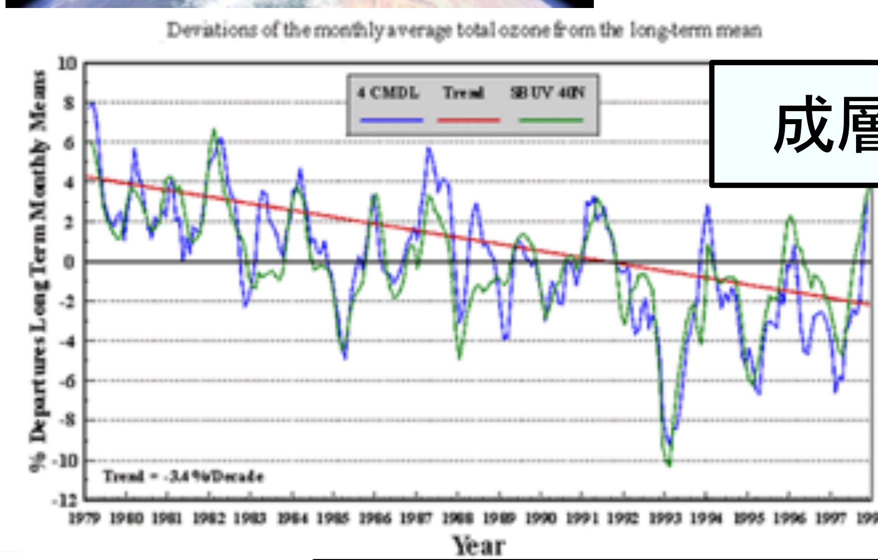
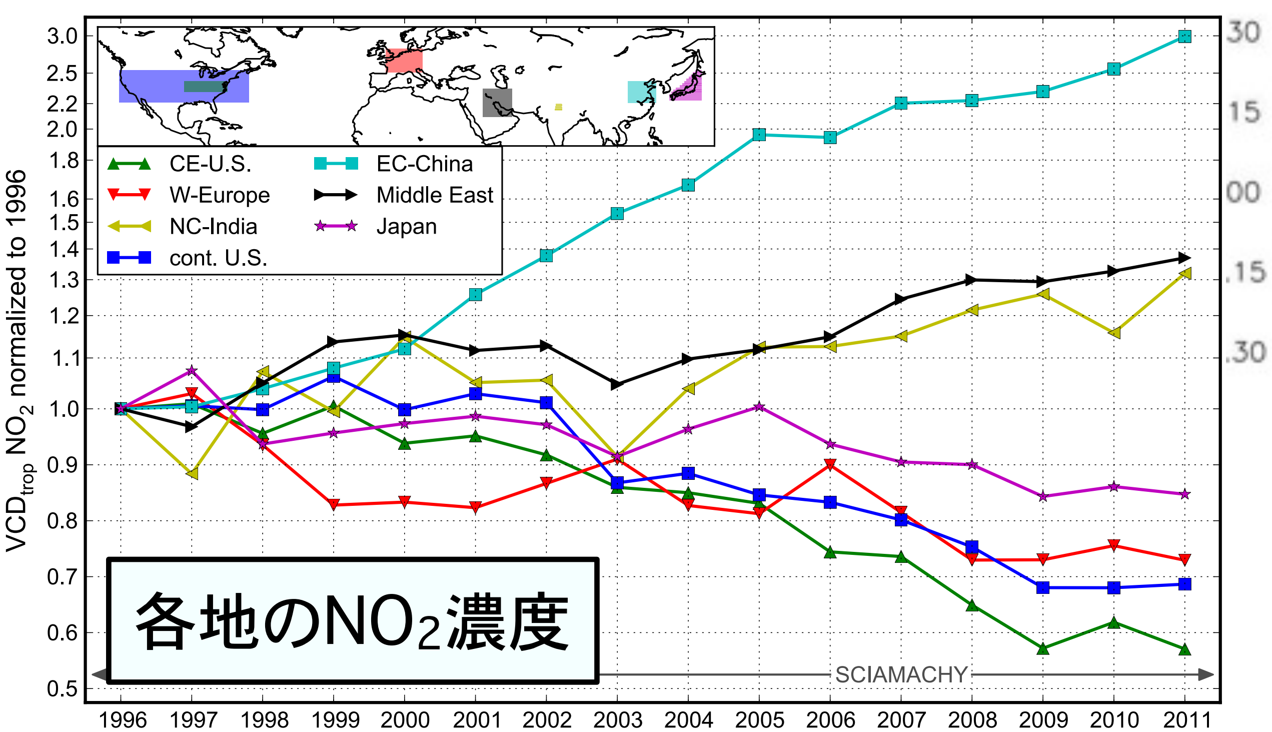
# 大気組成の長期再解析

