Impact of transport seasonal variability on ozone changes in the tropical mid-stratosphere

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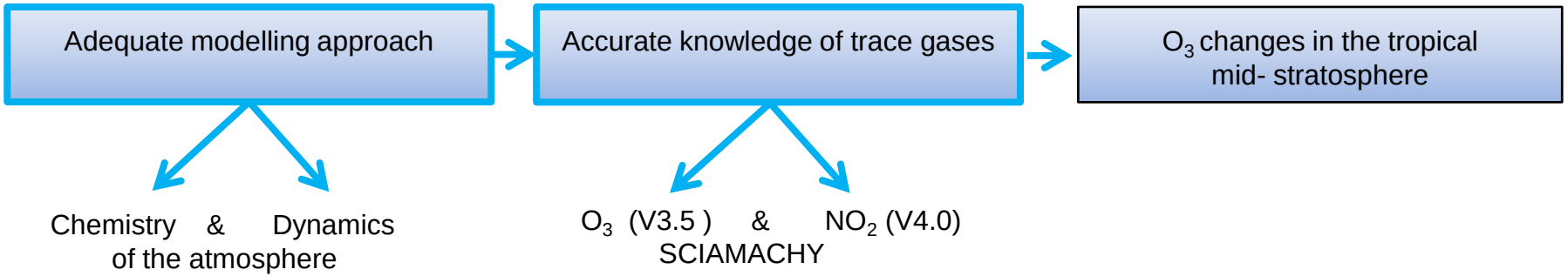
1 - Institute of Environmental Physics, University of Bremen, Bremen, Germany
2 - School of Earth and Environment, University of Leeds, Leeds, UK
3 - National Centre for Earth Observation, University of Leeds, Leeds, UK


Adequate modelling approach
Accurate knowledge of trace gases
O_3 changes in the tropical mid- stratosphere
Chemistry & Dynamics of the atmosphere
O_3 (V3.5) & NO_2 (V4.0) SCIAMACHY

Adequate modelling approach → Accurate knowledge of trace gases → O_3 changes in the tropical mid- stratosphere

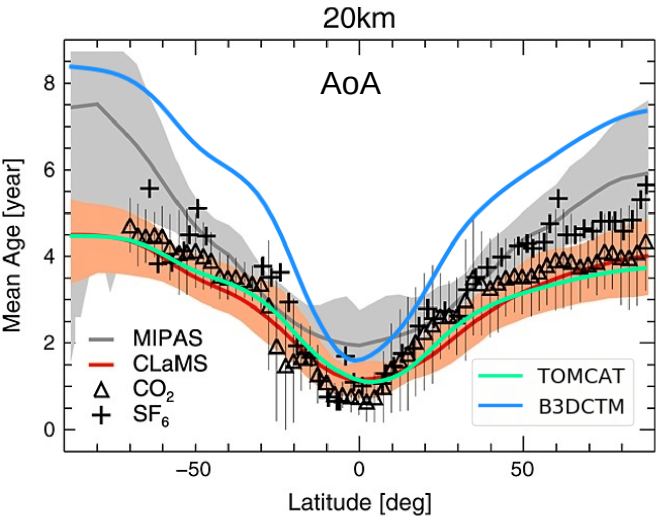
2002 B3DCTM by Dr. B.-M. Sinnhuber

1999 CTM development in Leeds

1995 Stratospheric SLIMCAT

1992 TOMCAT by Prof. M. P. Chipperfield

Adequate modelling approach → Accurate knowledge of trace gases → O_3 changes in the tropical mid- stratosphere



Taken from Ploeger et al., 2015

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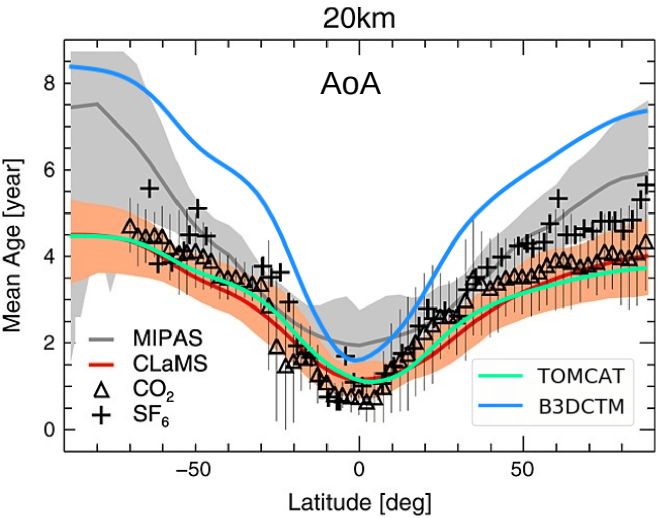

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O_3 (V3.5) NO_2 (V4.0)
SCIAMACHY

Validated by
A. Rozanov et al.,
ACVE, Frascati 2016

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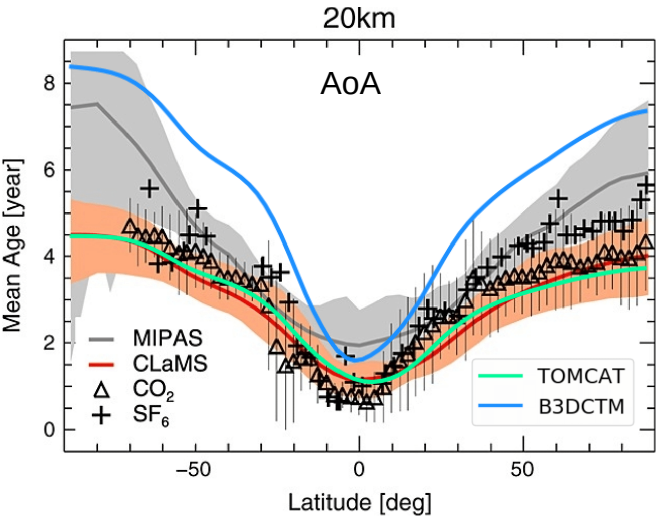

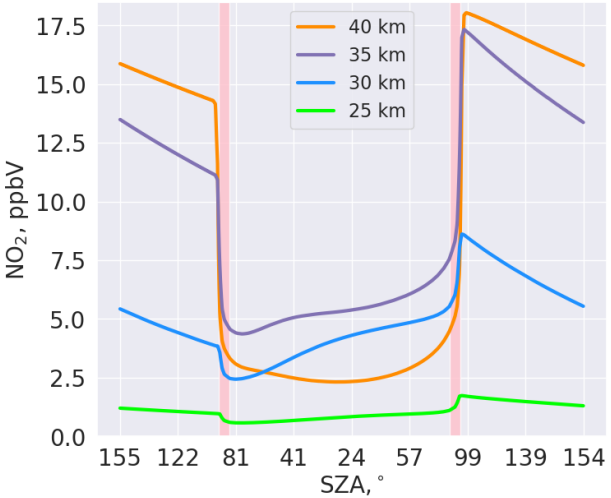

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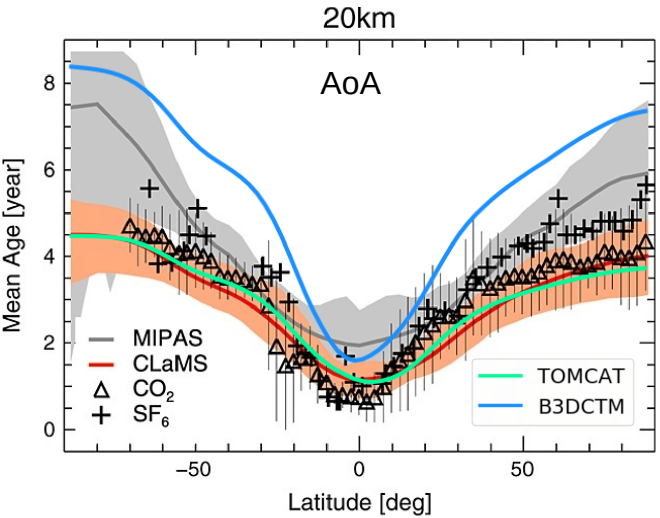

