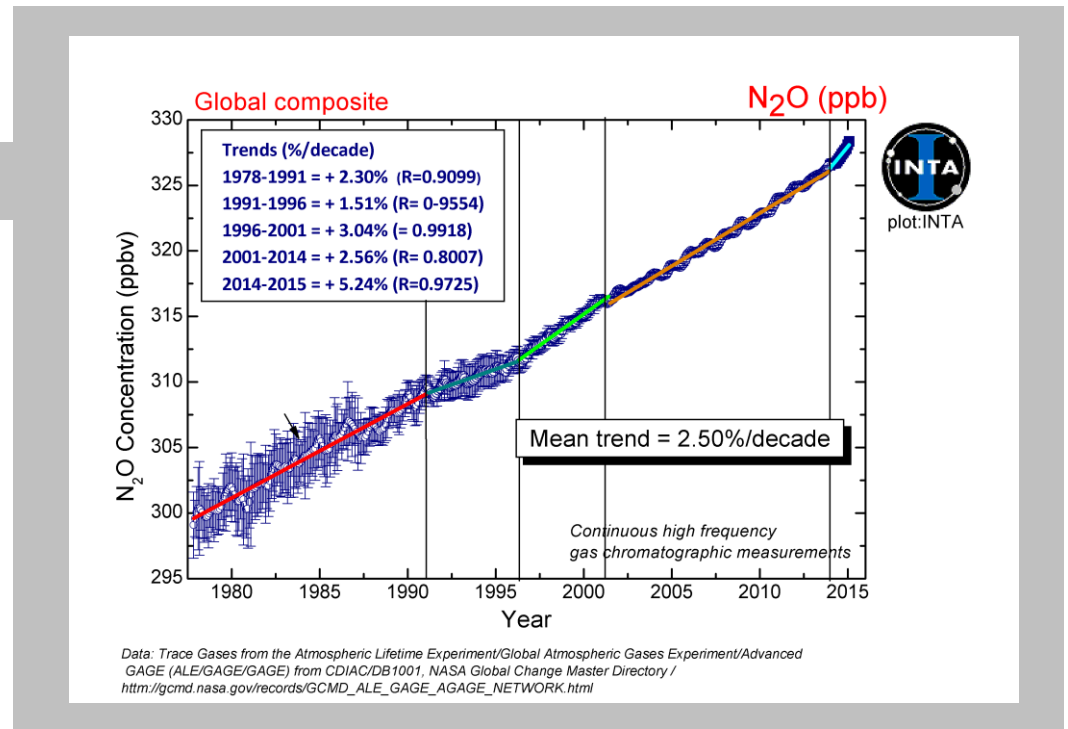


# NO<sub>2</sub> VCD Stratospheric trends: Hemispheric and latitudinal dependence

*M. Gil-Ojeda, M. Yela, M. Navarro, C. Robles, F. Hase, B. Funke,  
O. Puentedura, J. Iglesias, E. Cuevas.*

# Motivation

## *Background concentration of N<sub>2</sub>O*



- + N<sub>2</sub>O increasing at a steady rate of 2.20%/decade in last 36 years (1978-2015)
- + No signs of damping.
- + Lifetime of 120-150 years
- + Major contribution to NO<sub>x</sub> in the stratosphere
- + Signature of increase should be observed on long NO<sub>2</sub> VCD records

# INTA Stations for stratospheric monitoring

+ Zenith DOAS at twilight

+ Background stations in clean environments:  
tropospheric NO<sub>2</sub> by pollution not an issue

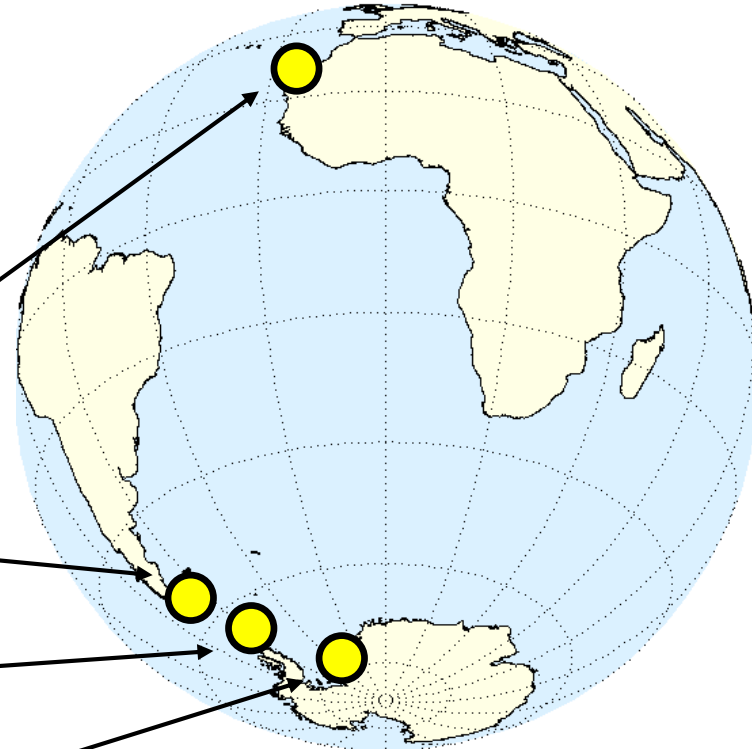
28°N. Izaña: FT NO<sub>2</sub> (20-40 pptv)

