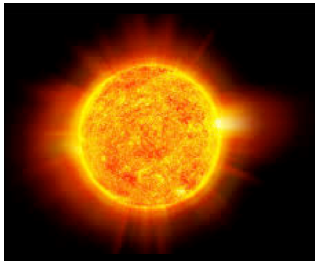
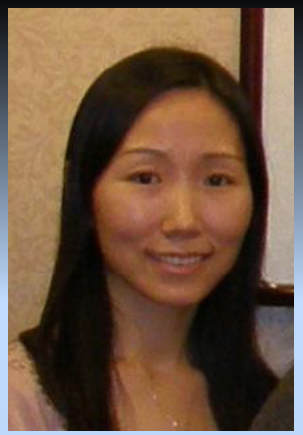


The 11-year Solar Cycle Signal in Global NO_2 Measurements from NDACC Stations



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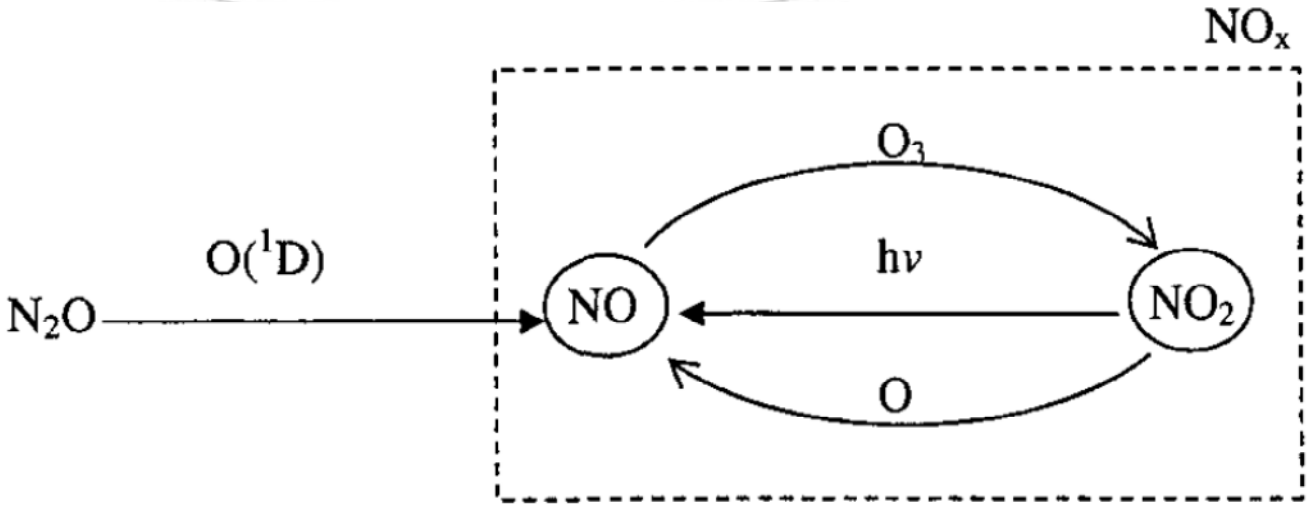
Yuk Yung
California Institute of Technology

Why NO_2 (or NO_x)?



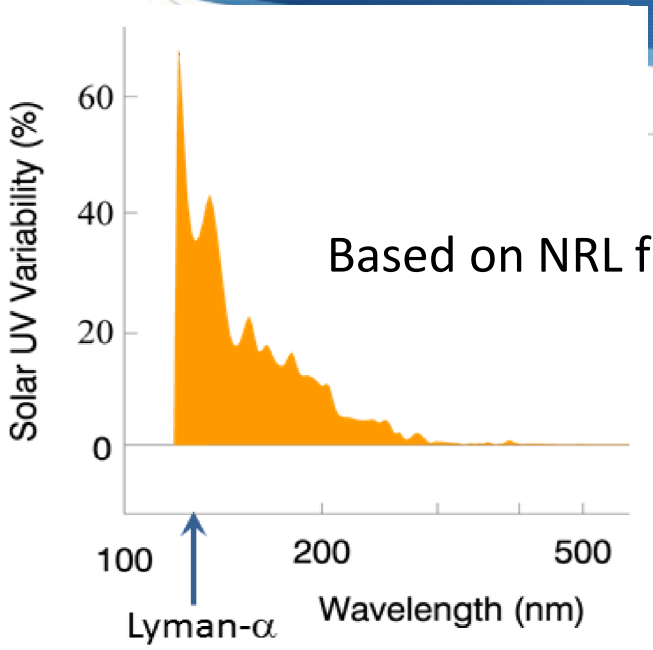
- NO_x is the main O_3-destroying catalyst in middle-to-lower stratosphere.
- In Paul Crutzen's 1995 Nobel Lecture:

  Regarding stratospheric ozone chemistry, I discarded the *(HO_x)* theory of Hampson and Hunt *(in 1970)* and concluded: "... The influence of nitrogen compounds on the photochemistry of the ozone layer should be investigated".

