# Biomass burning influences on ozone during the SAMBBA flight campaign.

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**Aims:**

1. Quantify $NO_x$ and $O_3$ concentrations during the Amazon dry season and determine the impact of fires.

2. Validate model data with satellite, aircraft and ground observations.

3. Test the skill of composition assimilation in C-IFS over the Amazon.

# Background: Fire impact on composition

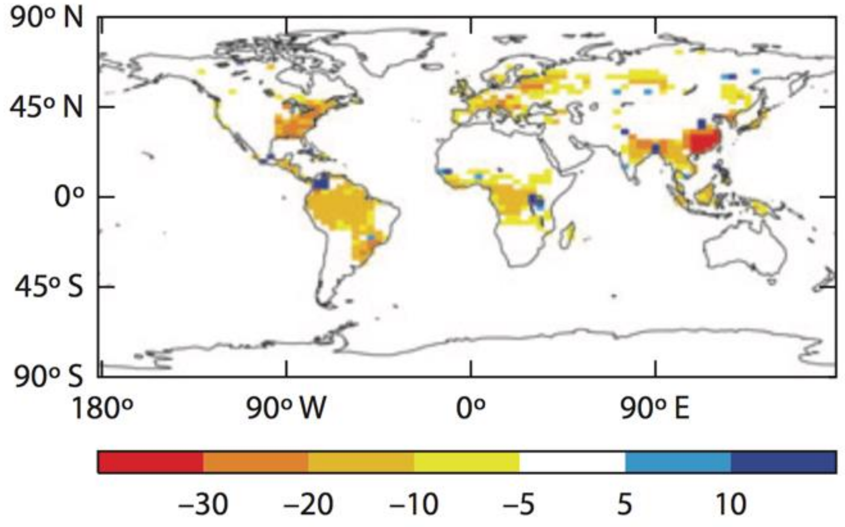
**Amazon biomass burning:**

- During the dry season fires significantly changes **Amazonian** atmospheric composition.
- Emissions of CO, VOCs, NOx and carbonaceous aerosols.
- Both deforestation and cerrado (savannah) fires.
- CO often used as a tracer for fires.

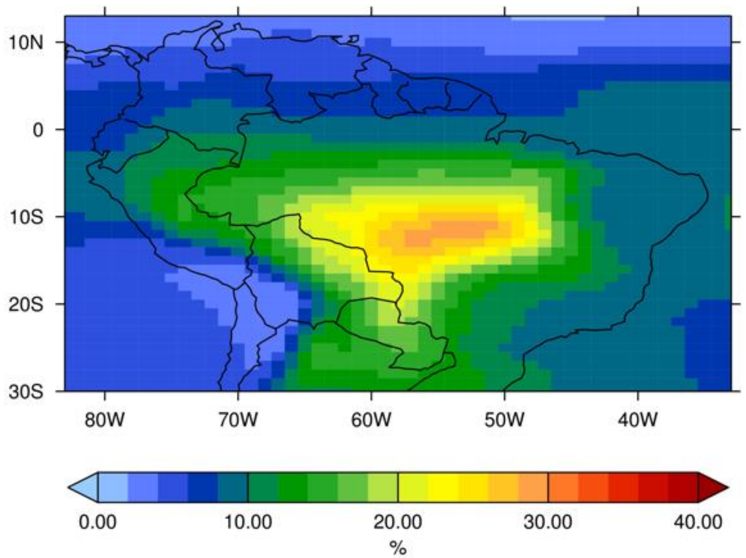
**Ozone ($O_3$):**

- Amazonian background tropospheric ozone **~20ppb**, some of the lowest concentrations on the planet.
- High VOCs concentrations make local $O_3$ concentrations **$NO_x$ limited.**
- Affects **photosynthesis**. Estimated forest sink for $CO_2$ is **2.4 ± pG C $yr^{-1}$** (IPCC).
- Higher $O_3$ concentrations increases the damage to plant stomata (Ainsworth 2012).
- This study: Fires cause an increase in $O_3$ of 30% in the East and 10-20% in West.

**Simulated ΔNPP (%) between 1901 and 2002 due to $O_3$ (Ainsworth 2012)**




**C-IFS Δ$O_3$ from fires: Sept/Oct 2012**

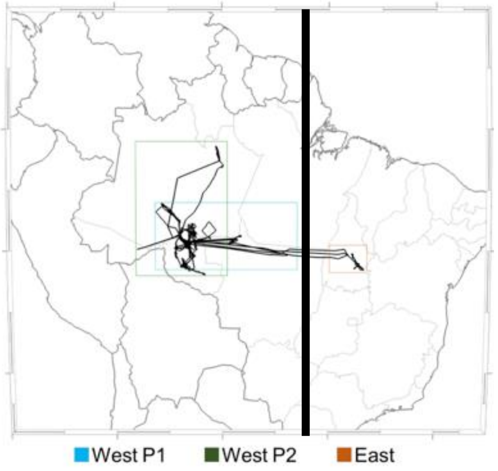


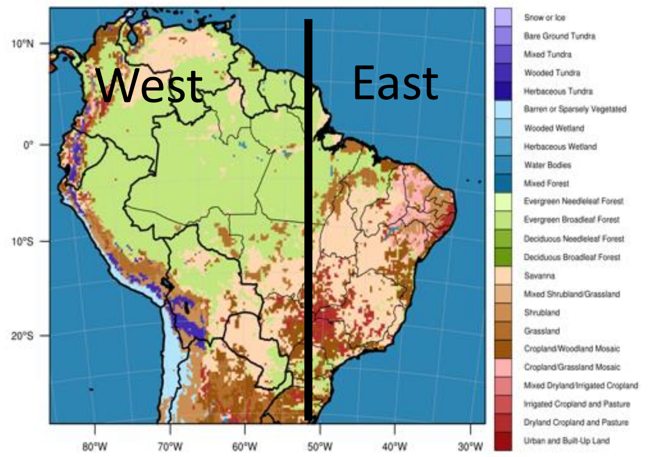
# 2012 Amazonian fire season: SAMBBA campaign

- Flight campaign September/October 2012

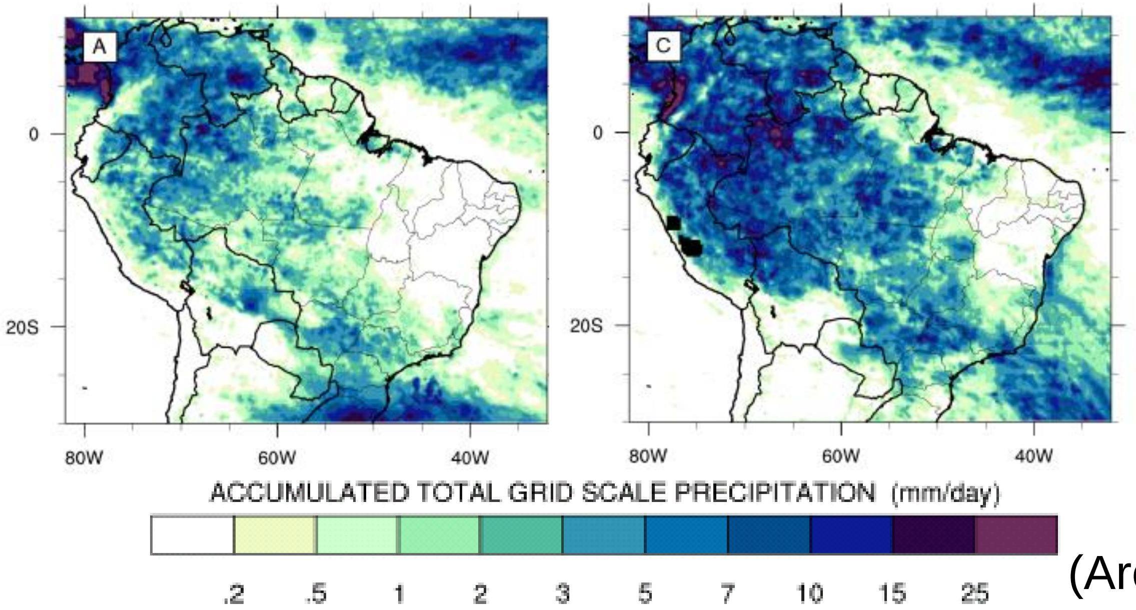
Flight phases:

- Western region: **deforestation** fires
- Eastern region: **cerrado (savanna)** vegetation.
- Phase 1 (04/09/12 - 22/09/12) : Representative of **dry season**
- Phase 2 (23/09/12 - 03/10/12): Transition to the **wet season**.

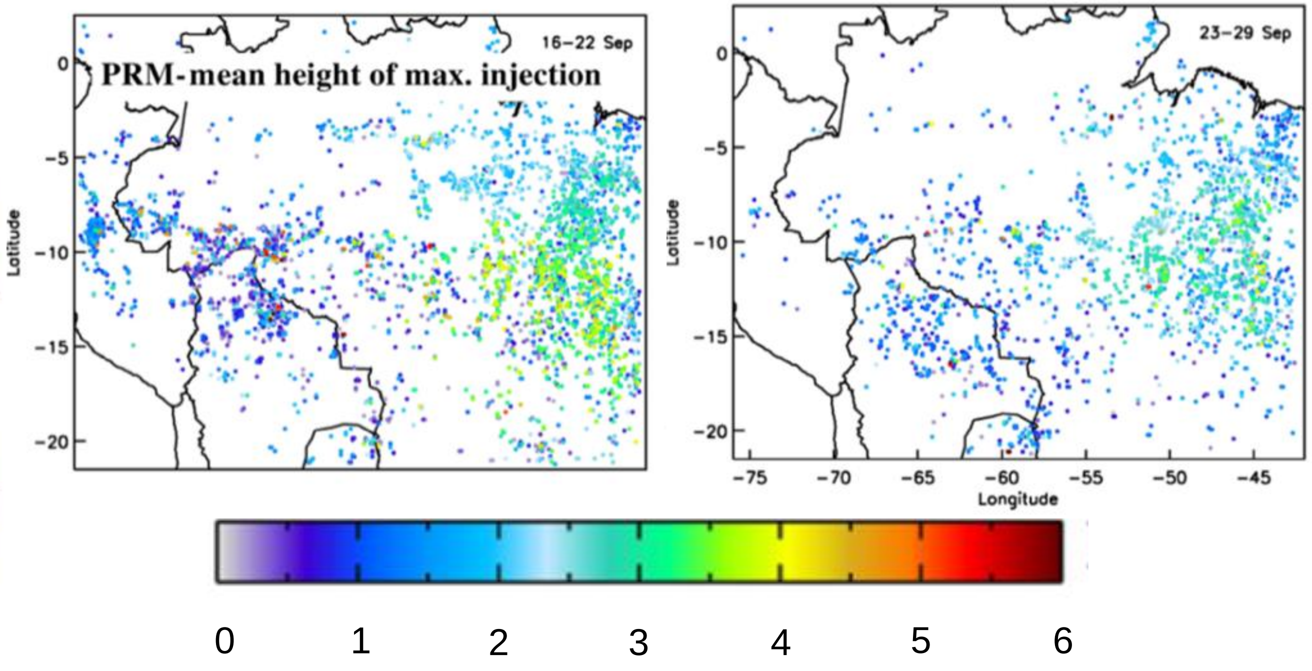



**Phase 1** **Phase 2**



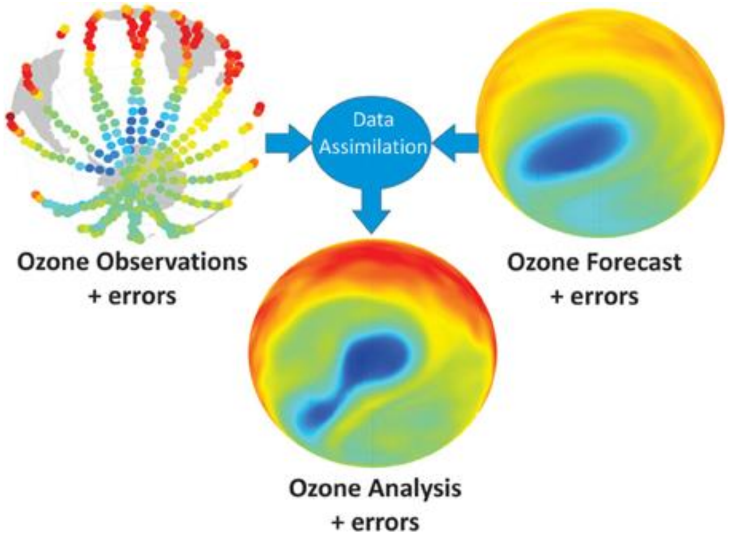

(Archer-Nicholls 2015)




(Remy 2016)

# **Data assimilation**: Introduction

- Combines observational data with an a-priori (model) estimate.
- Combines model coverage with observation accuracy.
- Provides an "analysis" a best estimate for the current state of the system.



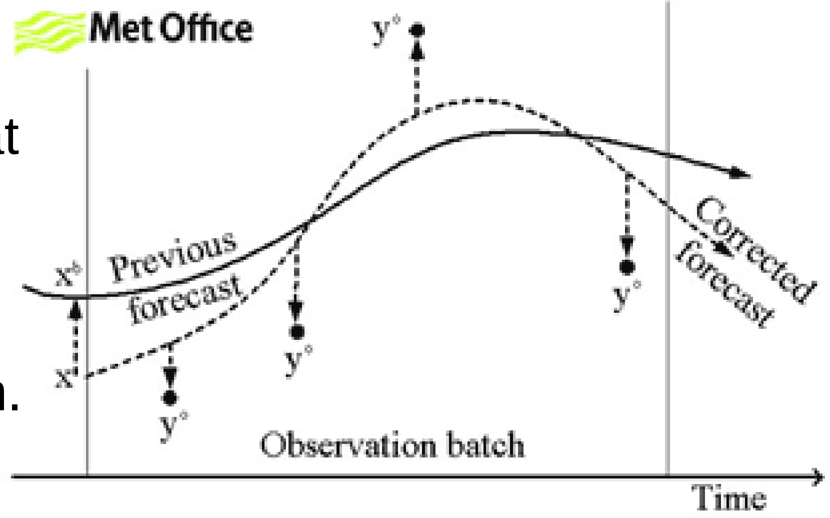

## 4d-var

- Used in ECMWF's NWP: IFS
- Minimises a cost function containing observations a-priori and their respective errors
- Incremental formulation: $$J(\delta x) = \frac{1}{2}\delta x^T \mathbf{B}^{-1}\delta x + \frac{1}{2}(\mathbf{H}\delta x - d)^T \mathbf{R}^{-1}(\mathbf{H}\delta x - d)$$

## Metrics:

- **Analysis increments**: analysis difference from background model at **each** time step.
- (impact of the assimilation of the single composition tracer)

- **Analysis – Control:** provides **total** difference from data assimilation. (impact of other assimilation of other composition tracer ).