54°S. Ushuaia -> GAW in the Beagle  
channel

64°S. Marambio -> Seymour Island.  
Antarctic Peninsula

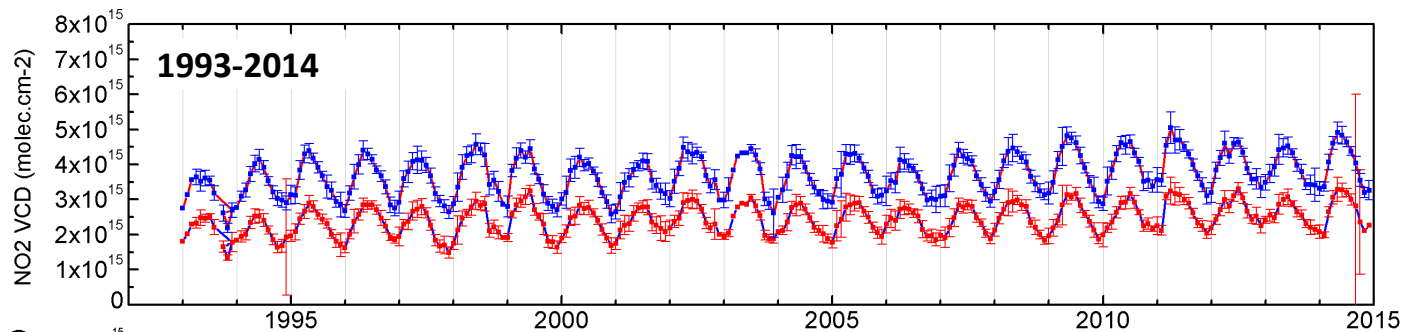
78°S. Belgrano -> Antarctic mainland

+ NDACC or NDACC applied instruments.

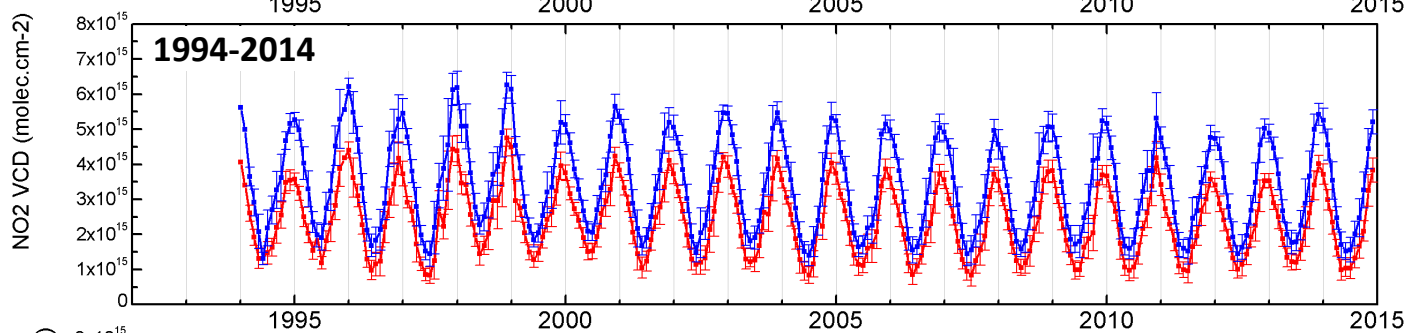


# Datasets

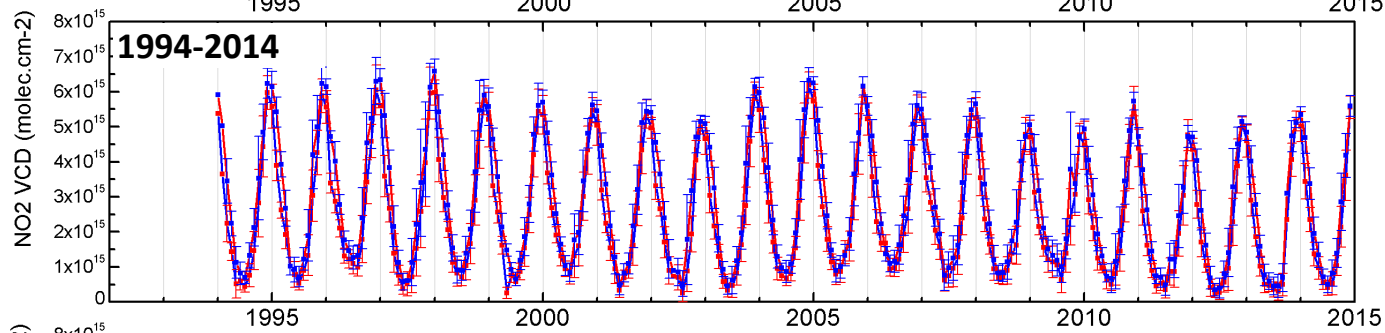
Izaña (28°N)



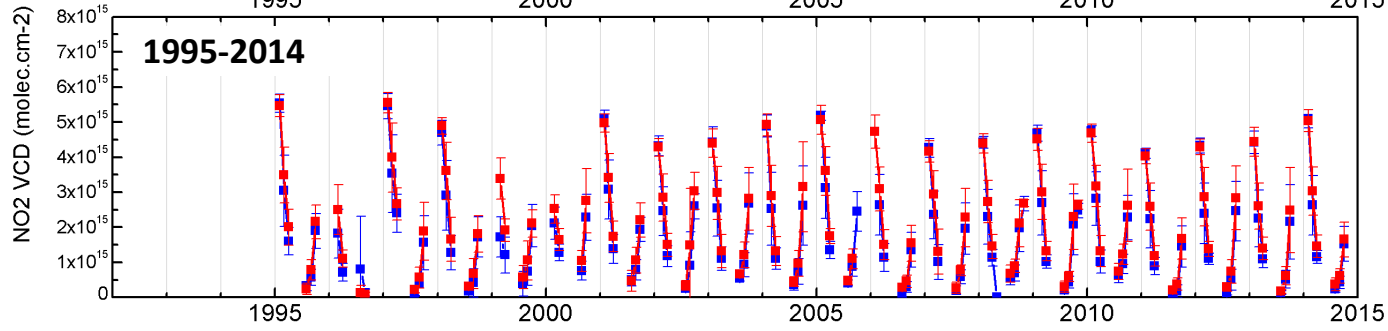
Ushuaia (55°S)