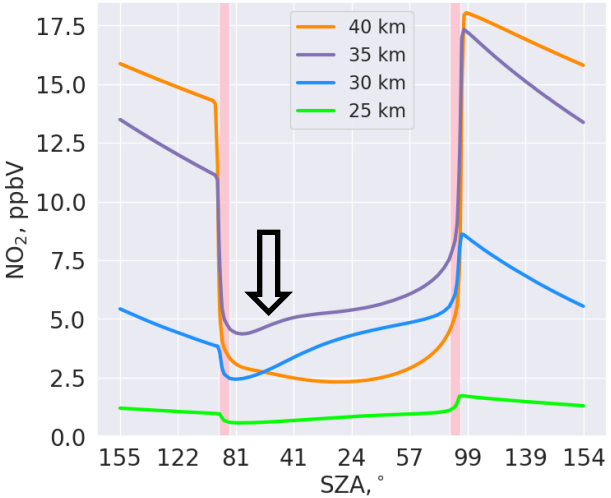

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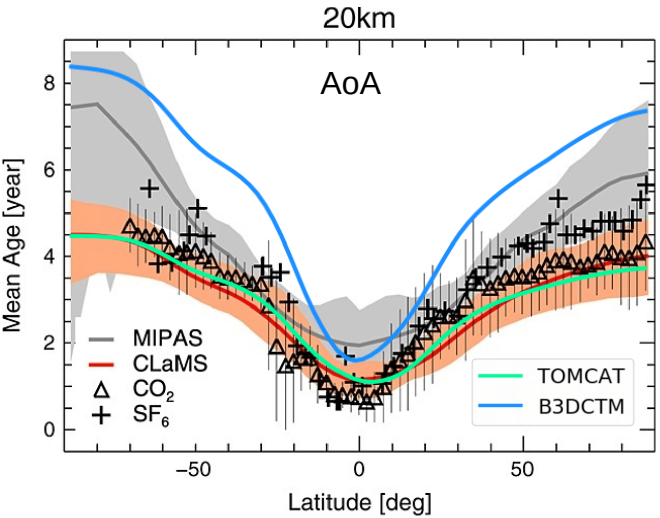

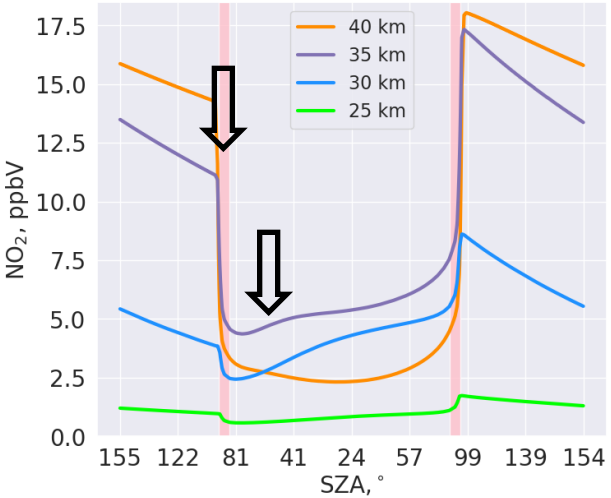

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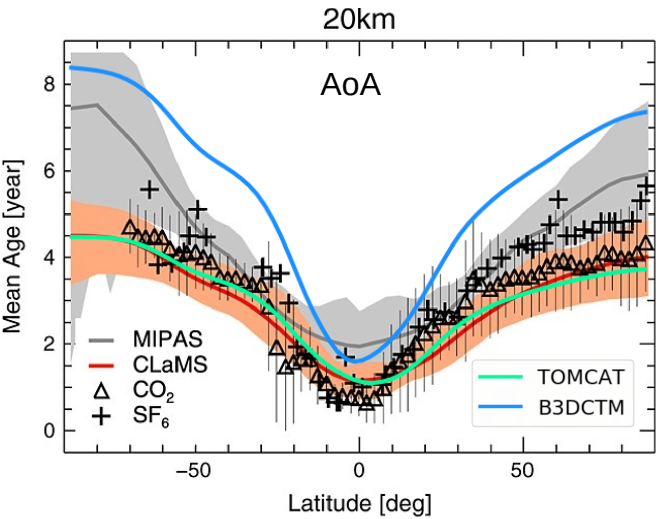

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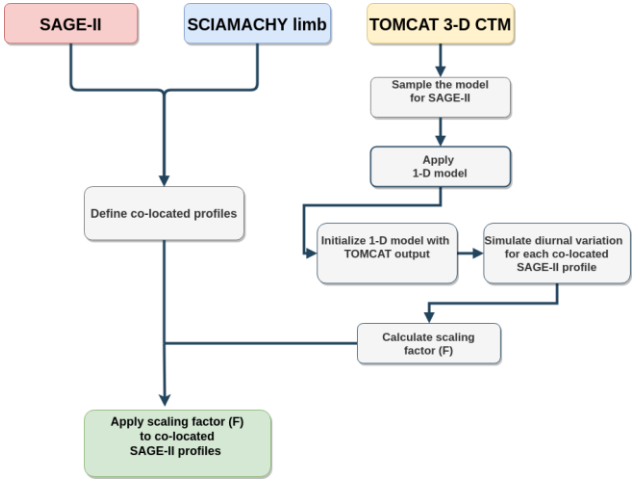

1. ESA report:"SCIAMACHY V6.01 NO_2 Validation",2017.
2. Galytska et al., 2019 (in preparation to AMT, NO_2 V4.0)

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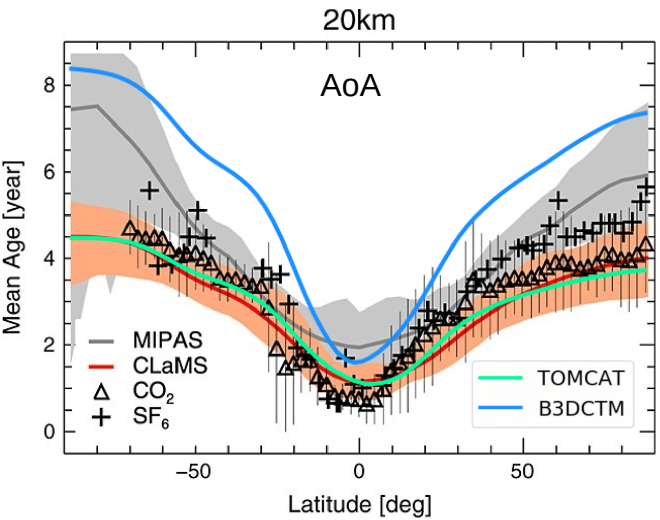