# C-IFS Model runs

**Setup:**

- 4d-var data assimilation system.
- T255 spectral resolution ($0.7^o$ x $0.7^o$)
- 60 Vertical levels
- Emissions: Daily **GFAS** fire emissions based on MODIS FRP.
- Emissions know to underestimate Aerosol emissions (Kaiser 2012 and Remy 2016)
- Fire emissions injected at surface.

| Instrument | Species | Type |
|---|---|---|
| MODIS | Aerosols, FRP, burnt area | Total optical depth (AOD) |
| GOME-2 | $O_3$ | Total Column |
| OMI | $O_3$ | Total Column |
| MLS | O3 | Partial profile |
| SBUV-2 | O3 | Partial profile |
| OMI | $NO_2$. | Column |
| MOPITT | CO | Total column |

**Experiments:**

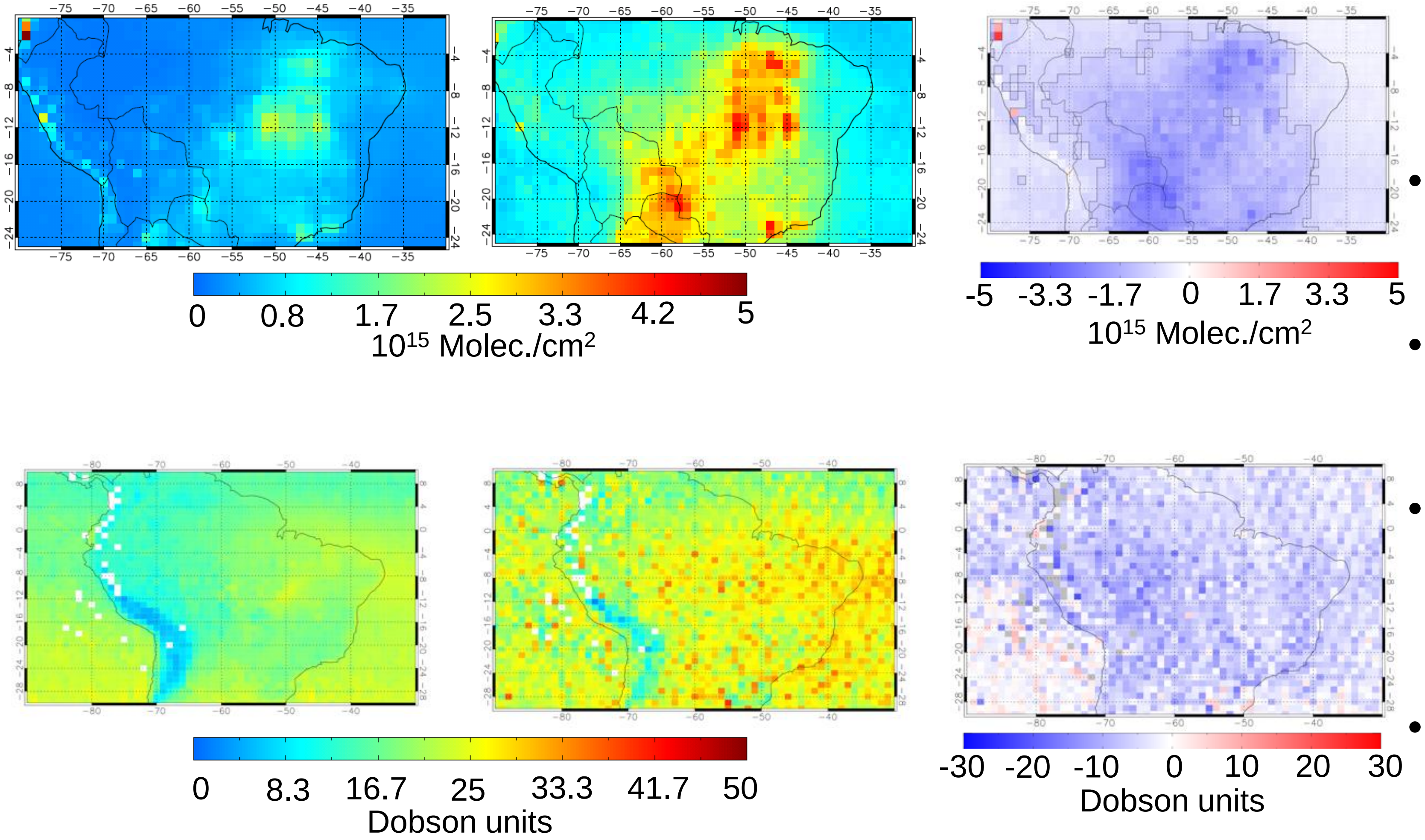
- **Control:** Assimilation of meteorological datasets only.
- **Analysis:** Assimilation of composition and meteorological datasets.
- **NBB**: Control-like experiment without GFAS fire emissions.