Marambio (64°S)



Belgrano (28°N)



# Multiple regression

Statistic model (Stolarski,1991, Brunner,2006, Bodeker,1998, 2001

$$Y(t) = a + \beta_0 t + \underbrace{\sum_{K=1}^2 \left[ \beta_{2k-1} \cdot \sin\left(2\pi t \frac{k}{12}\right) + \beta_{2k} \cdot \cos\left(2\pi t \frac{k}{12}\right) \right]}_{\text{seasonality}} + \underbrace{\sum_{j=5}^{m+4} \beta_j X_j(t)}_{\text{Other predictor terms}} + \varepsilon(t)$$

trend
seasonality
Other predictor terms
residual

$Y(t)$  = NO<sub>2</sub> measured column in t time

a = intercept (offset)

$X_j$  = explanatory function (Predictor)

$\beta_j$  = Coefficient of the explanatory function  $X_j$

t = time from measurements start (in months)

$\varepsilon$  = noise in time t

$$\hat{\beta} = (X'X)^{-1} X'Y$$

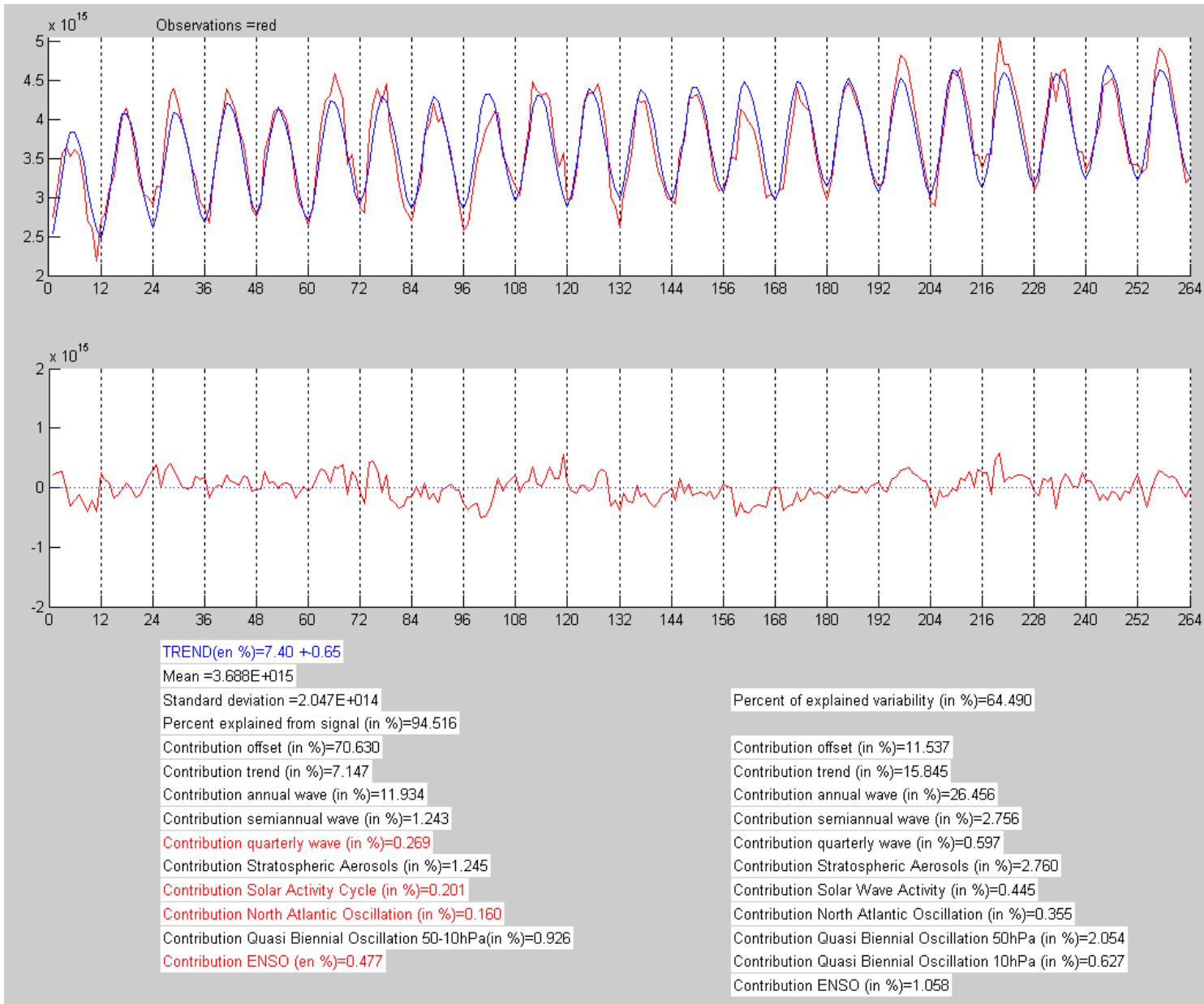
Monthly means data used for the analysis

Consideration of model errors and auto-correlations as described in Stiller et al., 2012.