- In 2010, he said:

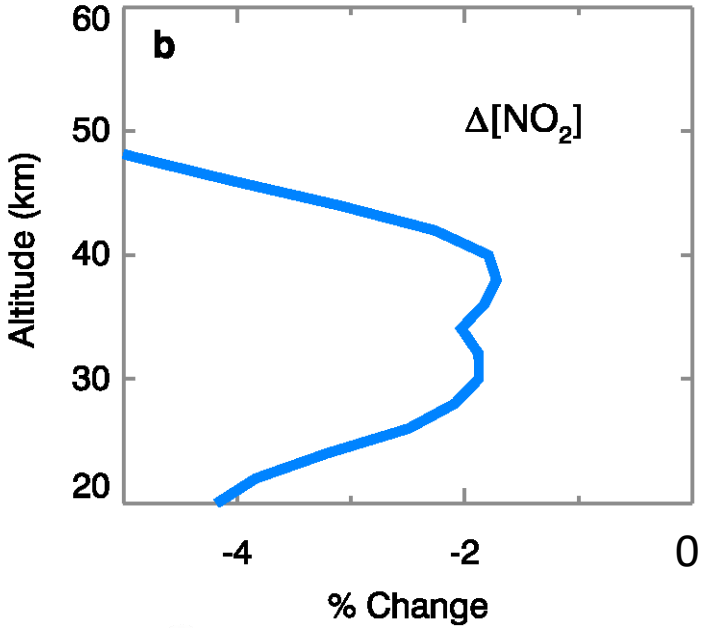
  I had no formal education in chemistry … I wrote the "NO_x papers" when I was 36 years old