# CIFS/Satellite comparisons: Without composition assimilation

CIFS-Control | Satellite | Difference

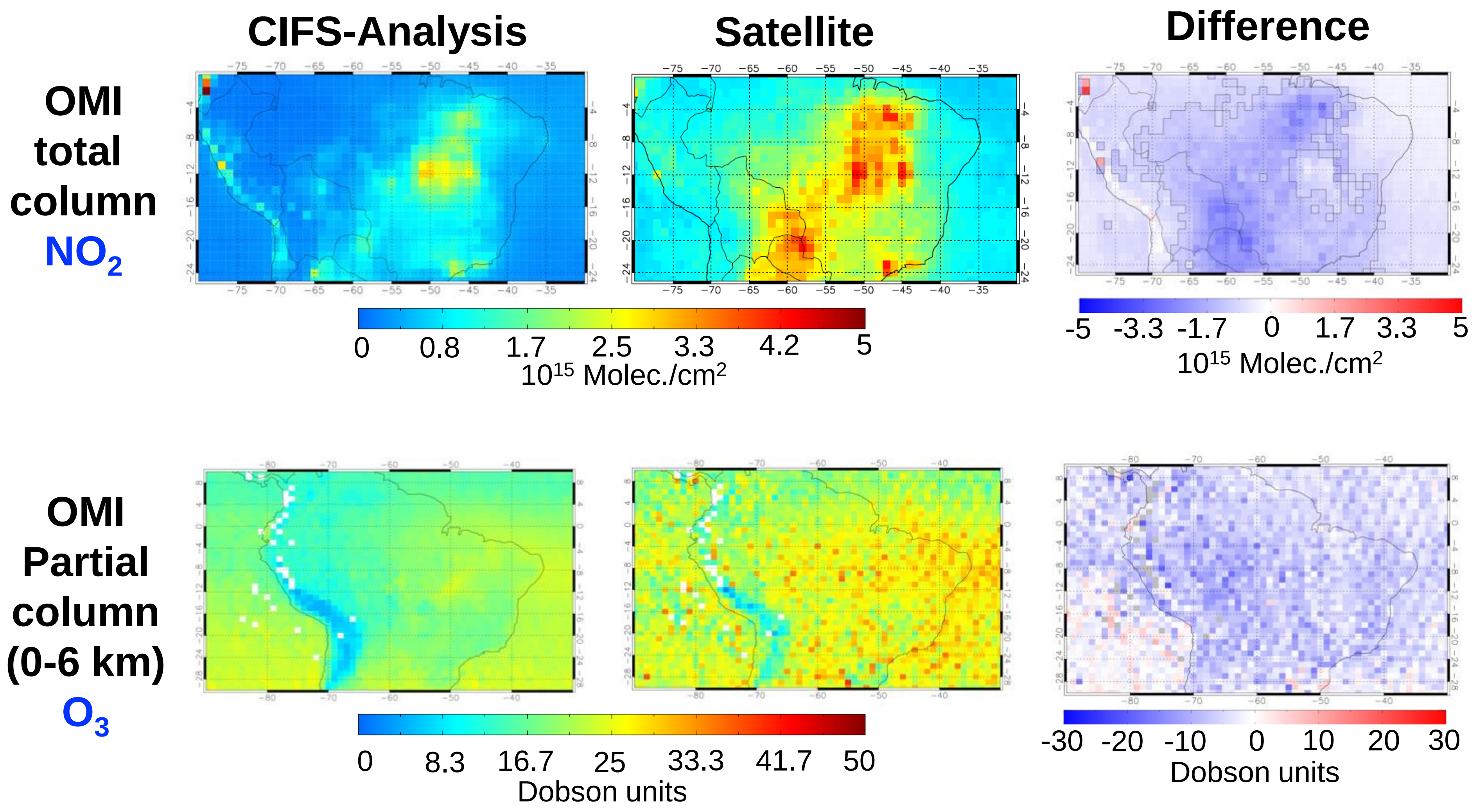
OMI total column $NO_2$

OMI Partial column (0-6 km) $O_3$




- Significant negative bias in C-IFS $NO_2$ and $O_3$.
  - $NO_2$ factor 3.2
- OMI $NO_2$ observed throughout the amazon.
- Higher values in eastern savannah region.
- Little to no modelled $NO_x$ in the western region.
- C-IFS $O_3$ ~10 DU lower than OMI, ~60% of western total.

# CIFS/Satellite comparisons: With composition assimilation

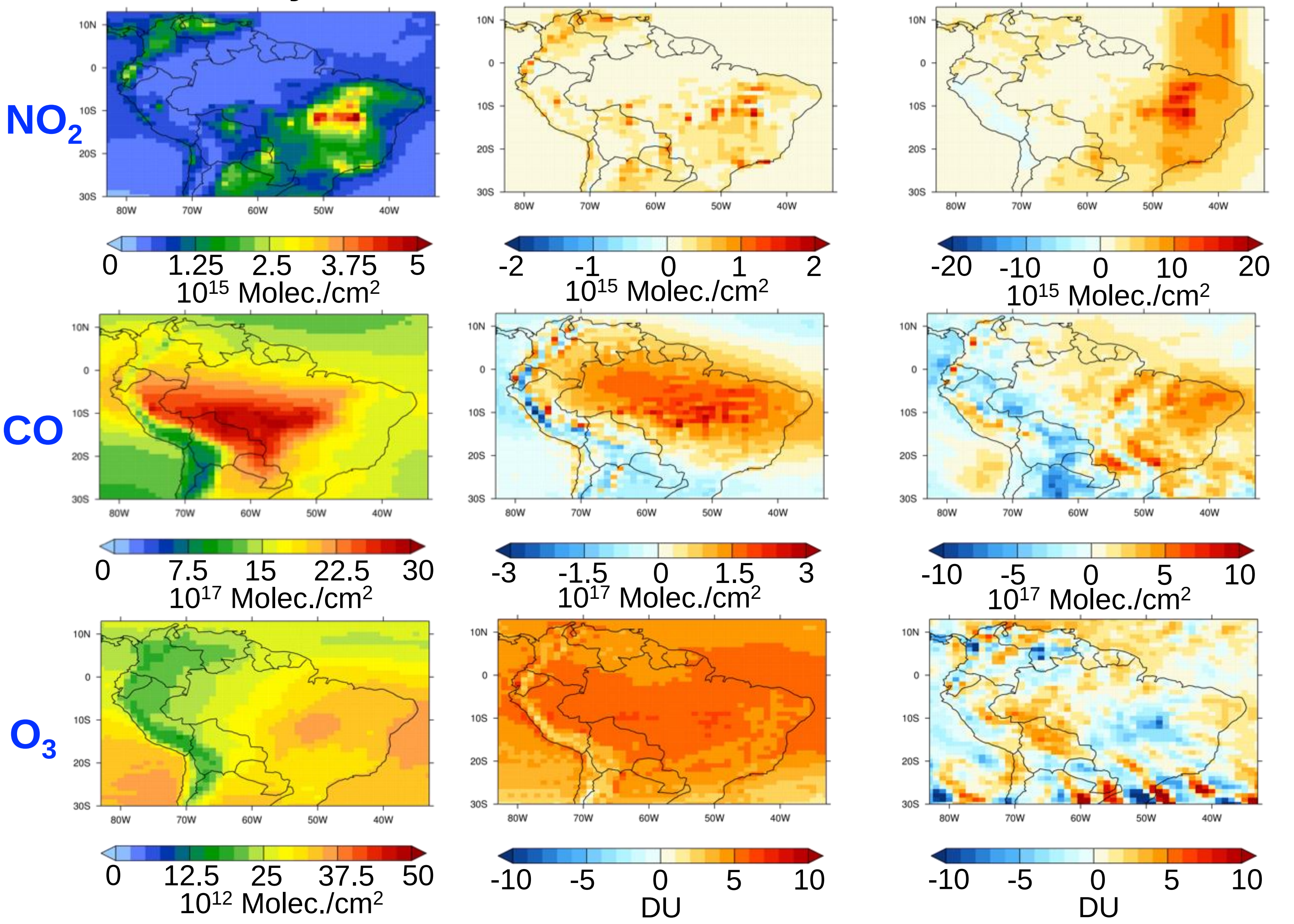



## Analysis

- Increase in $NO_2$ concs. but is still lower than OMI.
- Particularly in the eastern region.
- Western $NO_2$ and $O_3$ still significantly low.
- Smaller bias reduction in $O_3$ than $NO_2$