# Predictors:

- Offset (a)
- Trend ( $\beta_0 \cdot t$ )
- Seasonal terms (annual, semiannual, quarterly)  $Y(t) = \sum_{k=1}^2 \left[ \beta_{2k-1} \cdot \sin(2\pi t \frac{k}{12}) + \beta_{2k} \cdot \cos(2\pi t \frac{k}{12}) \right]$
- Solar activity (10.7cm flux) -> Penticton radio flux data stored in GCMD/NASA
- QBO (10hPa and 30 hPa zonal winds over a mean of 3 tropical stations, 2 quasi-orthogonal predictors) -> Berlin\_FU.
- Stratospheric aerosols optical thickness (Sato et al. 1998) -> Stored in GISS/NASA.
- ENSO (multivariate ENSO index MEI) -> (MEI variables: SAT, SST, Wind, Pres, Clouds) -> NOAA (*Wolter and Timlin, 1993, 1998*) stored in GCMD/NASA
- NAO (Monthly normalized index from CPC.NOAA (NCEP))

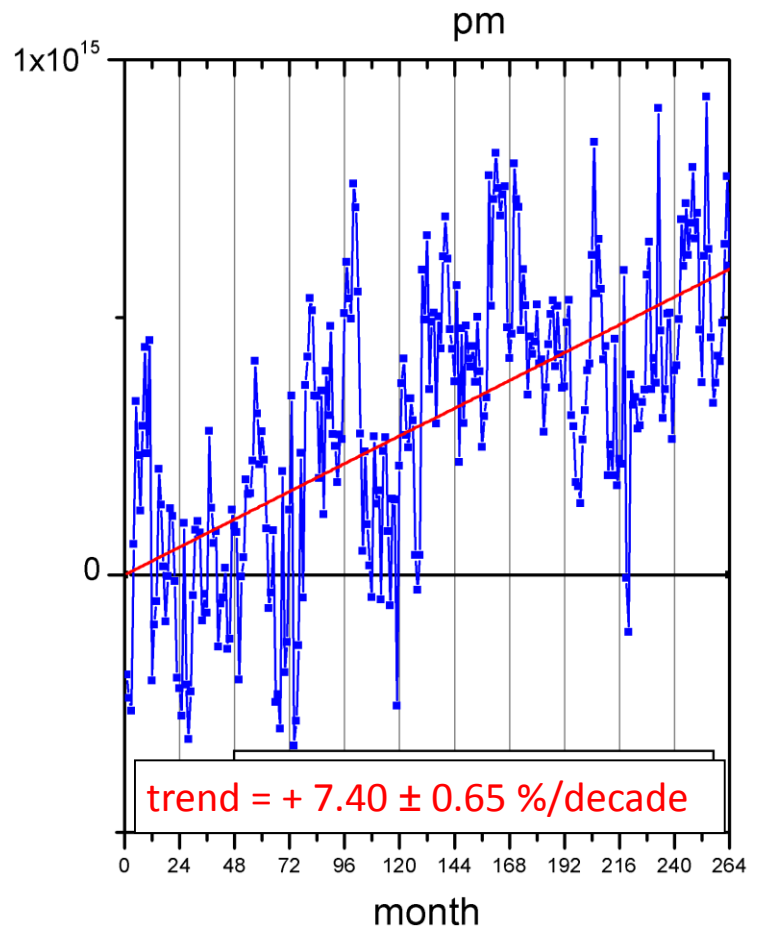
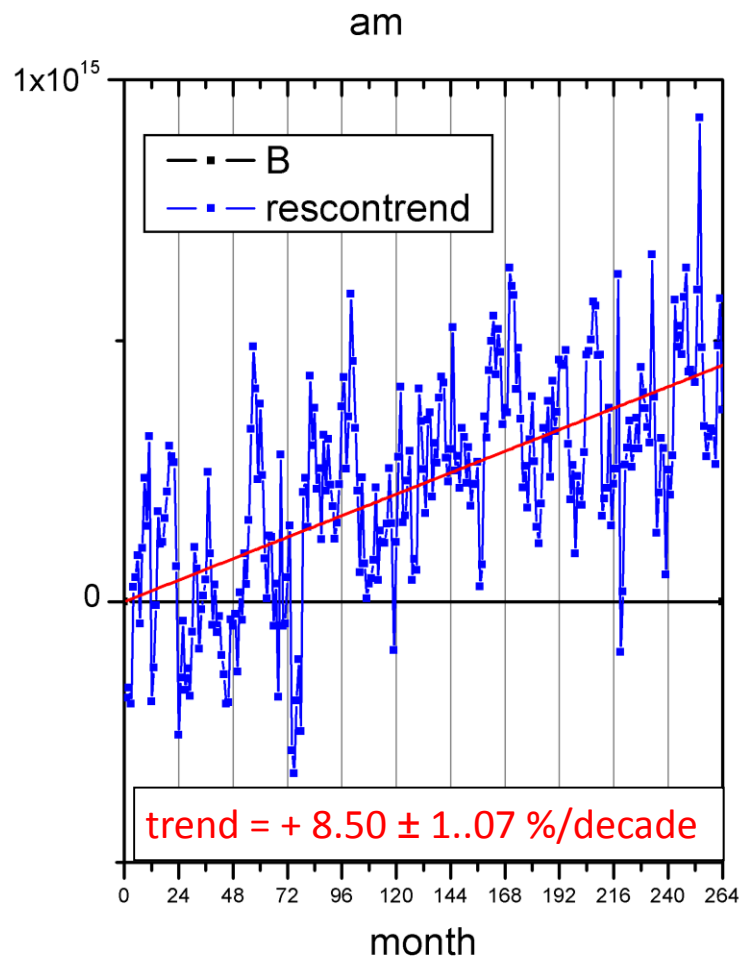
# Izaña (28°N) DOAS pm