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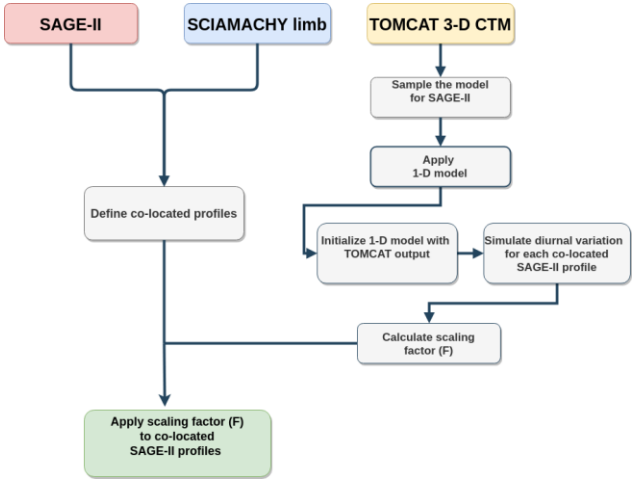

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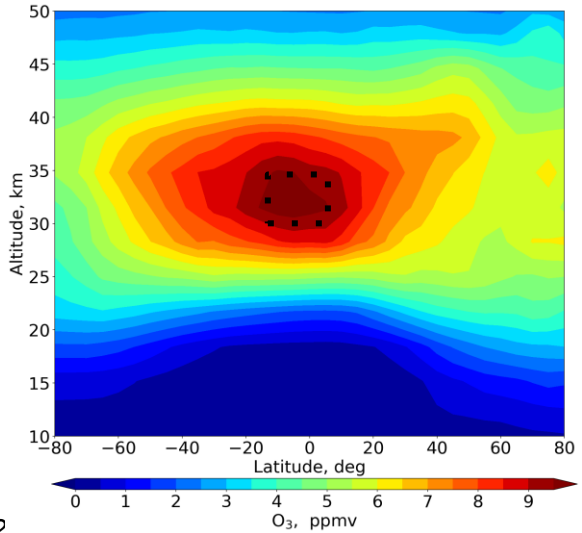


Galytska et al., ACP, 2019

OUTLINE

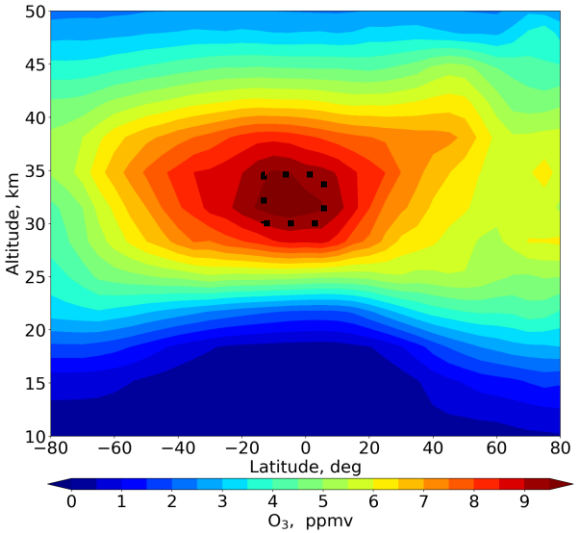
1. Scientific issue and previous findings

2. O_3 chemistry and stratospheric dynamics in 7 steps

3. Interpretation of observed and modelled changes during 2004-2012

4. Conclusions

O_3 changes in the tropical mid- stratosphere



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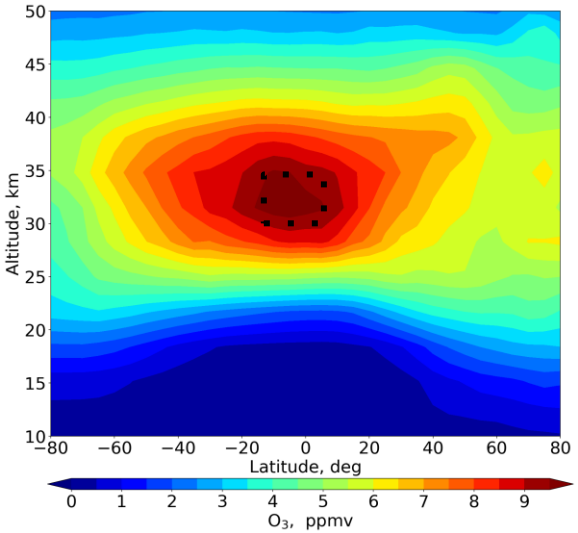
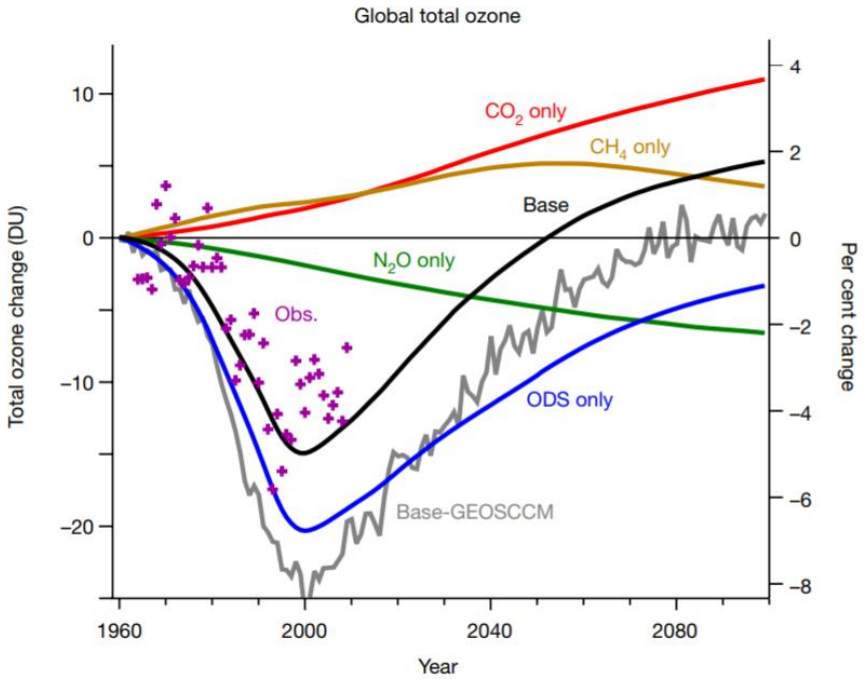