NO_x solar-cycle impacts on tropical O_3

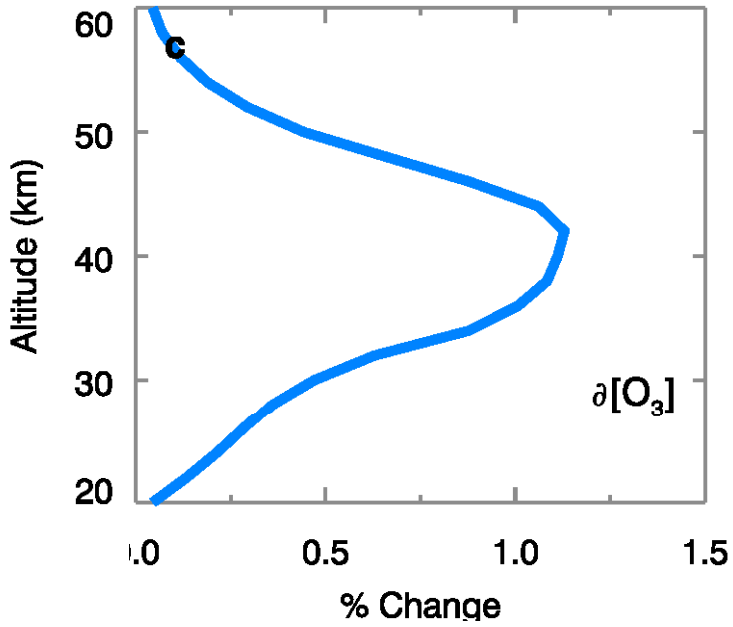


Based on NRL flux

Chemistry model



O_3 change



Total NO_2 column data

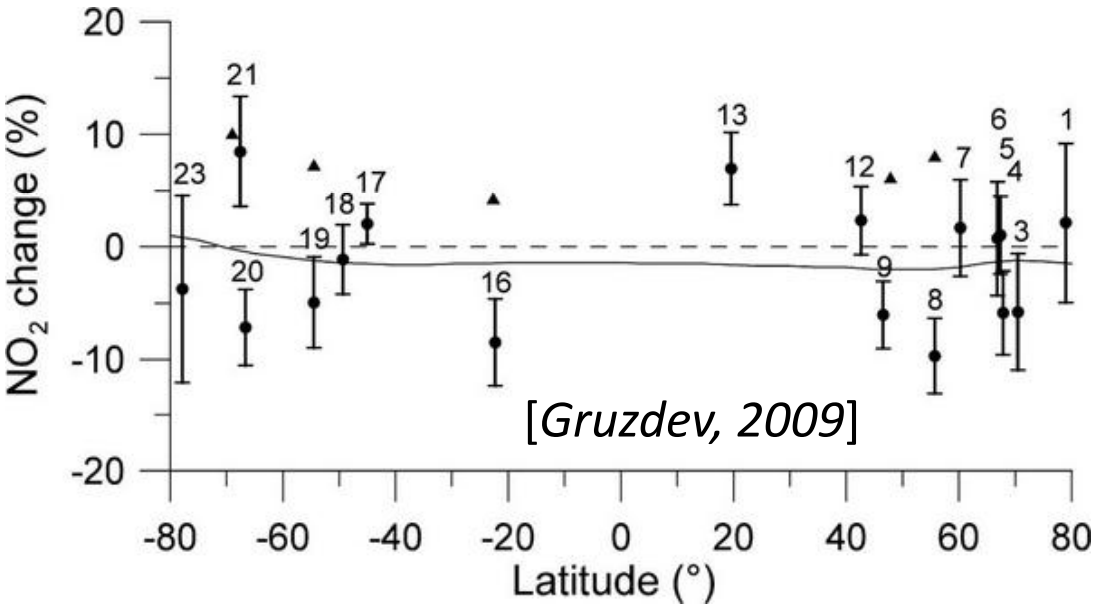
- ✓ NDACC (Network for the Detection of Atmospheric Composition Change): 1990s–now
  - We identify 12 stations with long and continuous records for solar cycle studies

    (** More stations may be used after gap filling and removal of Pinatubo effects.)

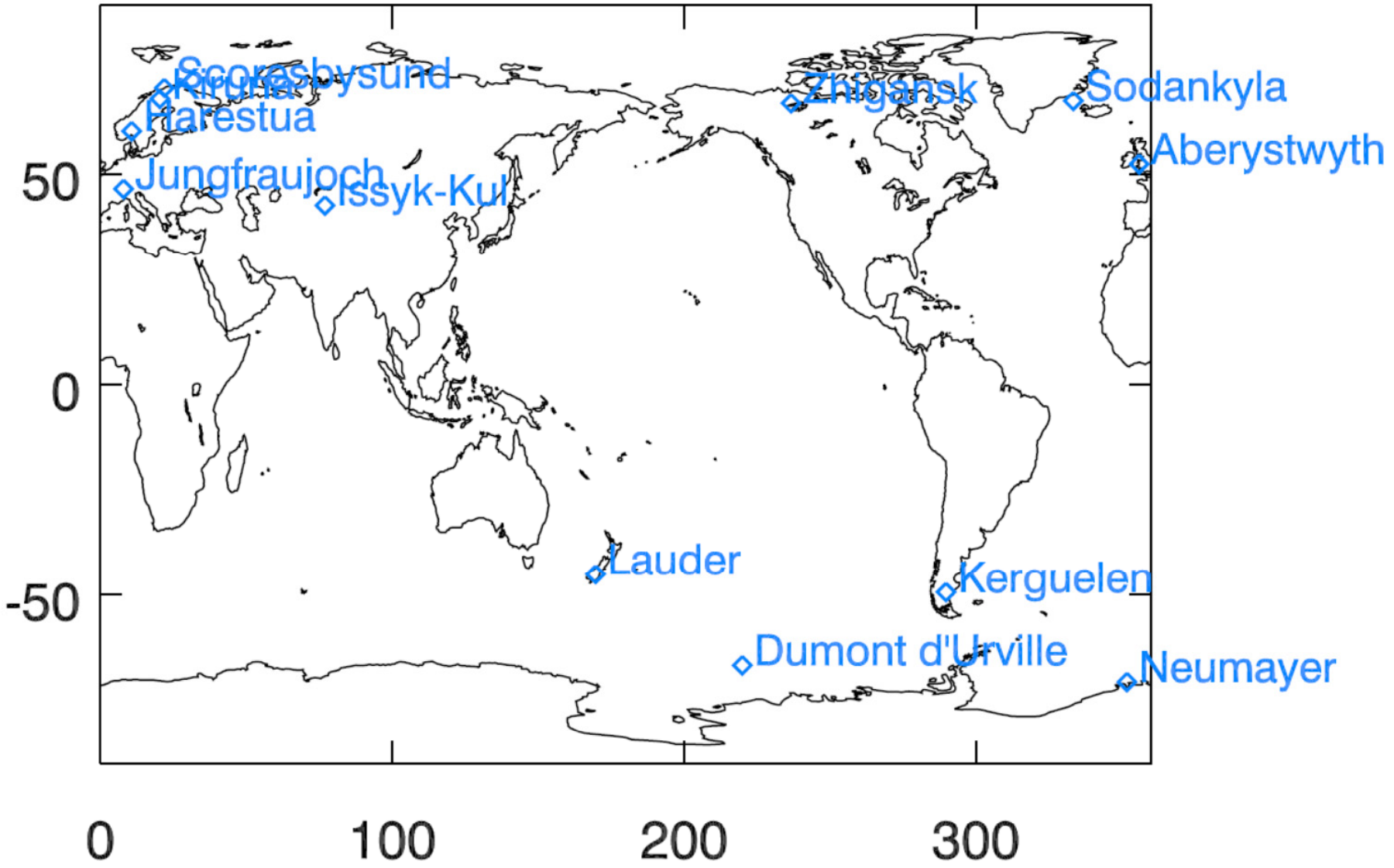
- ✓ Satellite: needs to be merged before use …
  - GOME: 1995 – 2003
  - SCIAMACHY: 2002 – 2012
  - GOME-2: 2006 – now
  - OMI: 2004 – now