Black text: significant to 95%

# Izaña data sets

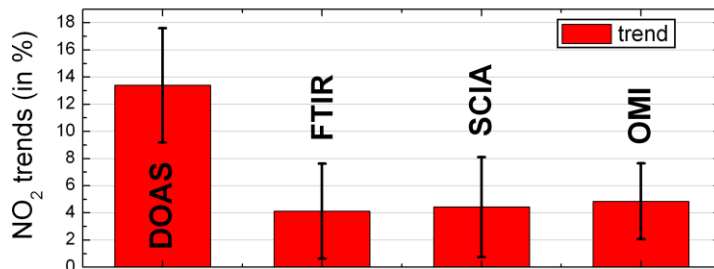
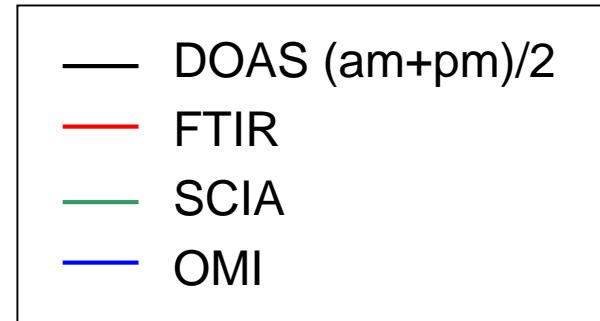
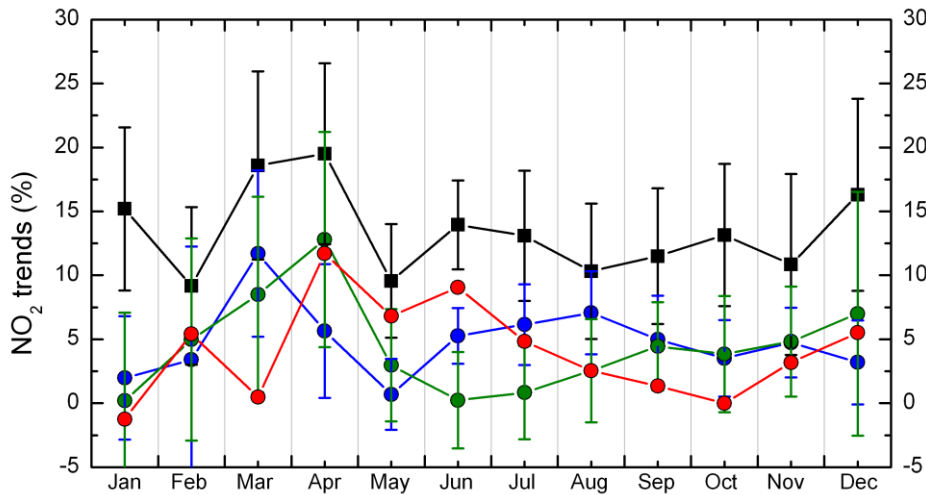
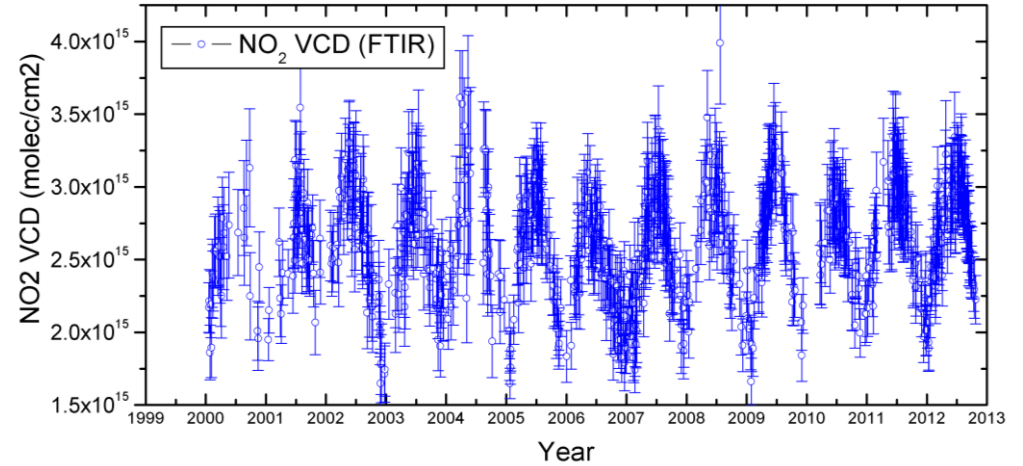
## Residuals with trends



**Izaña mean trend (1993-2014) = 7.95%/decade**



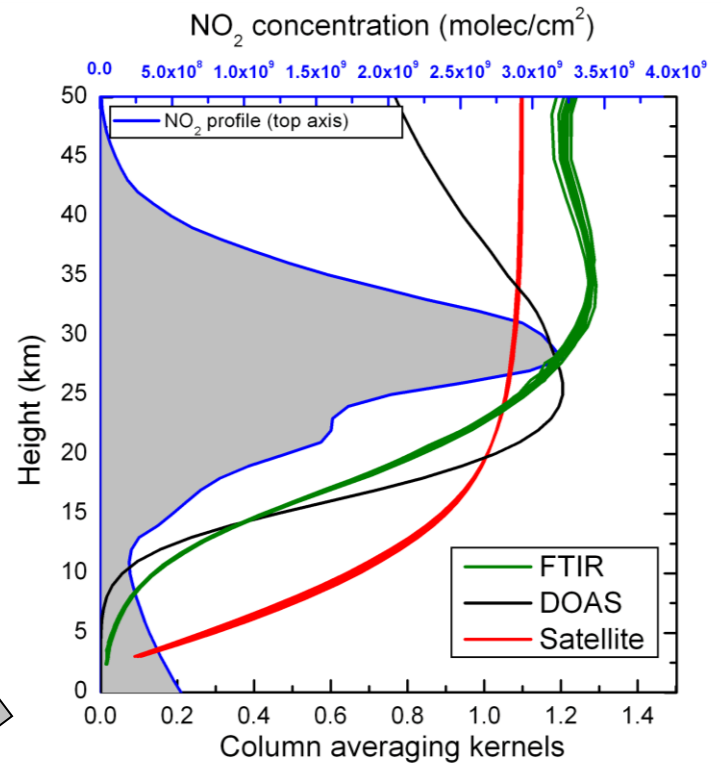
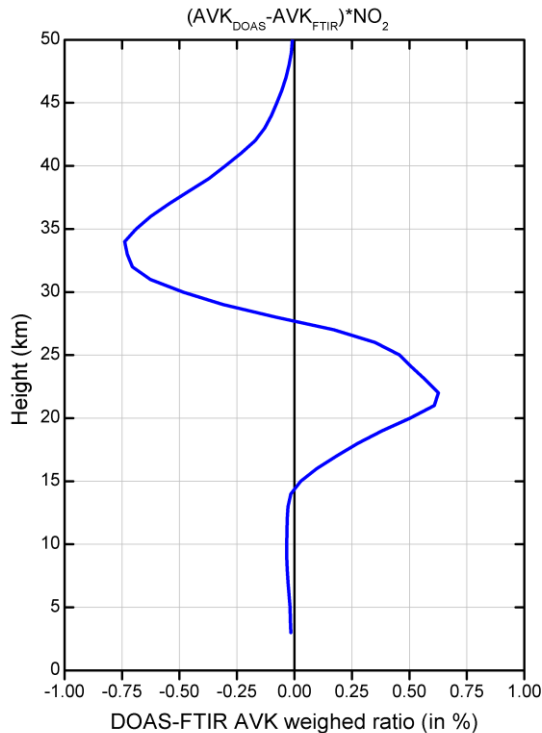
# FTIR at Izaña