# Impacts of assimilation: Tropospheric column

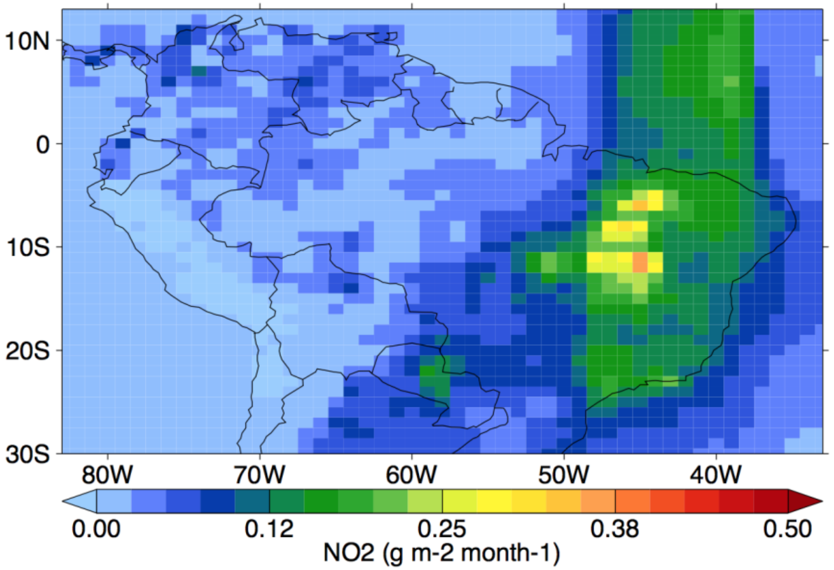
**Average Analysis** | **Average Analysis - Control** | **Daily cumulative Analysis increments**



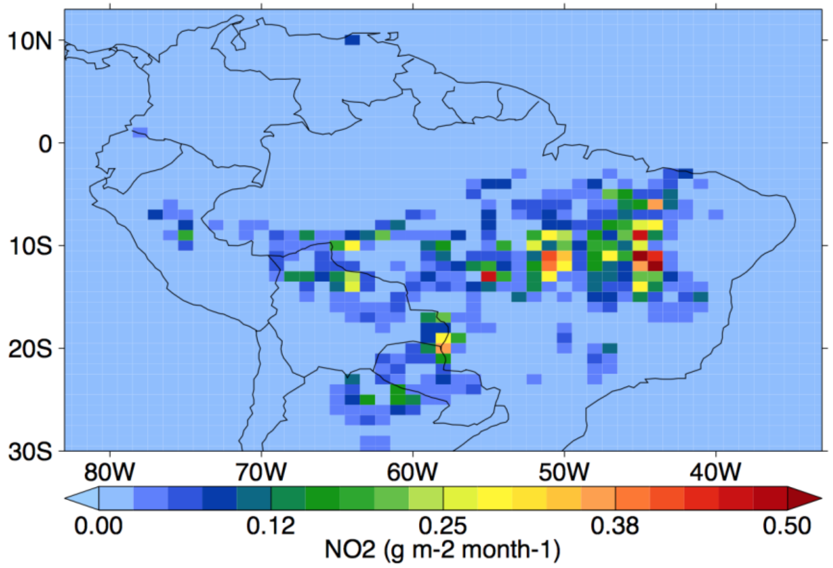

- $NO_2$ increased in ER region, where observations are highest.
- Little to no changes in WR.
- CO also mainly increased in east.
- Smaller CO increments compared to $NO_2$.
- Eastern CO increments dispersed west.
- $O_3$ uniformly increased by same amount.
- Different changes between analysis increments and analysis – control for $O_3$.

# Impacts of assimilation: $NO_2$ total Mass

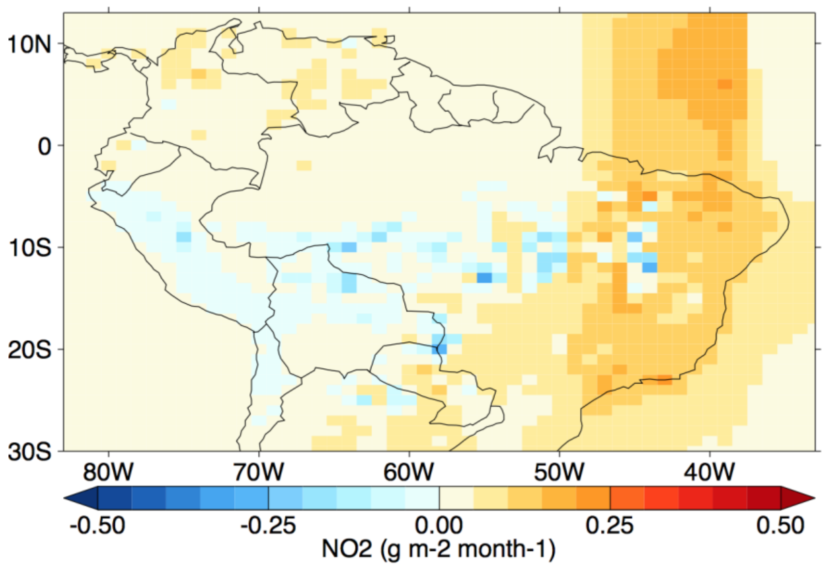
### Analysis increments




### GFAS emissions




### Difference




- 0.056 g m-2 month-1 added by assimilation.
- 0.015 g m-2 month-1 added by emissions.
- Emissions low compared to satellite observations
- Emissions aren’t injected at high enough altitude.