Galytska et al., ACP, 2019

Global total O_3 variations in the atmosphere

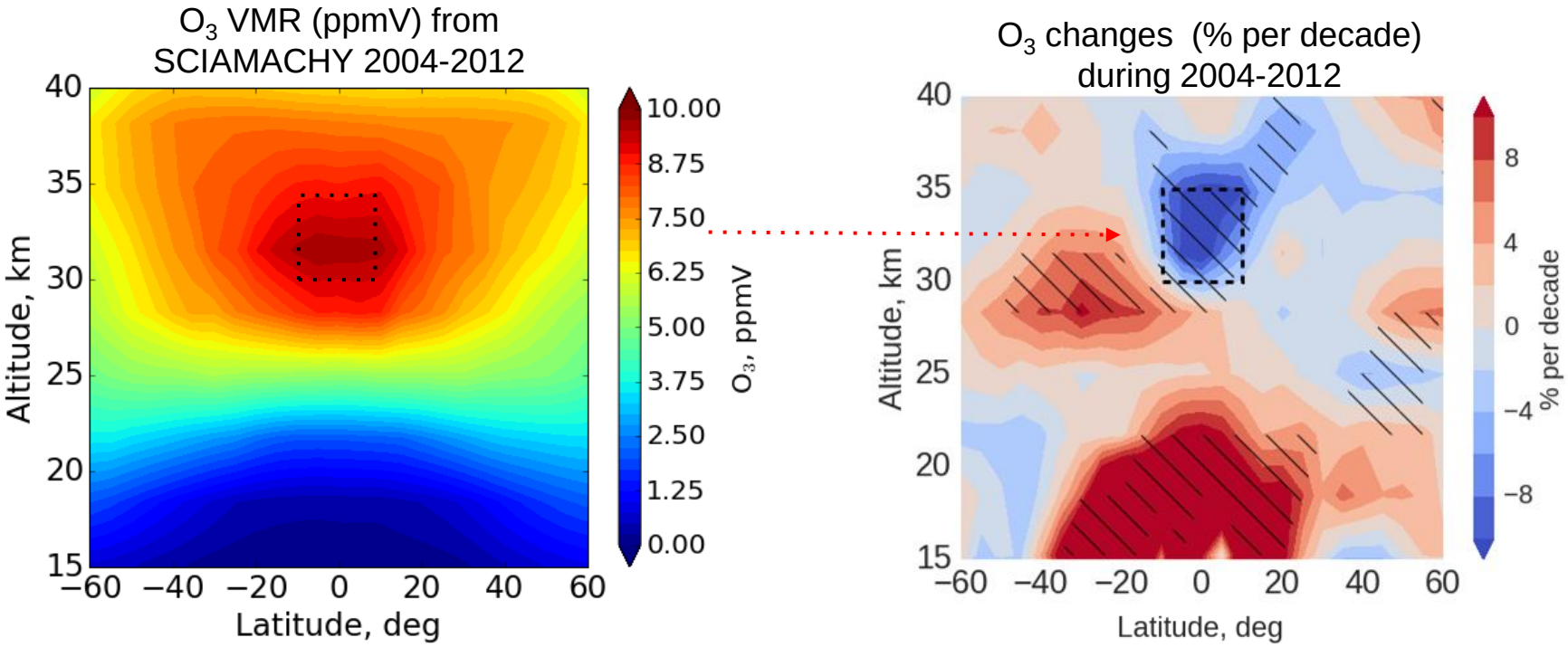


The 1980 O_3 levels are expected in 2030

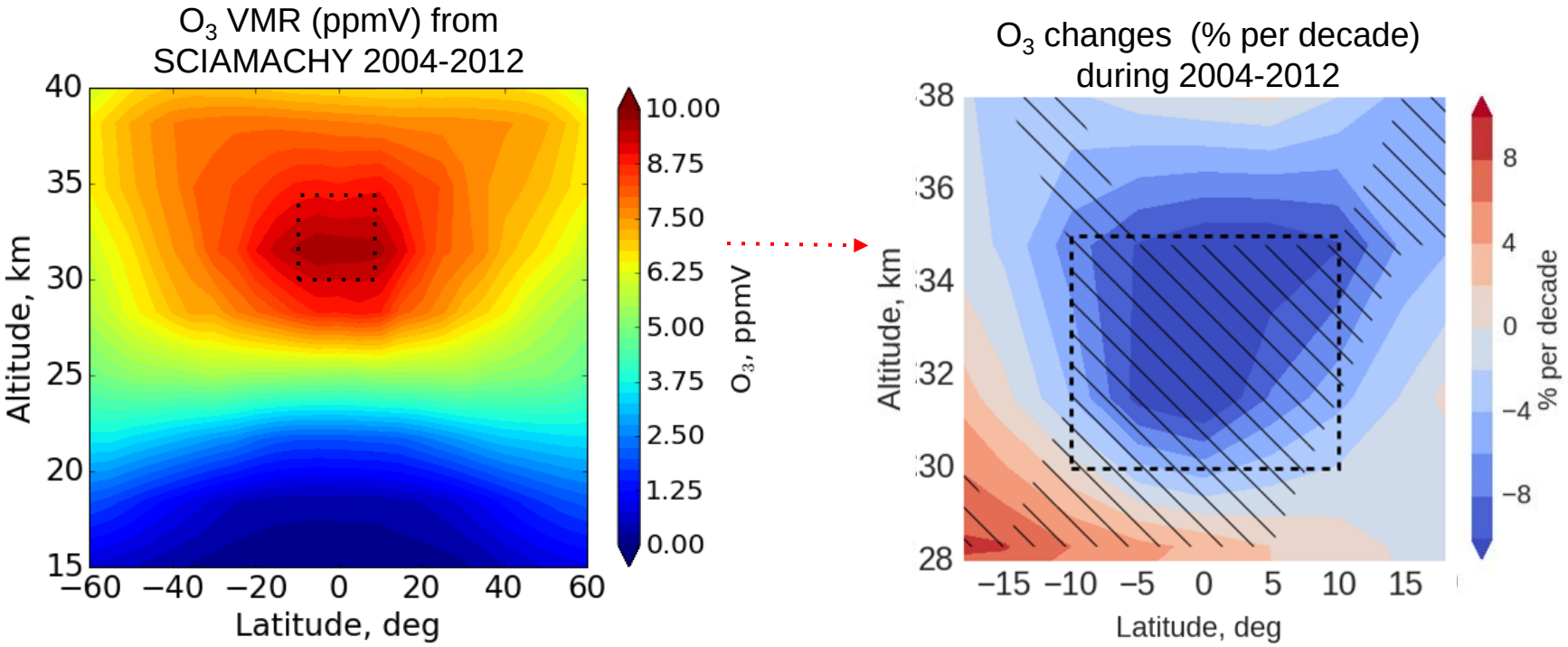
The 1960 O_3 levels are expected in 2050

Chipperfield et al., Nature, 2017

1. Scientific issues and previous findings

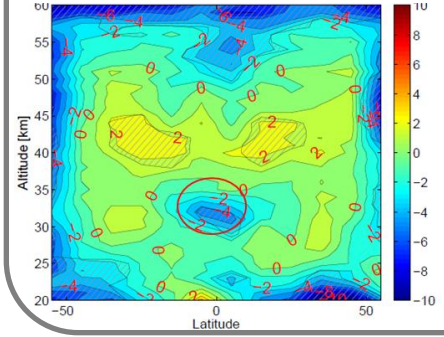


1. Scientific issues and previous findings

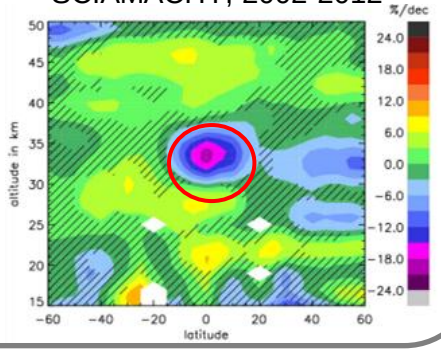


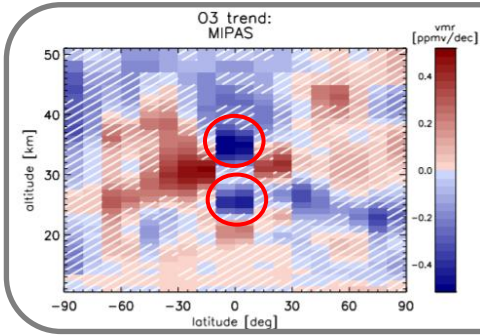
1. Scientific issues and previous findings