Previous efforts

- Crutzan 1975: Predicted the impact of solar proton events
- Liley et al. [2000], Hendrick et al. [2012]: few stations only
- *Gruzdev* [2008; 2009]: 23 stations, but data were short, might be heavily affected by Pinatubo eruption
- Statistically noisy responses.
- Goal: 1. Re-investigate NO_2 column with longer records
  2. Compare with CCMI models



[*Gruzdev, 2009*]


Scoresbysund
Kiruna
Harestua
Jungfraujoch
Issyk-Kul
Zhigansk
Sodankyla
Aberystwyth
Lauder
Kerguelen
Dumont d'Urville
Neumayer
50
0
-50
0
100
200
300

Empirical Mode Decomposition (EMD)

- Fourier transform assume stationary processes

$$y(t) = \sum a_j \exp\left(-i\omega_j t\right)$$

- Hilbert transform generalizes to

$$y(t) = \sum a_j(t) \exp\left[-i\int \omega_j(t)\, dt\right]$$

- EMD obtains the Hilbert transform by amplitude modulation [Huang et al., 1998, 2016].

Newman et al. [ACP, 2016]
Kobayashi–Kirschvink et al. [*AADA*, 2013] (summer student)
Shi et al. [Clim Dyn, 2013] (summer student)

EMD Modes

Raw data: FFT

1st mode: Semi-annual

2nd mode: Annual

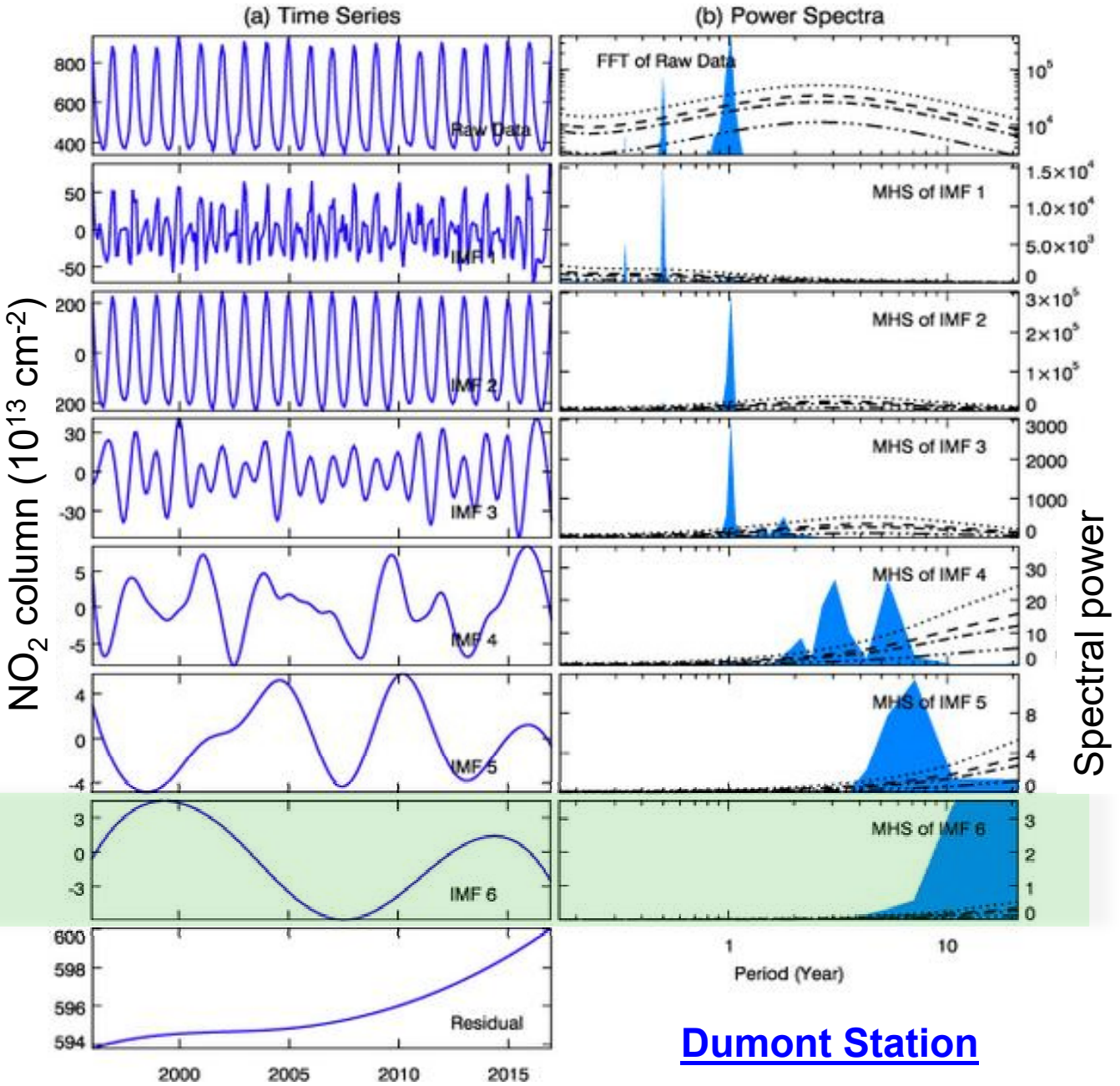
3rd mode: Annual+QBO

4th mode: ENSO

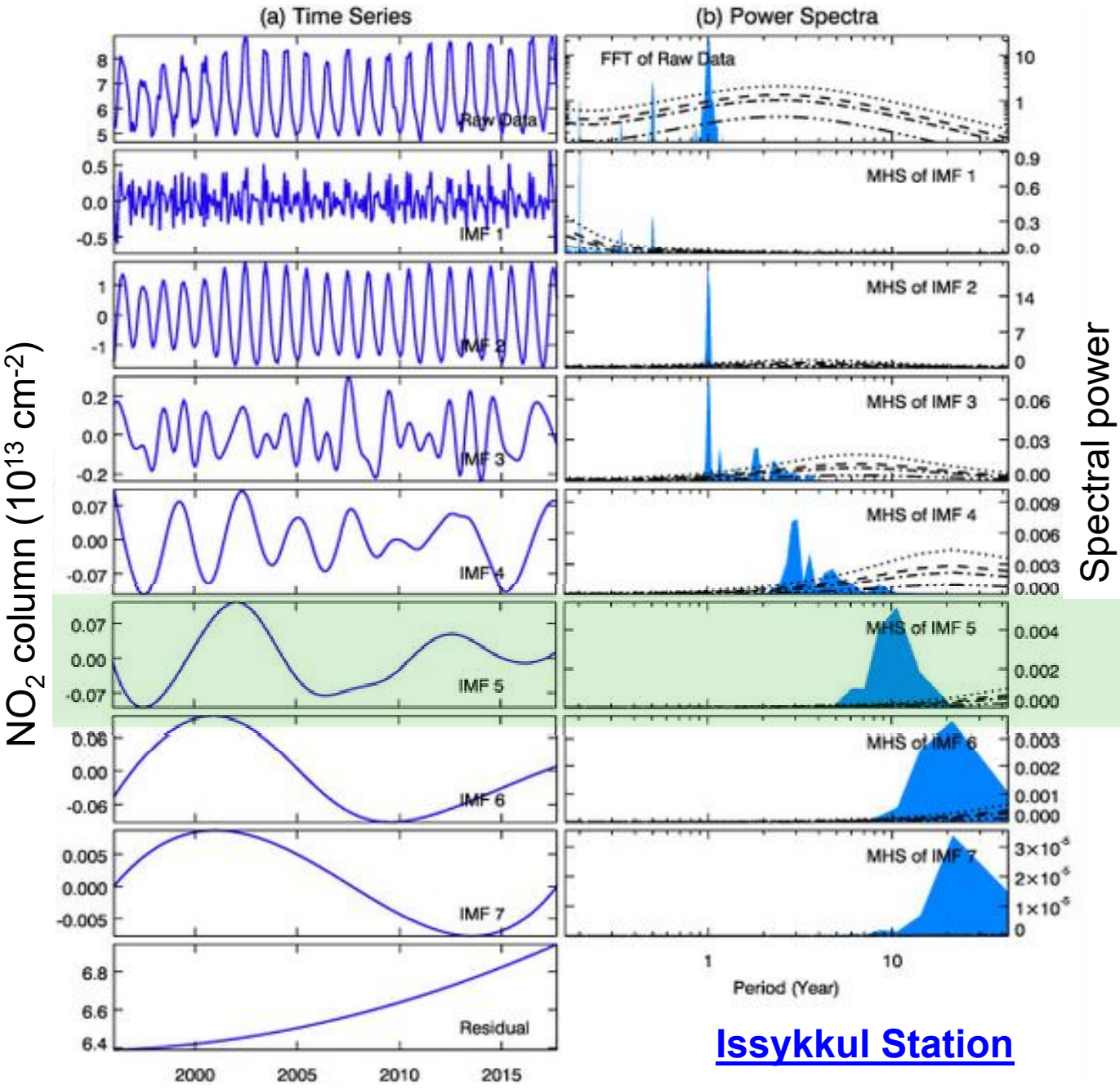
5th mode: ENSO

6th mode: Solar Cycle

Last mode: Trend



Dumont Station



Issykkul Station

Raw data: FFT

1st mode: Semi-annual

2nd mode: Annual

3rd mode: Annual+QBO

4th mode: ENSO

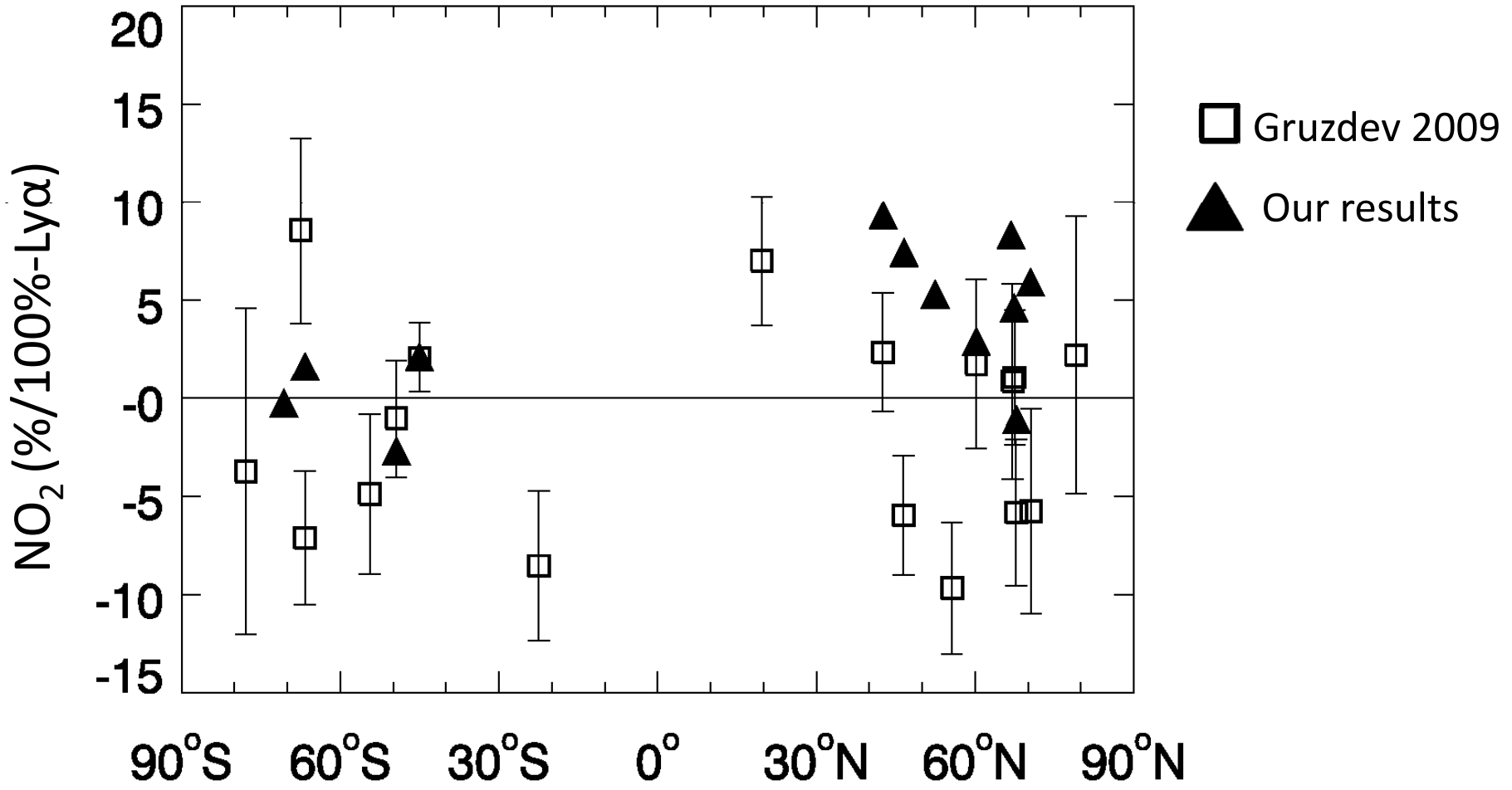
5th mode: Solar Cycle

6th mode: PDO?