DOAS over 3 times larger trends than FTIR. ¿Why?

# FTIR-DOAS-Satellite

All instruments have their largest sensitivity in the stratosphere, but there are differences in vertical sensitivity between instruments



At 22 km DOAS sensitivity is over 50% larger than FTIR whereas at 34 km the opposite is true

Most of the trends occur in the lower stratosphere

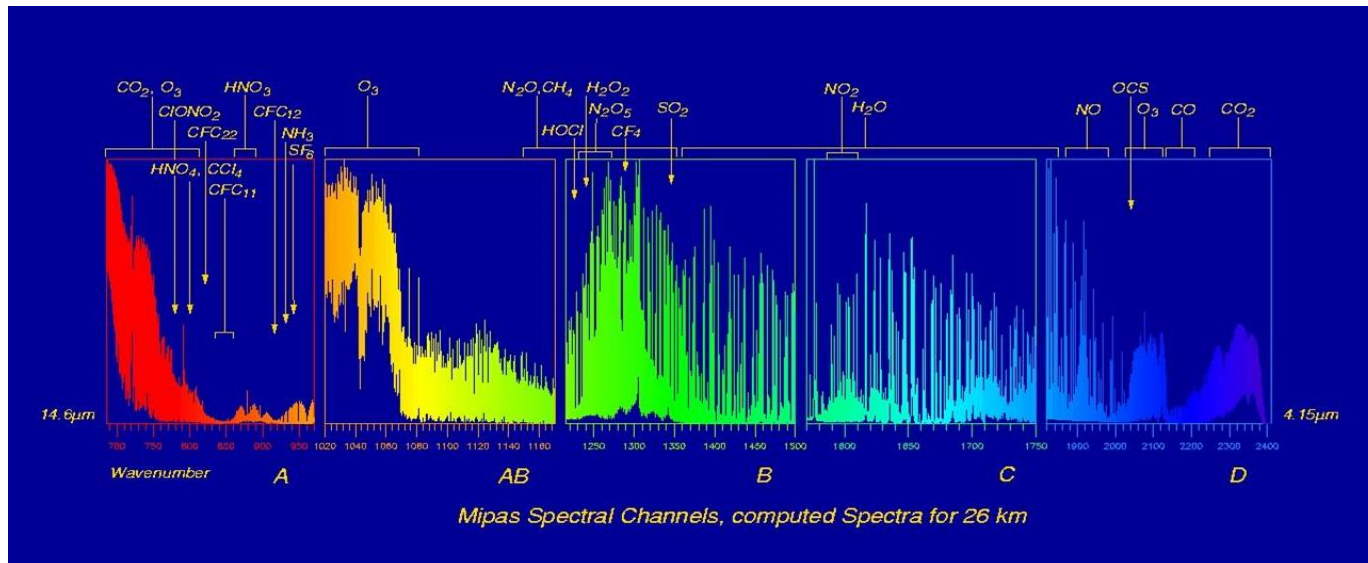
Probably dynamic induced

# MIPAS



## NO<sub>y</sub> Climatology (Funke et al., 2015)

- Monthly zonal means (10 deg latitude bins) of  
 $\text{NO}_2 + \text{NO} + \text{HNO}_3 + 2\text{N}_2\text{O}_5 + \text{ClO}$   
 $\text{NO}_2 + \text{HNO}_4$
- Full global coverage  
(independent on solar illumination)

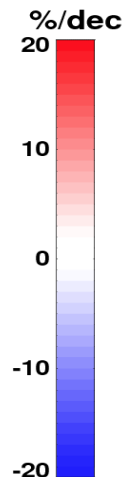
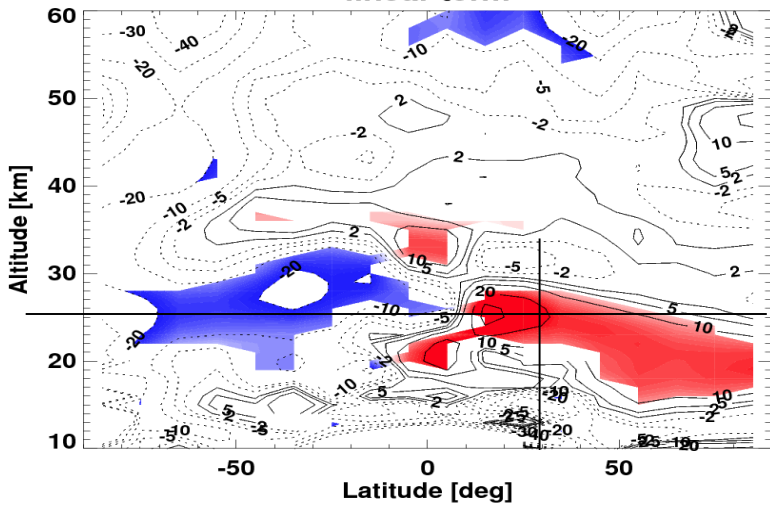