- 大気汚染物質排出量の長期変動
- オゾン濃度変動要因の理解
- 気候モデル・気象再解析への適用

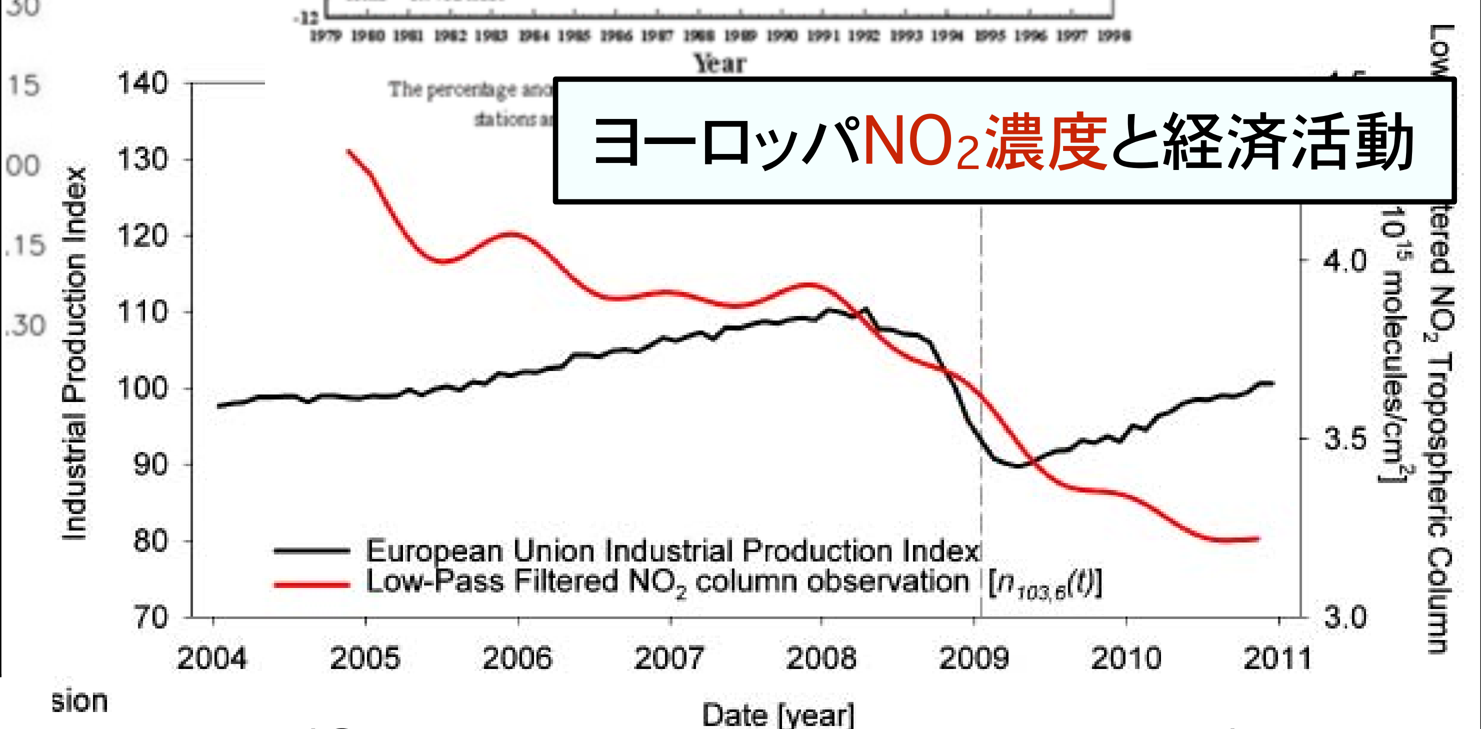



(Hilboll et al, 2013)




(Castellanos and Boersma, 2012)