7th mode: PDO?

Last mode: Trend

Updated responses



Chemistry-Climate Model Initiatives (CCMI)

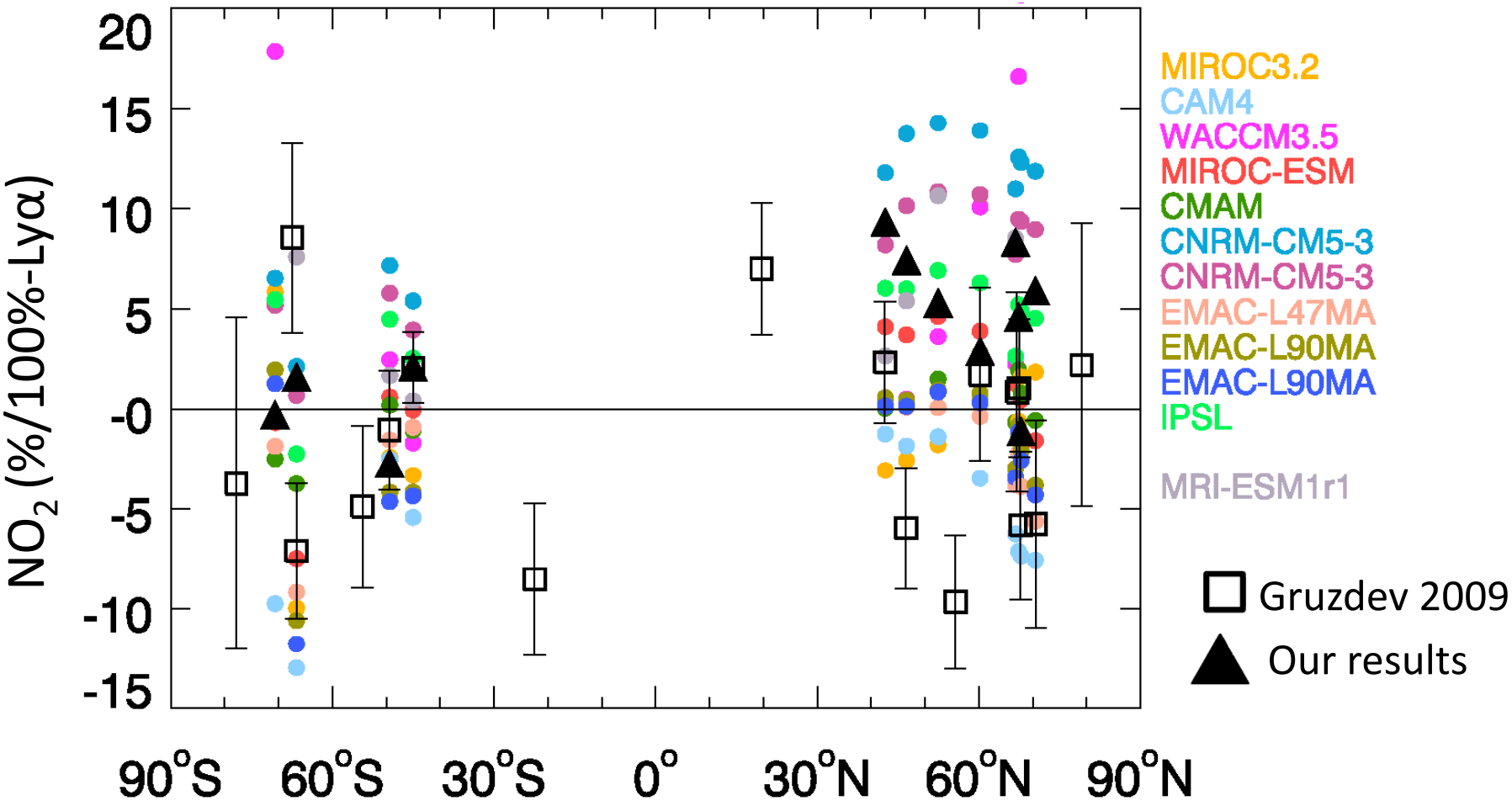
- Scope: Simulate and predict the changes of lifetime/distributions of greenhouse gases change over time.
- Involve 23 international models, all provide free runs or runs nudged with observed winds and temperature
- We focus on NO_x in the nudged runs (10 models)