Kyrölä et al., ACP, 2013
SAGE II-GOMOS, 1997-2011



Gebhardt et al., ACP, 2014
SCIAMACHY, 2002-2012



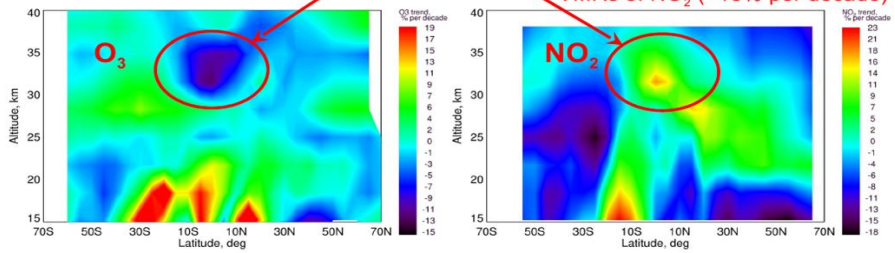


Eckert et al., ACP, 2014
MIPAS, 2002-2012

"Upwelling does not explain the negative values in the tropical mid-stratosphere. It cannot explain the double-peak structure either".

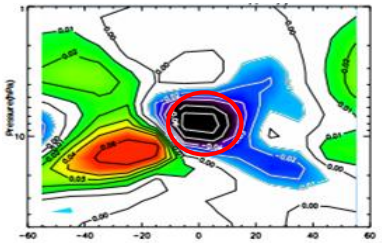
Significant decrease in O_3 VMR between 30 and 35 km is observed (~10% per decade)

Highly correlated with increased VMRs of NO_2 (~18% per decade)

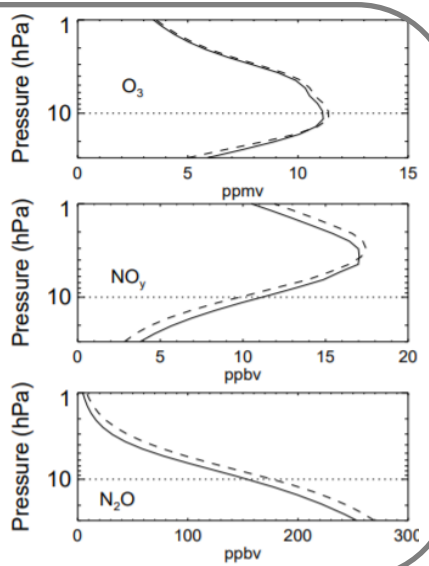


* From the presentation of **Dr. A. Rozanov**, 9th Workshop on Long Term Changes and Trends, Kuhlungsborn, Germany, September 2016

Nedoluha et al., ACP, 2015, MLS, 2004-2013



Suggested the slow-down of the tropical upwelling, which via the N_2O and NO_x chemistry causes decline of O_3.



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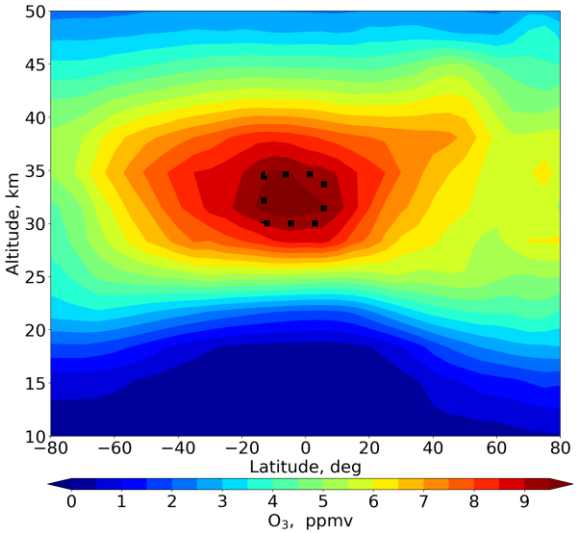
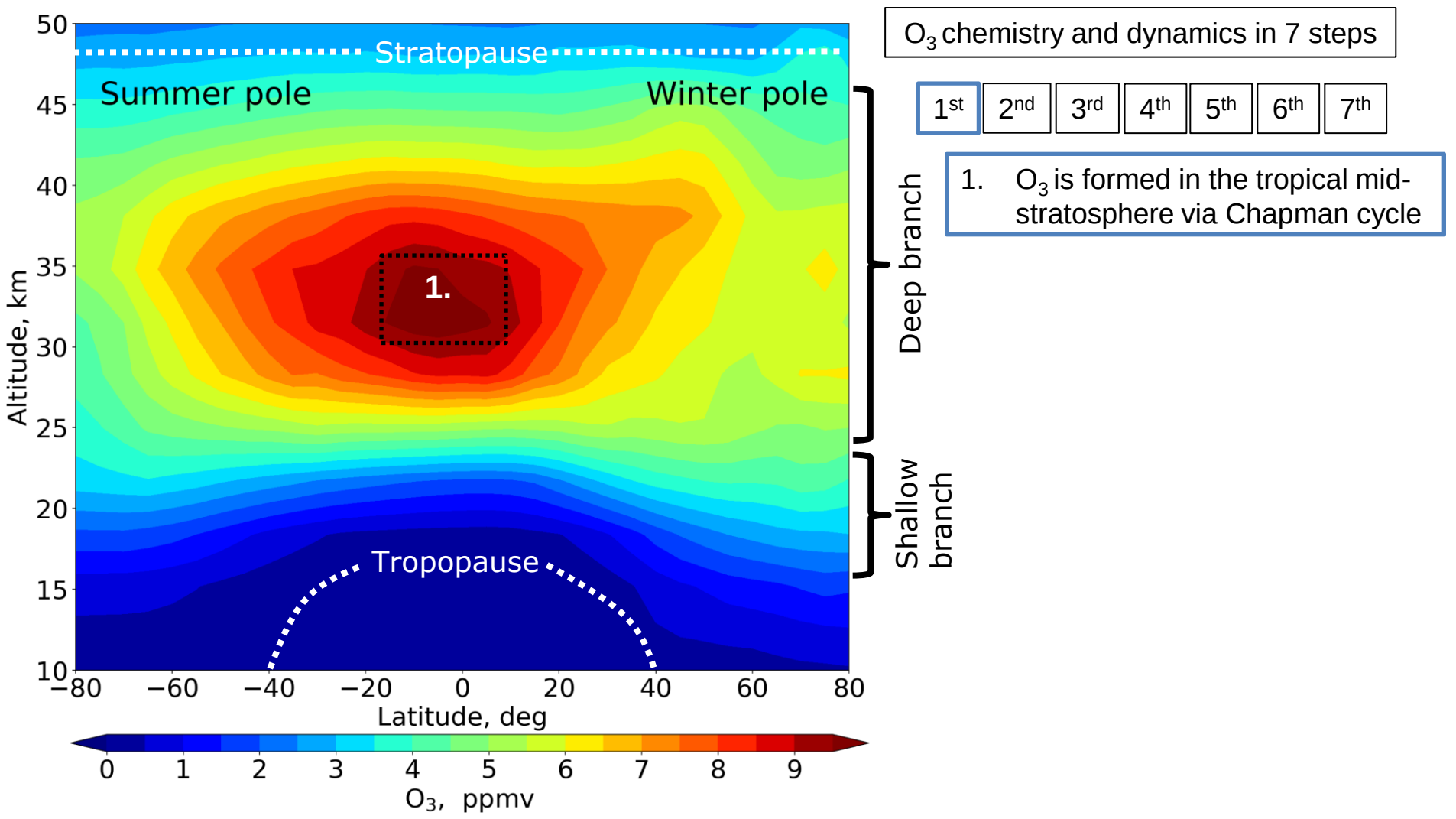