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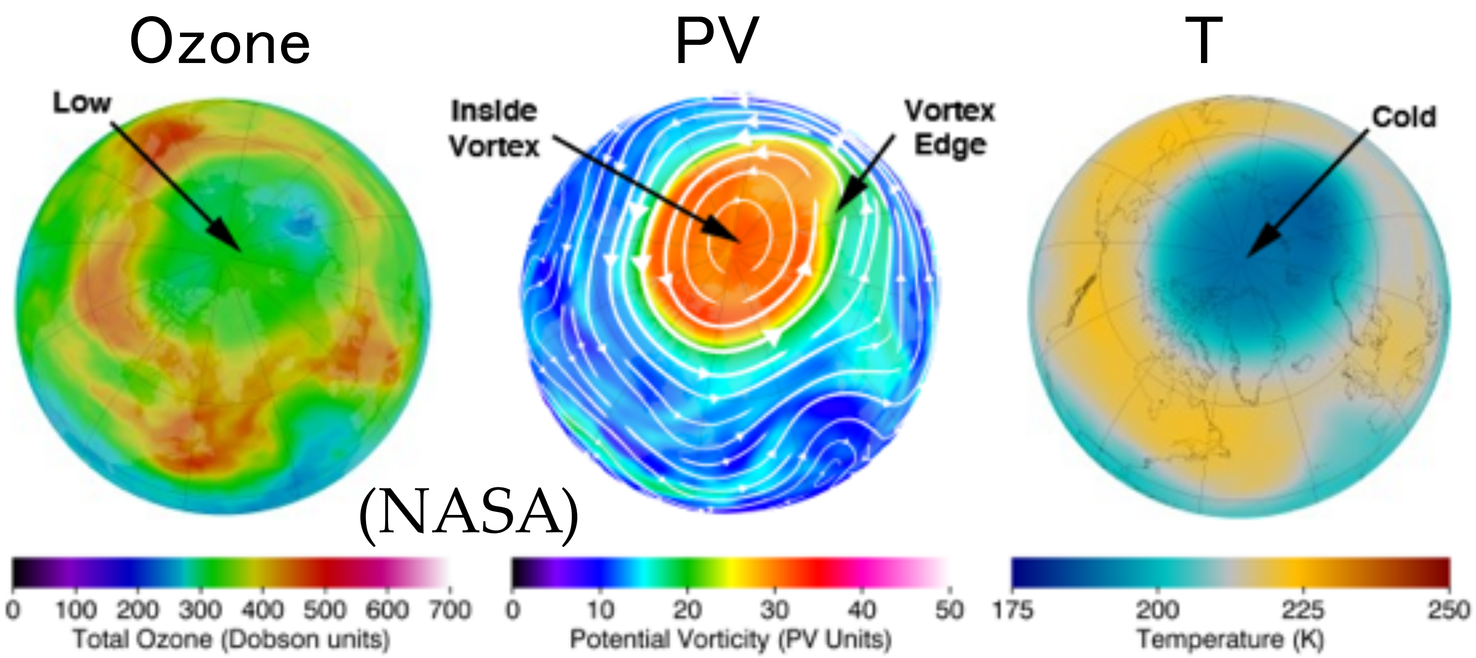
4. 長期再解析の実施