# NO<sub>y</sub> Global Trend (B. Funke et al, 2015)

MIPAS 2002-2012

linear term

2002-2012

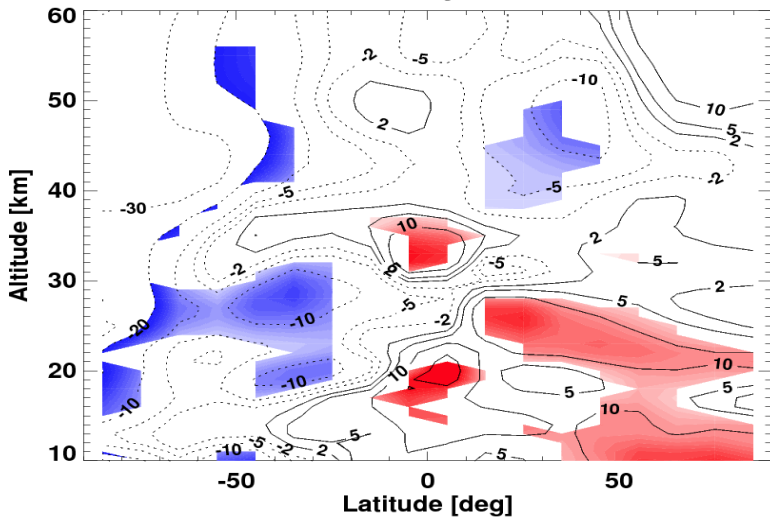


- For 2002-2012, both MIPAS and WACCM show hemispherical asymmetric behavior in the lower and middle stratosphere.
- WACCM 1980-2012 shows a global increase (2-5% per decade) in the polar regions and in the UT, but decrease (2%) in the LM at 30N/30S

WACCM 2002-2012

linear term

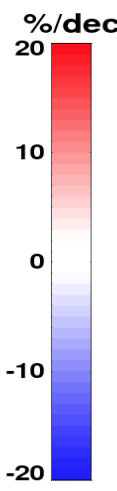
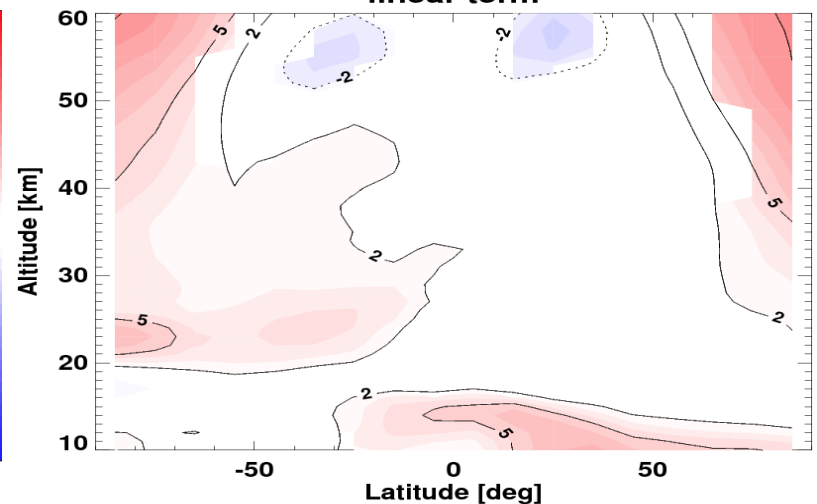
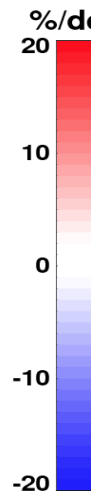
2002-2012