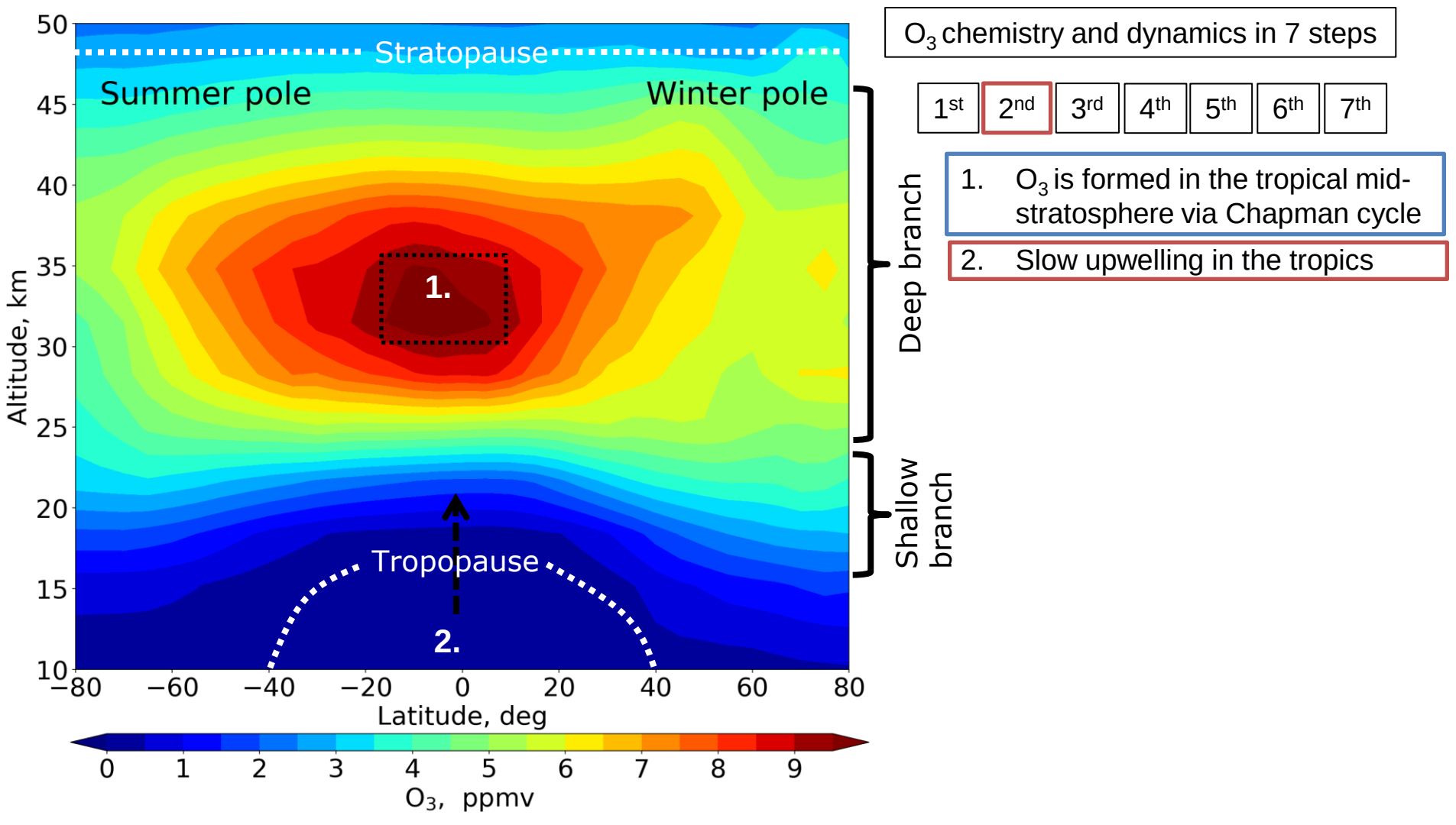
Galytska et al., ACP, 2019



O_3 chemistry and dynamics in 7 steps

1st	2nd	3rd	4th	5th	6th	7th

1. O_3 is formed in the tropical mid-stratosphere via Chapman cycle



O_3 chemistry and dynamics in 7 steps