# SAMBBA comparison:

**Average SAMBBA vertical profiles**

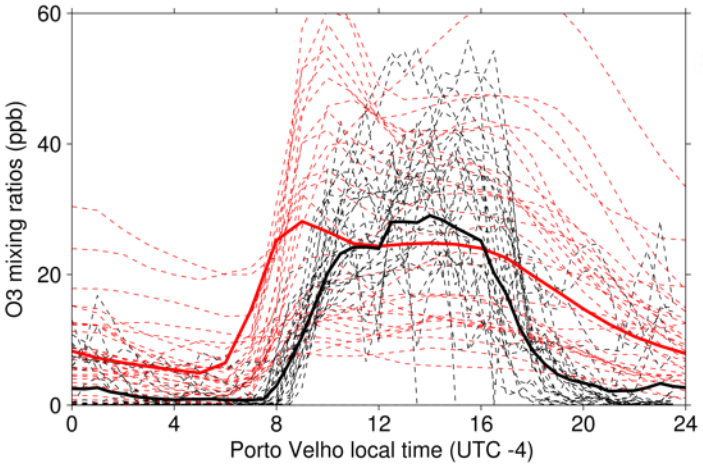
- Obs.
- Control
- Analysis
- NBB

**WR1:** western region phase 1

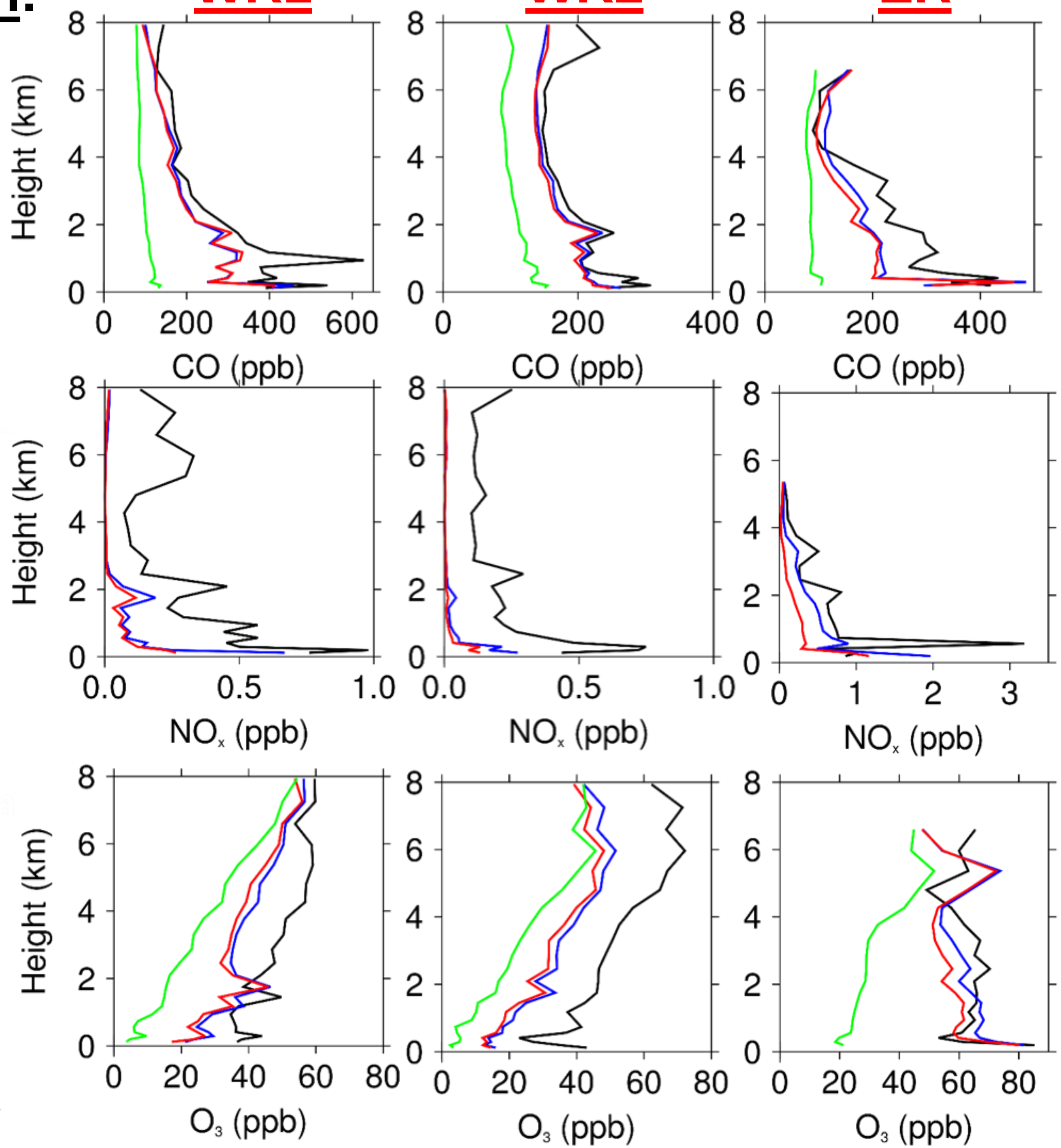
**WR2:** western region phase 2

**ER:** Eastern region

**Porto Velho surface $O_3$**




**WR1** **WR2** **ER**




**CO**

- Well captured wet season.
- Poor vertical structure and large bias in ER.

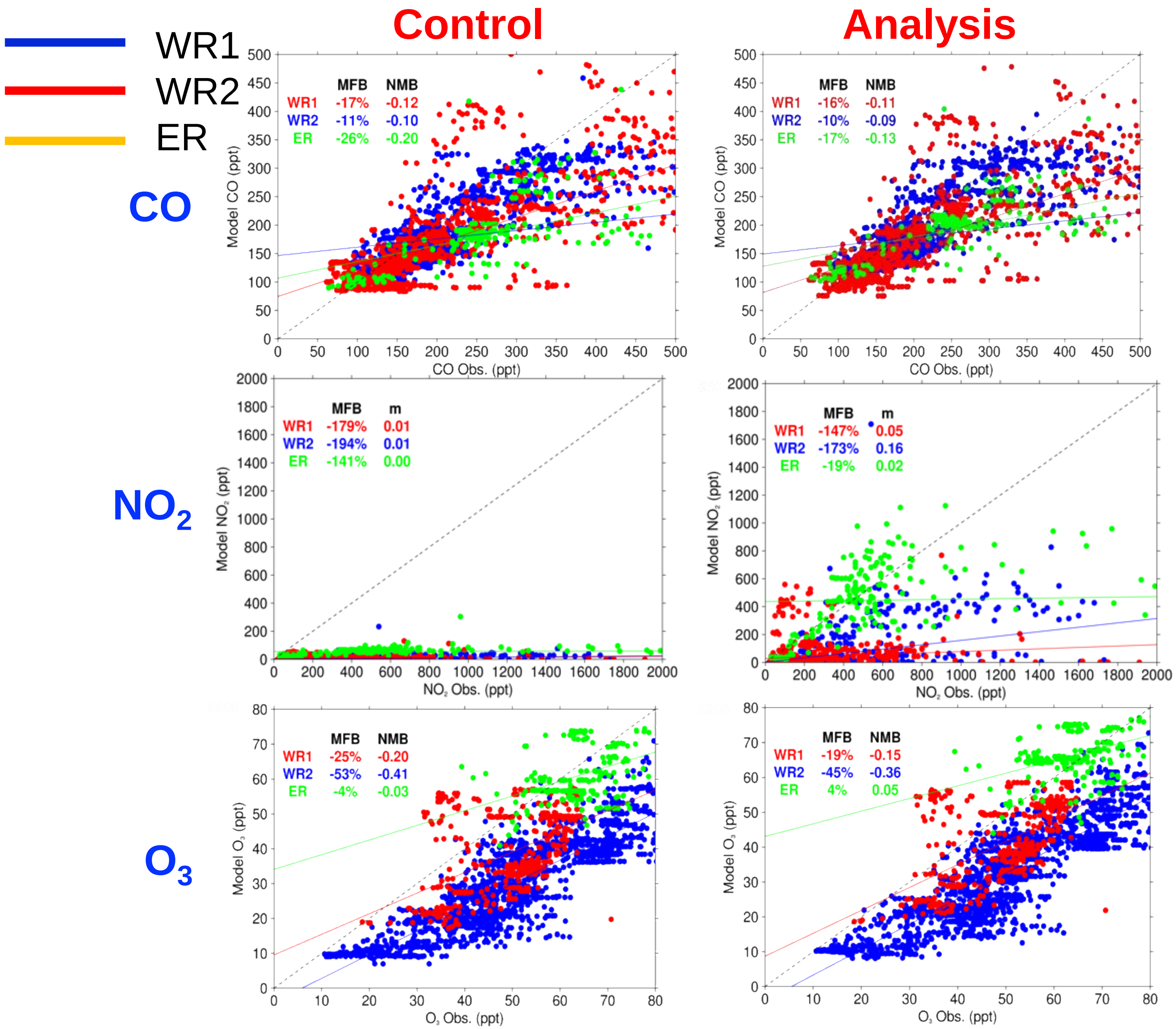
**$NO_x$**

- Negative bias, including above fire injection height.
- ER better rep. after OMI assim.

**$O_3$**

- Large impact from fires near the surface ~30-40 ppb.
- Higher concs. In eastern region.
- Negative bias
- Captures surface conc. during day.
- Night-time bias.

# SAMBBA correlations




## CO

- Well captured in WR2.
- High CO concentrations underestimated in the model and analysis.
- Part of the bias probably due to model injection height.
- Little change from assimilation

## $NO_x$

- Assimilation improves ER representation.
- Higher concentrations have larger bias.