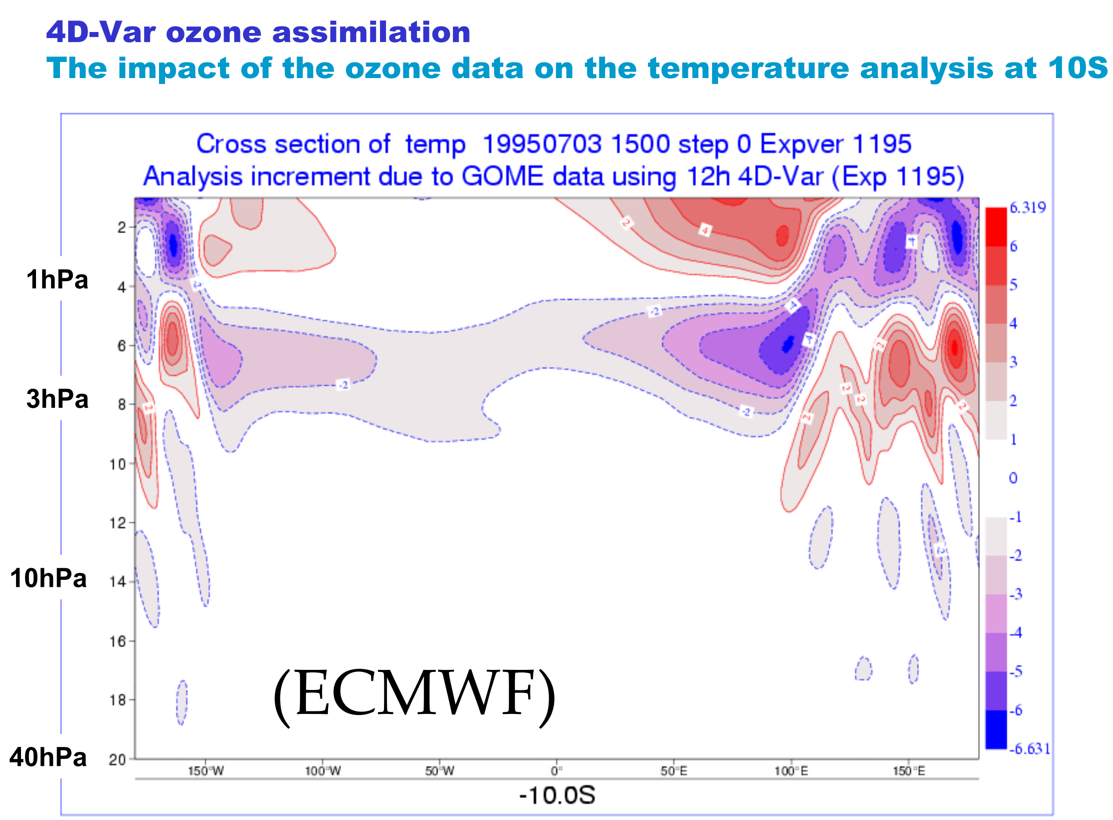
5. 今後の課題

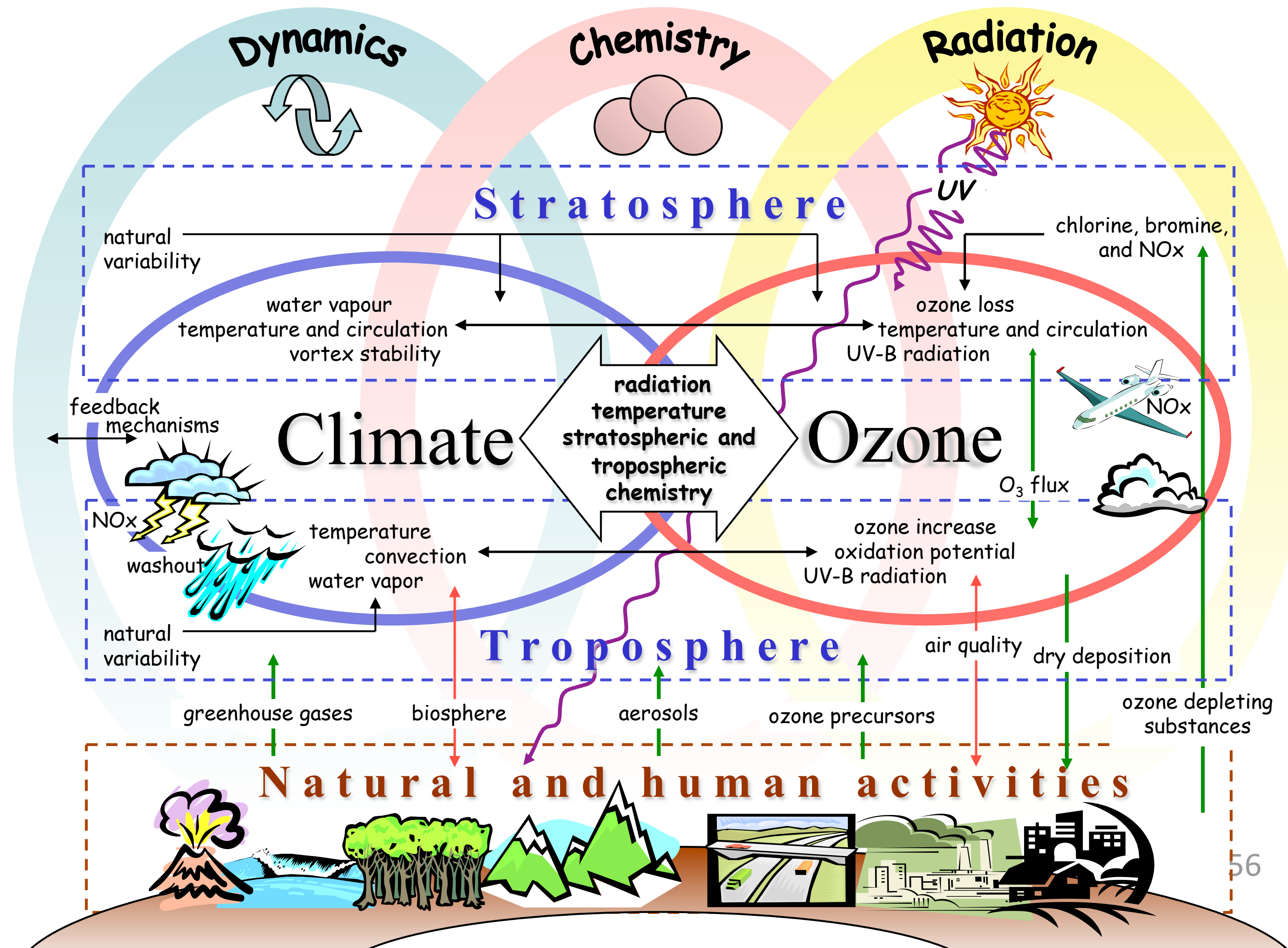
# 大気組成ー気象統合解析




- 放射過程を介した結合