MIROC3.2	CAM4	WACCM3.5
MIROC-ESM	CMAM	CNRM-CM5.3
EMAC-L47MA	EMAC-L90MA	
IPSL	MRI-ESM	

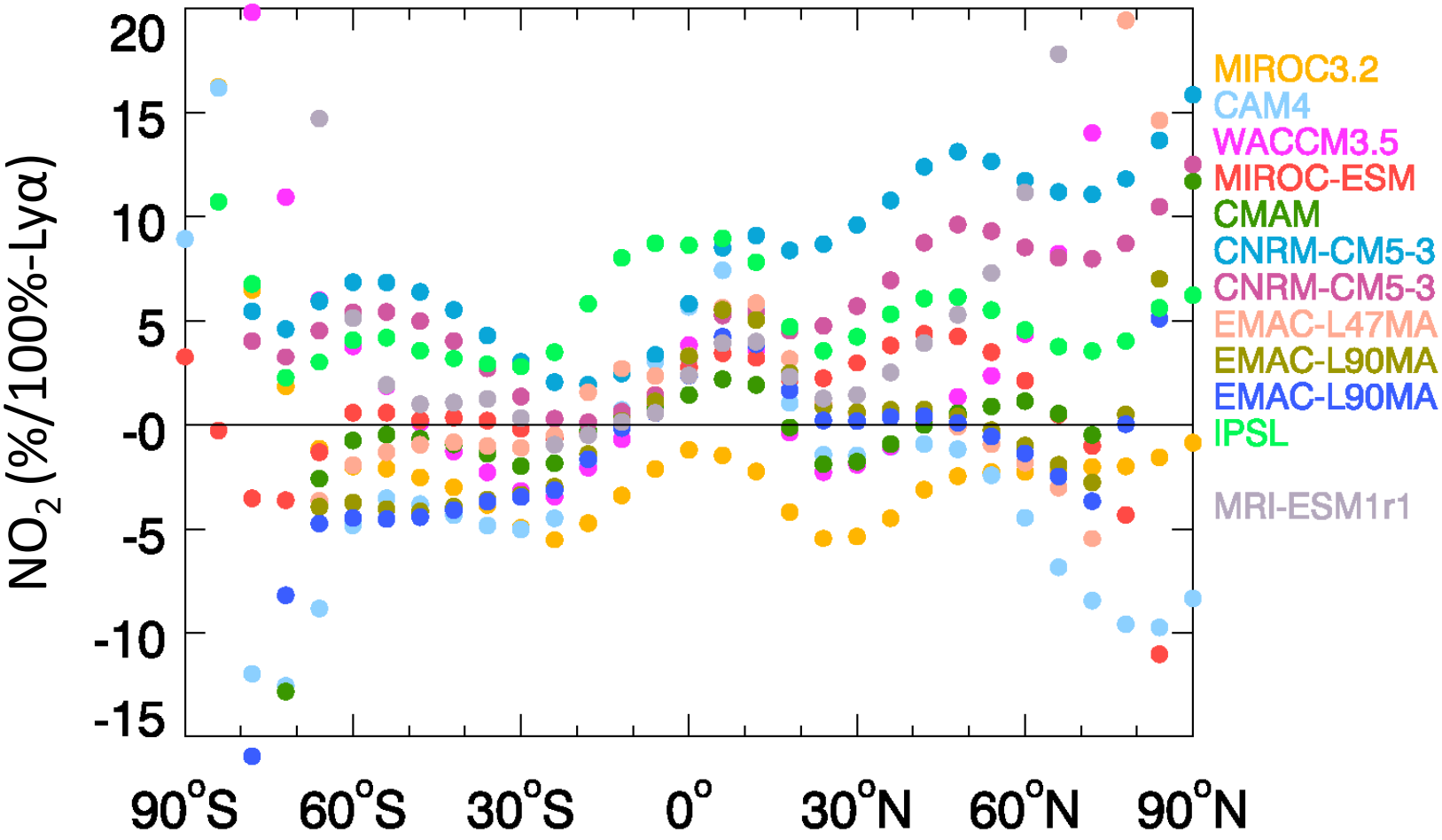
- Since we know the exact solar forcing (NRL flux), linear regression is used to extract the solar responses.

Model responses

- Surprise: Model distribution is as noisy!
- The mean positive behavior in the NH agrees with our EMD extraction



Zonal averages won't help



Summary

- ✓ NO_x plays an important role in the O_3 solar response
- ✓ Secular changes in ground-based NO_2 are re-investigated
- ✓ Updated NO_x response suggests a mean positive response in NH
  (SH response is still uncertain)
- ✘ NO_x responses in chemistry-climate models need to be improved.