## $O_3$

- Largest underestimation in WR2: The dry season away from fire sources.
- ER slightly overestimated in the analysis.
- $O_3$ MFB reduced by assimilation

# TOMCAT Model runs

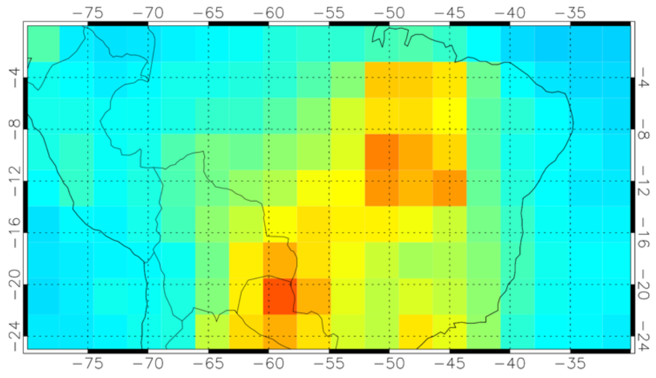
- To test some model sensitivities the TOMCAT CTM is also compared to OMI and SAMBBA observations.
- Monthly instead of daily GFAS fire emissions.
- Lower horizontal and vertical resolution.

**Experiments:**

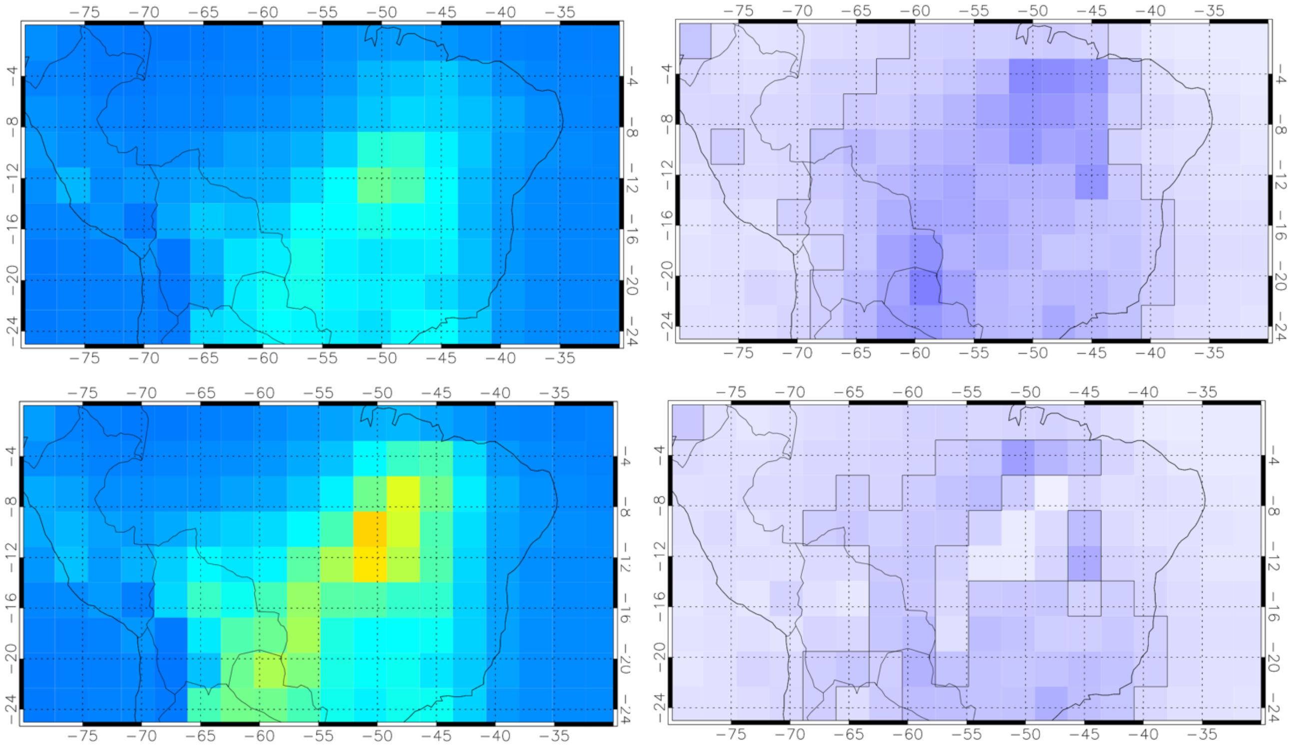
- **Control:** Tomcat run with GFAS fire emissions
- **GFAS x 3.2 :** Perturbed $NO_2$ emissions based on Sat/Model difference