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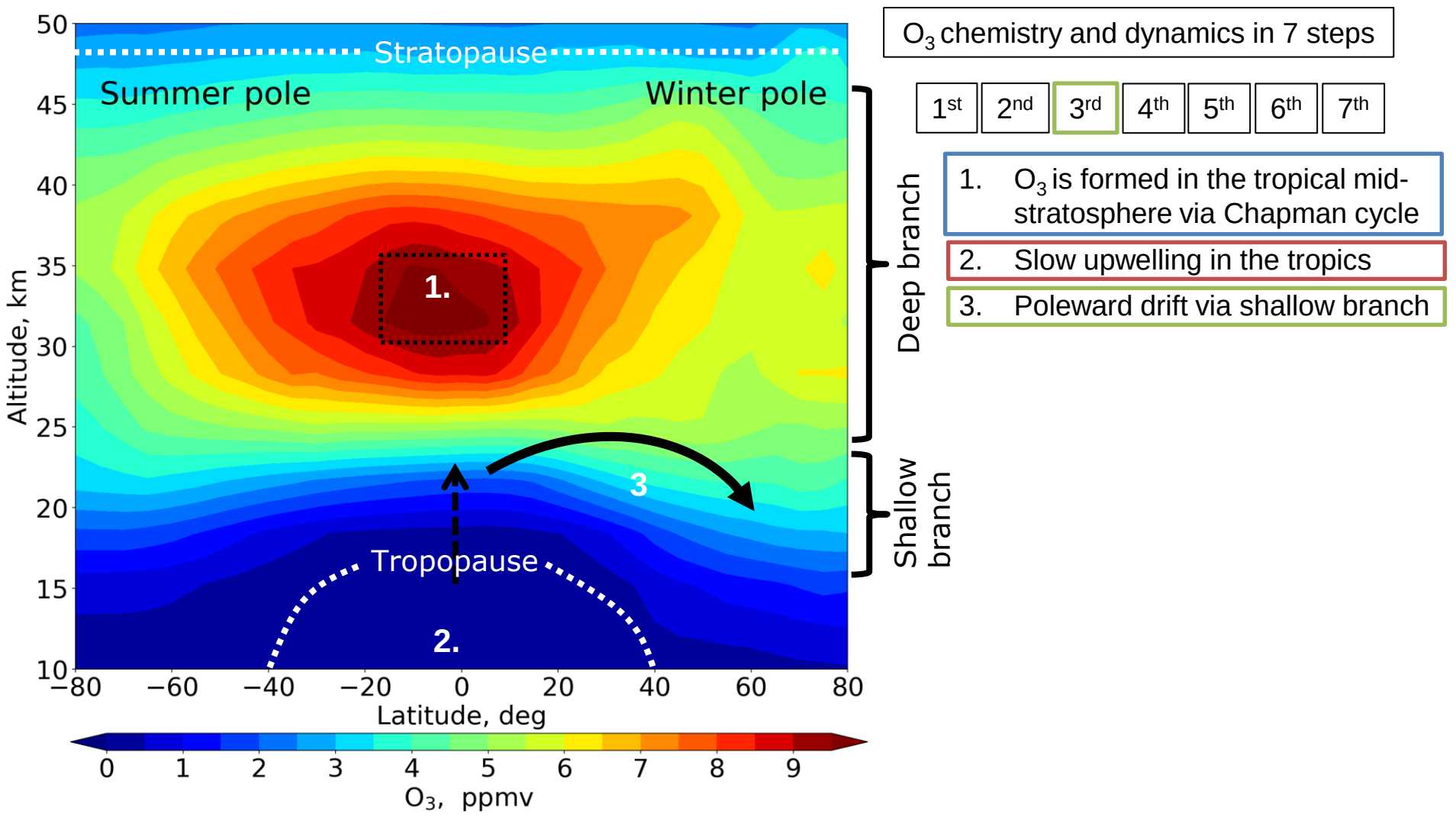
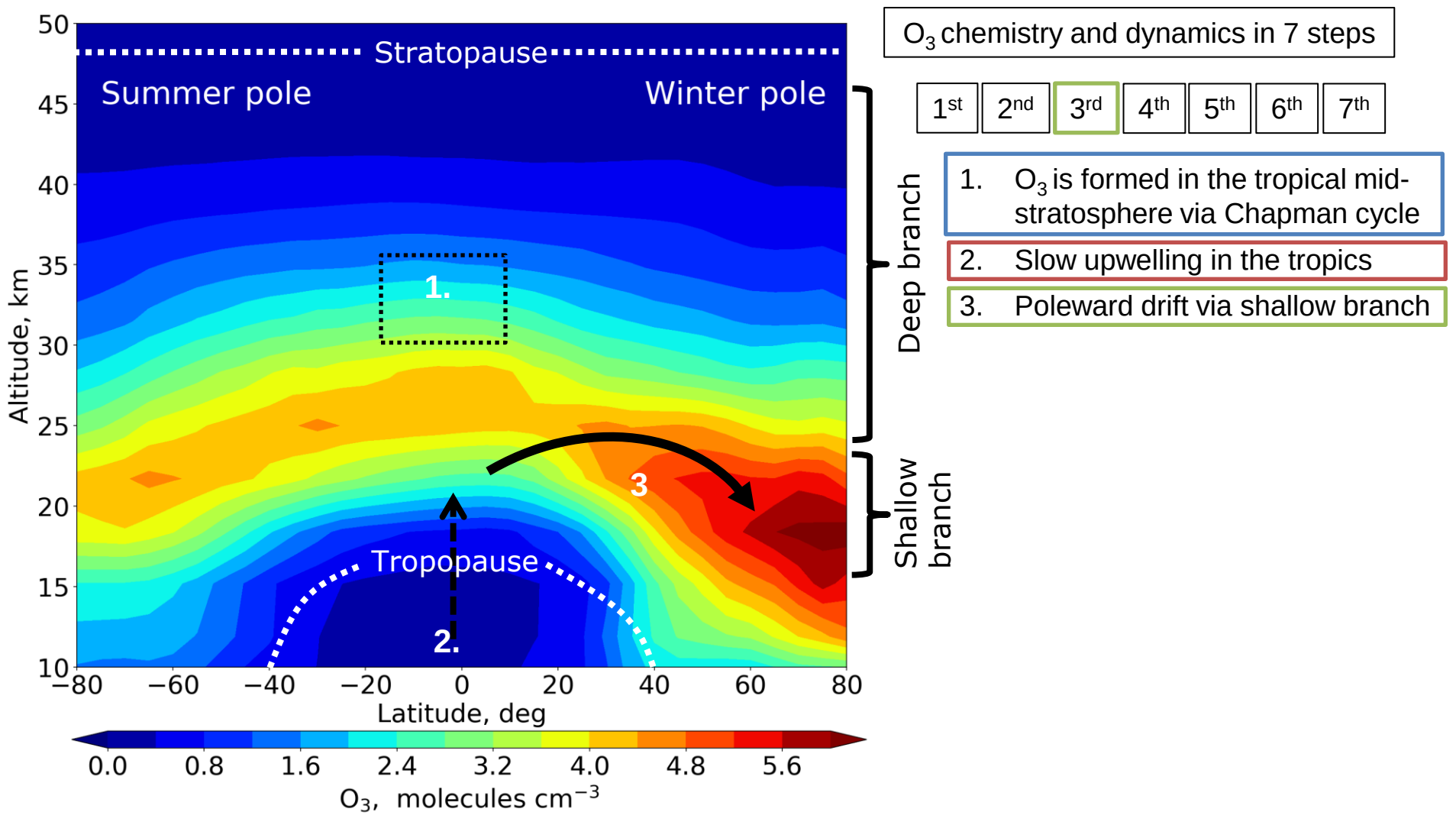
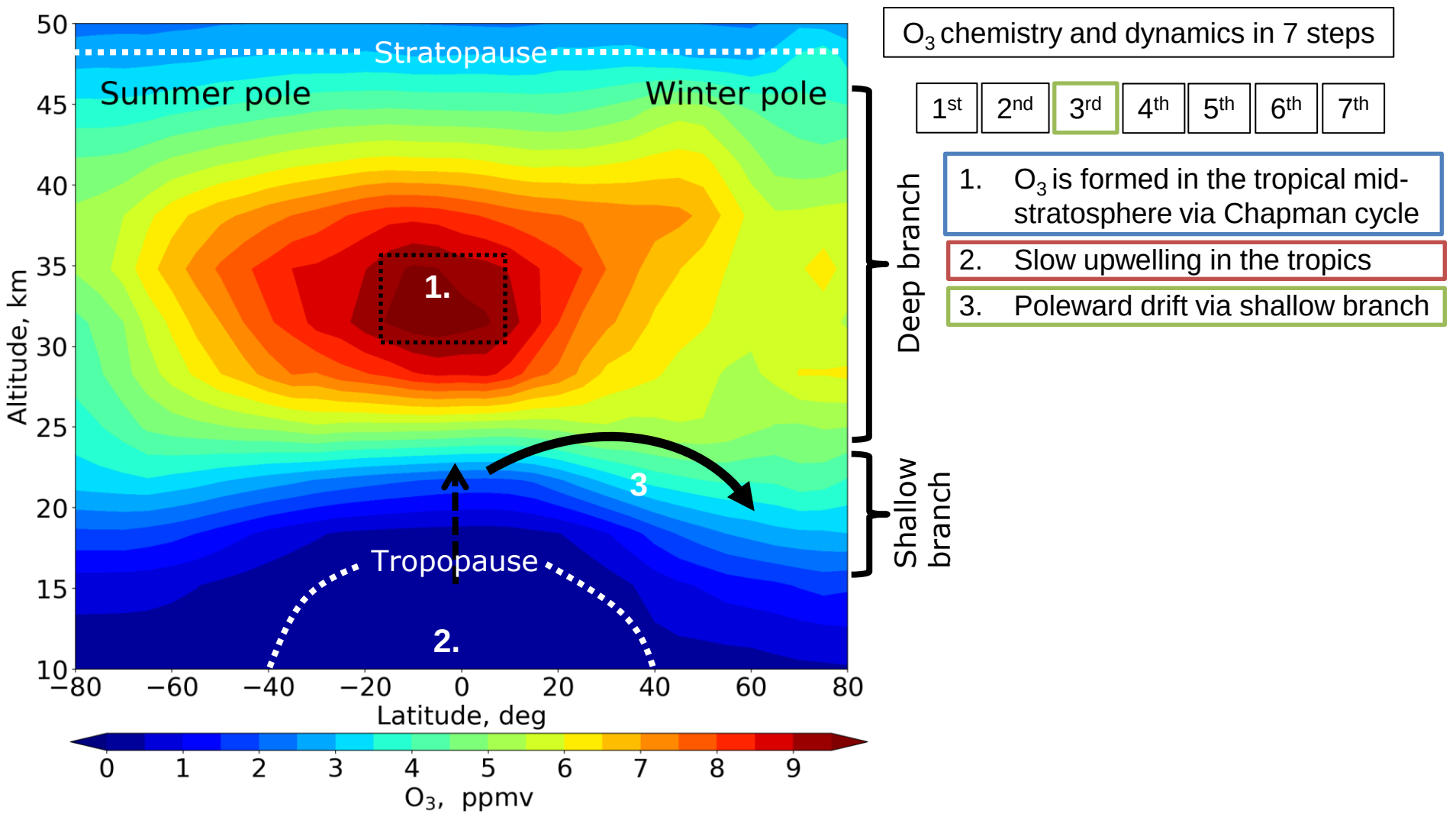
1. O_3 is formed in the tropical mid-stratosphere via Chapman cycle
2. Slow upwelling in the tropics