- 大気組成-PV(U)関係
- 気象場不確定性→背景誤差

（気温→反応係数、風→輸送）




[From EU report, 2003]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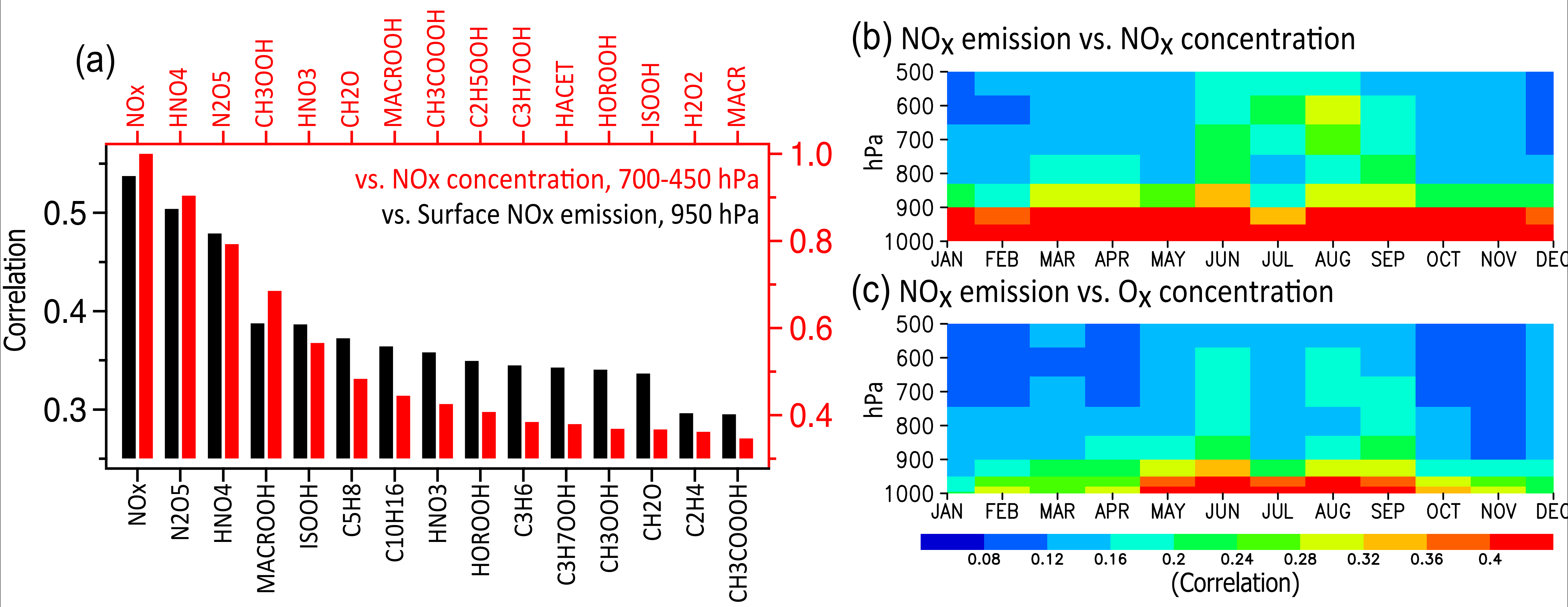
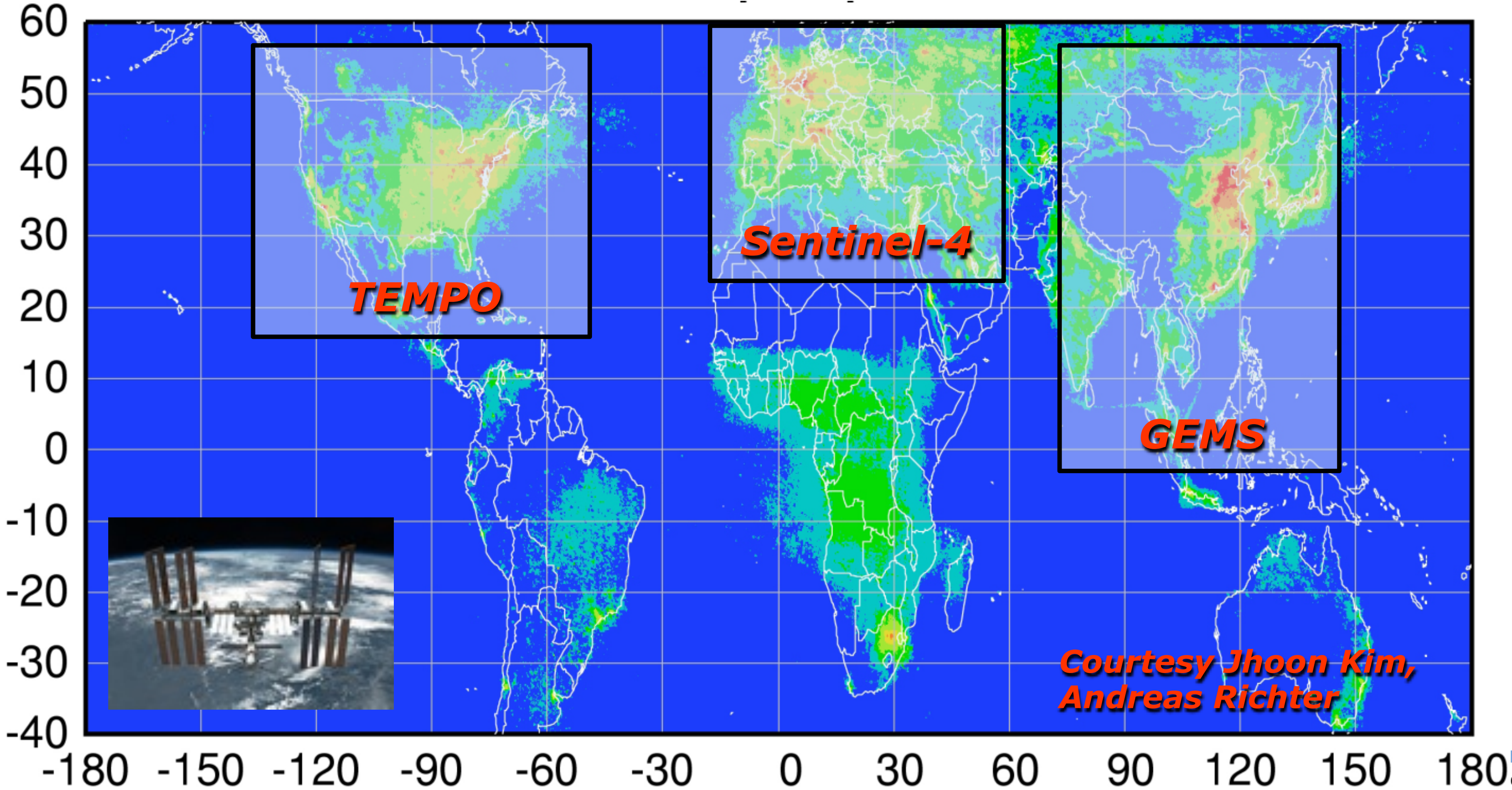
# For further improvements in the emission estimates