# TOMCAT/Satellite comparisons: $NO_2$

**OMI**
**Partial column**
**(0-6 km)**
**$NO_2$**



**TOMCAT** | **Difference**



**TOMCAT control**

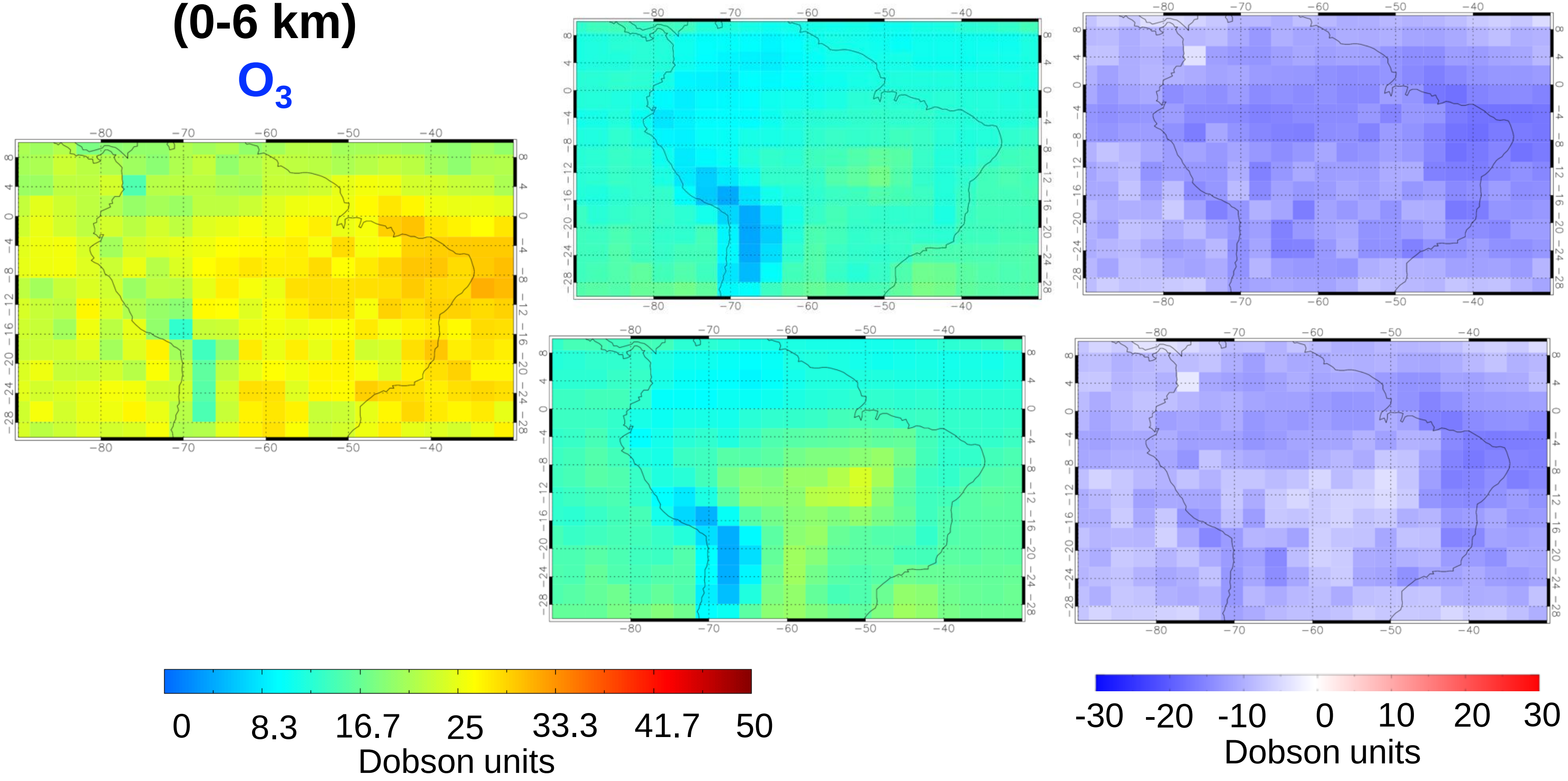
**TOMCAT GFAS x 3.2**


# TOMCAT/Satellite comparisons: $O_3$

**OMI**
**Partial column**
**(0-6 km)**
**$O_3$**

**TOMCAT**

**Difference**



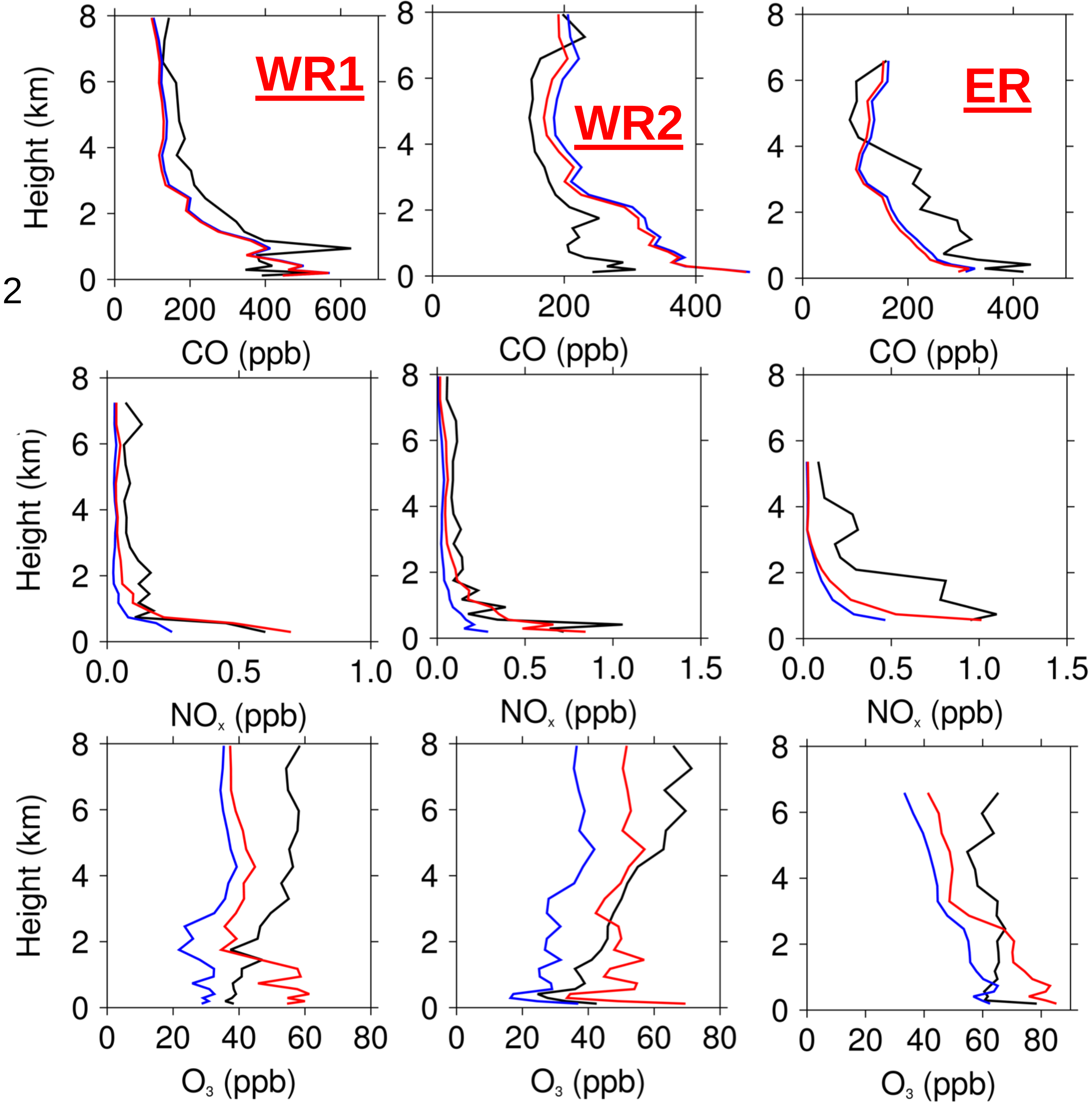

**TOMCAT control**

**TOMCAT GFAS x 3.2**

# SAMBBA comparison:

**Average SAMBBA vertical profiles**

Obs.
TOMCAT
TOMCAT GFAS x 3.2




**WR1:** **western region phase 1**

**WR2:** **western region phase 2**

**ER:** **Eastern region**

# Conclusions

**$NO_x$ and $O_3$ concentrations during the Amazon dry season:**

- Higher $NO_x$ and $O_3$ concentrations over eastern savannah fires than western deforestation fires, but western region shows $NO_x$ concentrations throughout the tropospheric profile.
- Model predicts a large contribution of fires to $O_3$ concentrations: ER (30%) and WR (10-20%)

**Model skill:**

- CO is generally well captured by the model, suggesting fires are well detected in GFAS.
- C-IFS $O_3$ captures day time surface concentrations but underestimates satellite and in-situ aircraft observations.
- Overestimation of $O_3$ night time values: potential model underestimation of local $O_3$ loss rates.
- Mid-tropospheric $O_3$ bias most likely due to low modelled $NO_x$
- Perturbing $NO_x$ fire emissions by 3.2: still an underestimation of total column $O_3$, but now an overestimation of boundary layer $O_3$.
- NOx bias either from injection of emissions or another emission source (e.g. lightning).

**Composition assimilation:**

- Assimilation of $NO_2$ and $O_3$ satellite fields improves model representation in the Eastern savannah region against in-situ and satellite observations.
- Changes in O3 values most likely due to NO3 assimilation changes than from O3 total column assimilation.
- Despite a small improvement in the western region, a significant negative bias still remains.