WACCM 1980-2012

linear term

1980-2012

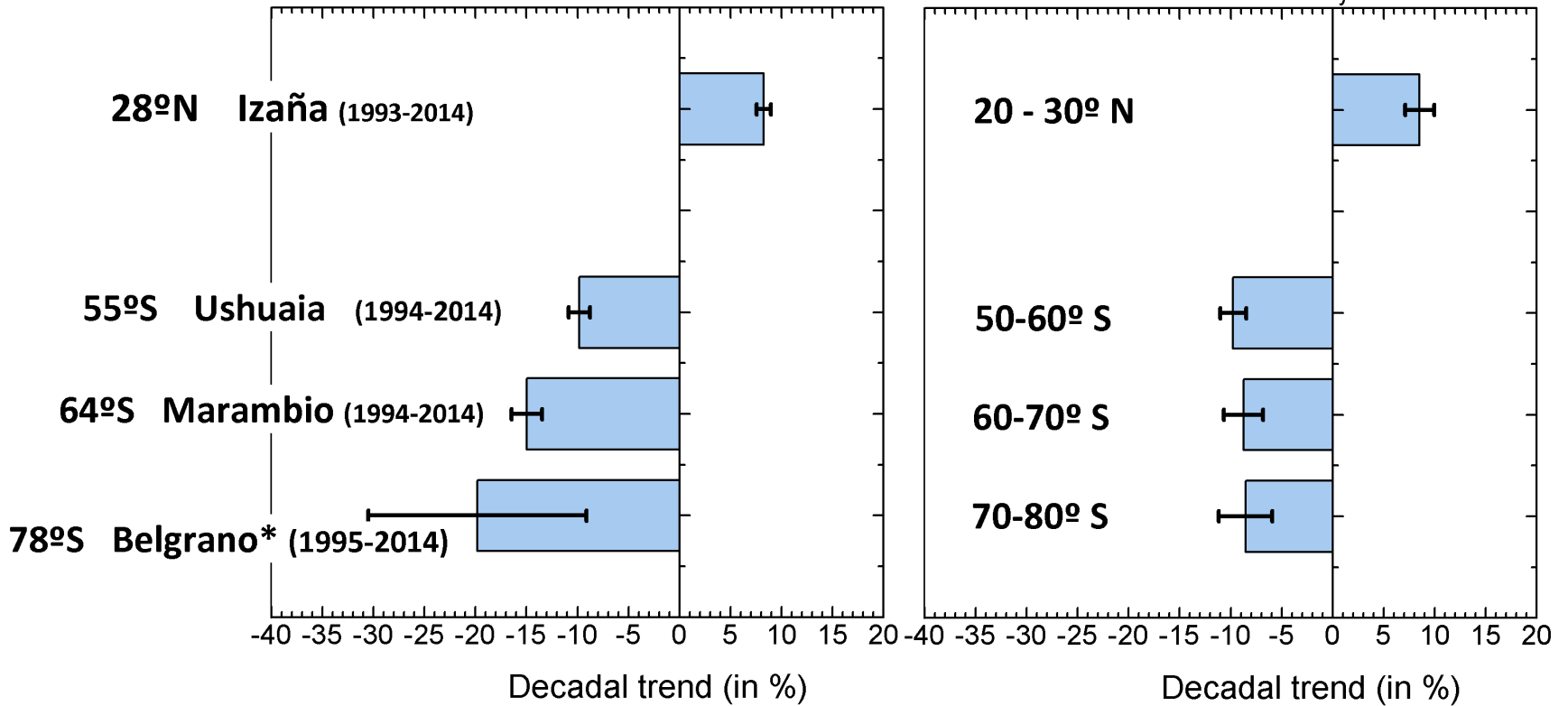


Color shading: significance (95% confidence level)

All data series available

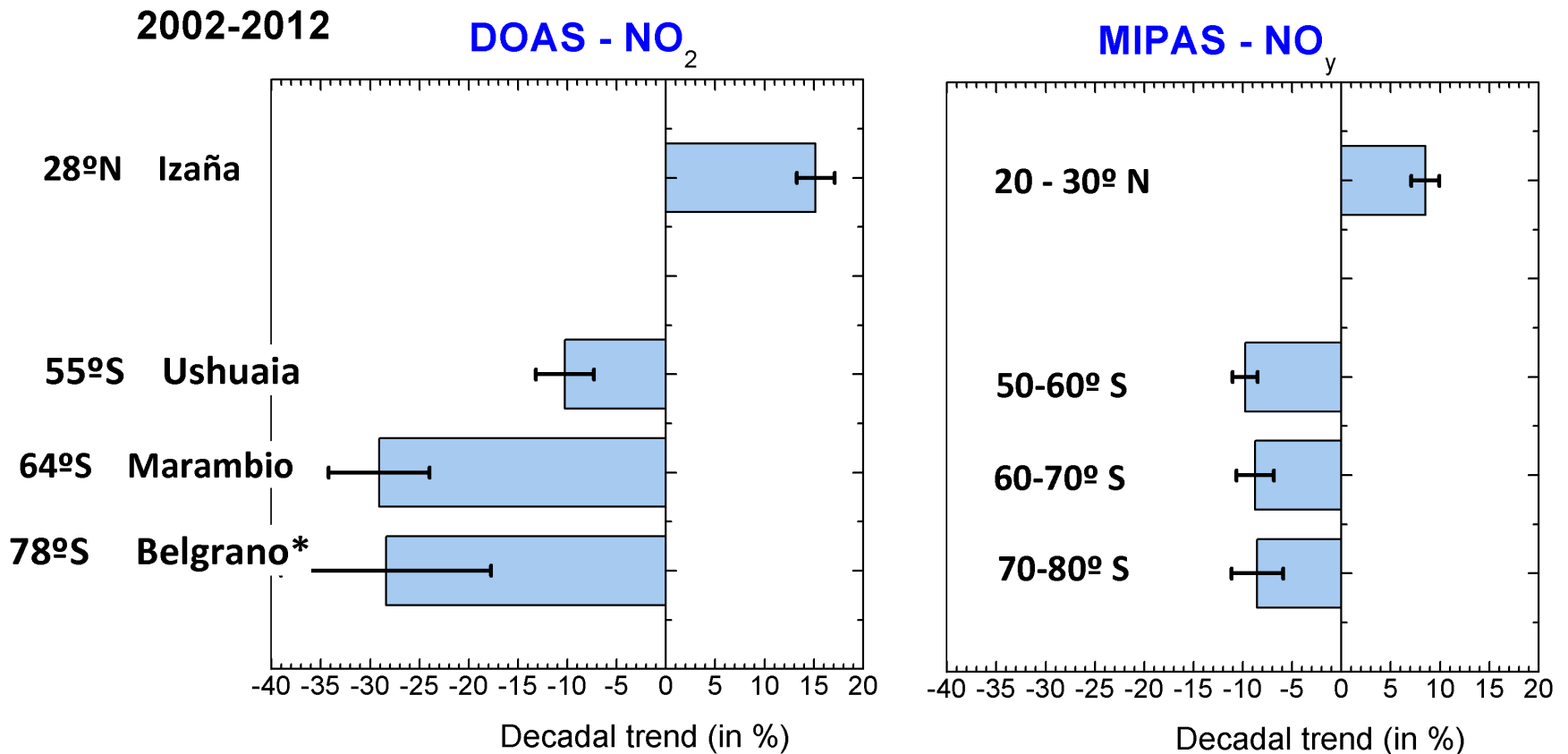
### DOAS - NO<sub>2</sub>

### MIPAS - NO<sub>y</sub> (2002-2012)



\* In Belgrano only months with twilight (JFM and ASO)

Period 2002-2012



\* In Belgrano only months with twilight (JFM and ASO)

+ Qualitative agreement between DOAS-NO<sub>2</sub> and MIPAS NO<sub>y</sub>

+ Larger trends in GB instruments