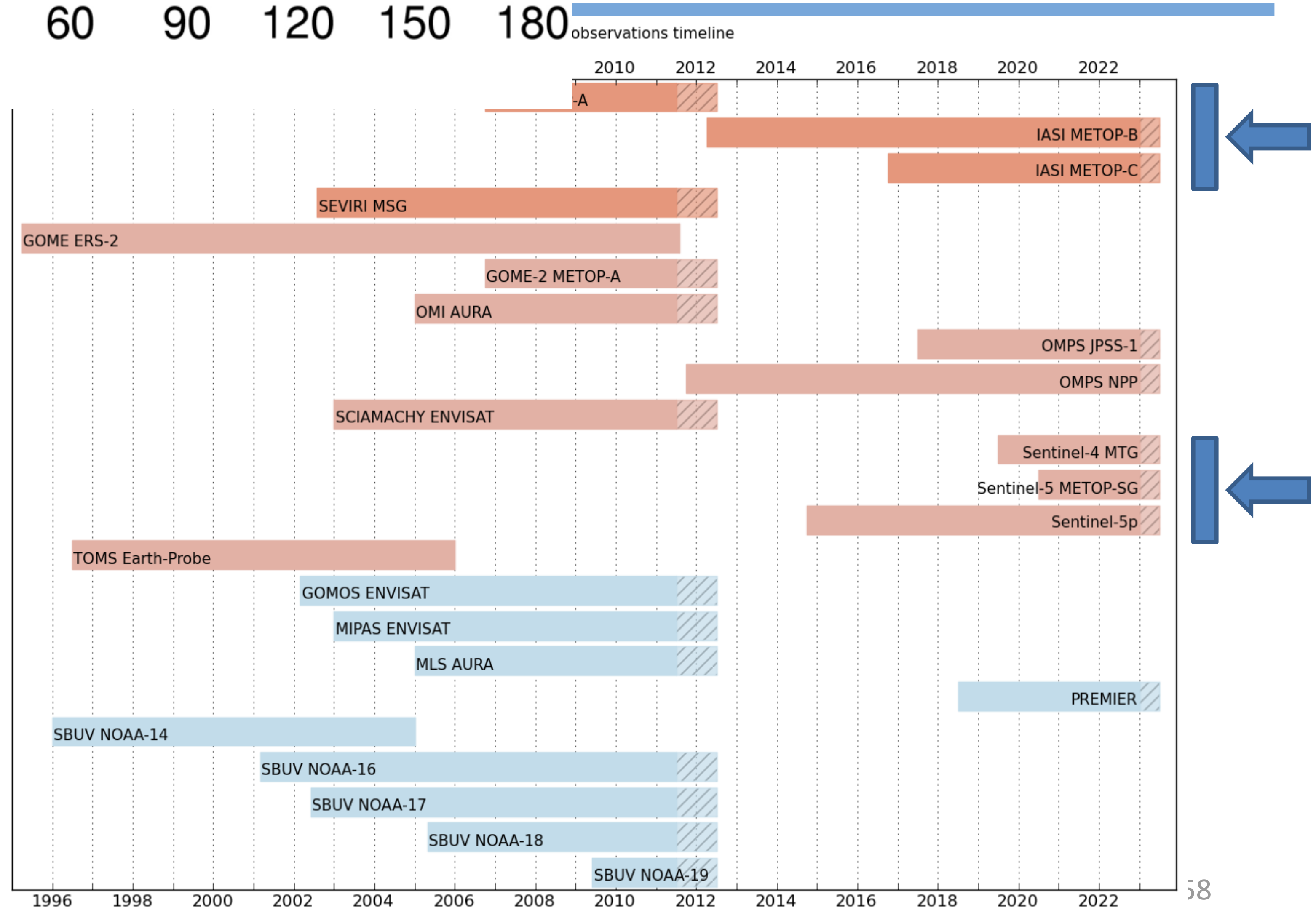



OSSEs with a careful consideration of the complex chemical interactions and measurement characteristics for various species (incl. the seasonality) will support future instrumental design to improve the emission analysis.




# 新たな観測データの利用に向けて

## Past & future - O3




- モデルの高分解能化
- マルチスケール解析
- 衛星・地上観測の統合
- インベントリーとの統合
- 環境政策へ活用

# まとめと今後の課題

- 大気組成データ同化システム CHASER-DAS を開発
- 衛星観測データを統合した長期再解析を実施
- 大気汚染・大気組成変動・気候研究への提供を計画
- 更なる観測データの利用、 将来の観測計画への貢献
- 宇宙開発センターなどとの連携
- 気象解析への貢献も重要