Stratopause
Summer pole
Winter pole
1.
2.
3
Tropopause
Altitude, km
50
45
40
35
30
25
20
15
10
−80
−60
−40
−20
0
20
40
60
80
Latitude, deg
0
1
2
3
4
5
6
7
8
9
O3, ppmv
O3 chemistry and dynamics in 7 steps
1st
2nd
3rd
4th
5th
6th
7th
Deep branch
Shallow branch
1. O3 is formed in the tropical mid-stratosphere via Chapman cycle
2. Slow upwelling in the tropics
3. Poleward drift via shallow branch


Stratopause
Summer pole
Winter pole
1.
2.
3
Tropopause
Altitude, km
Latitude, deg
O_3, molecules cm^{-3}
0.0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
O_3 chemistry and dynamics in 7 steps
1st
2nd
3rd
4th
5th
6th
7th
1. O_3 is formed in the tropical mid-stratosphere via Chapman cycle
2. Slow upwelling in the tropics
3. Poleward drift via shallow branch
Deep branch
Shallow branch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20
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60
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Latitude, deg
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1
2
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6
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8
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O3, ppmv
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1st
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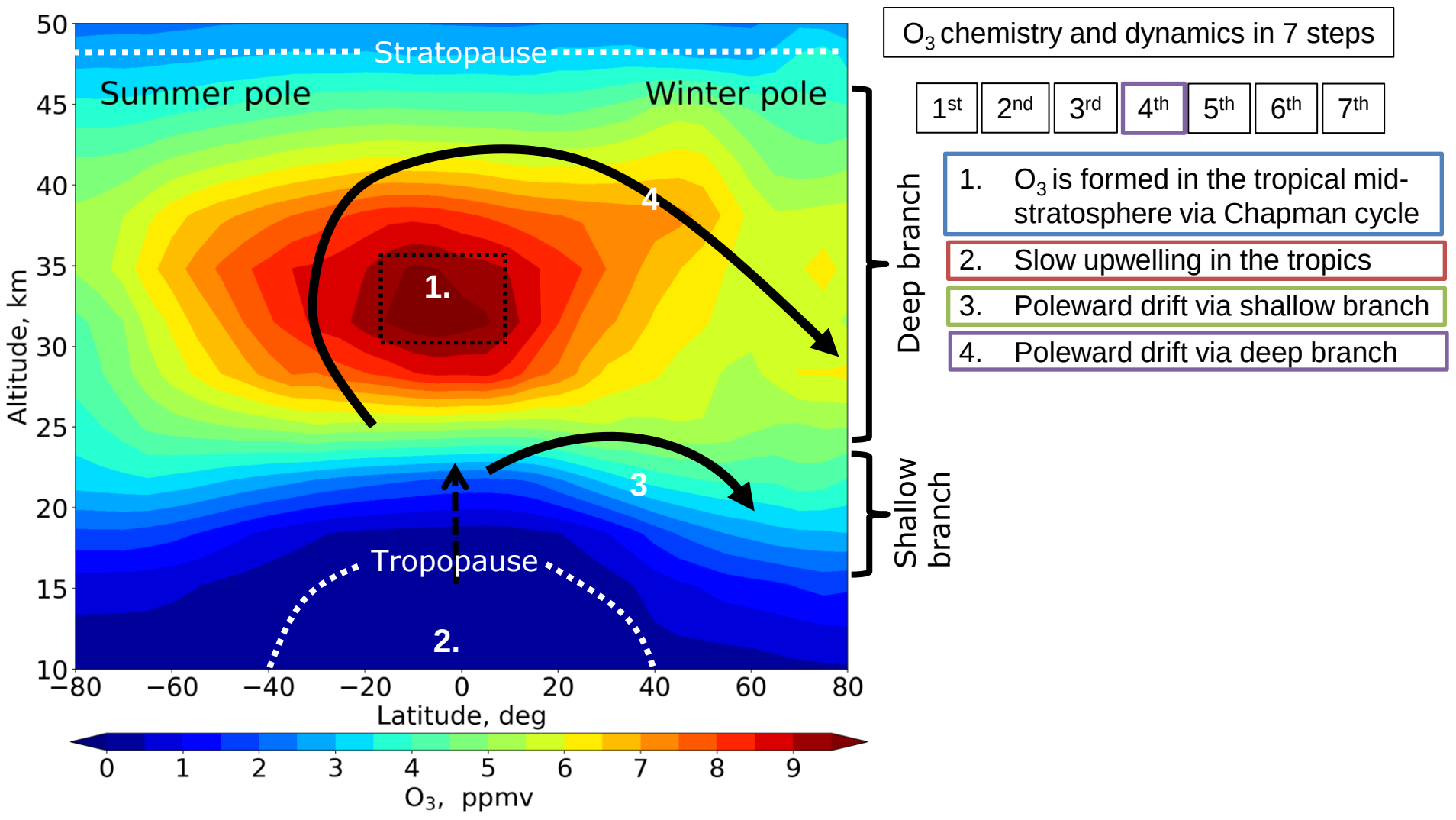
Stratopause
Summer pole
Winter pole
Tropopause
1.
2.
3
4
Altitude, km
Latitude, deg
O_3, ppmv
Deep branch
Shallow branch
O_3 chemistry and dynamics in 7 steps
1st 2nd 3rd 4th 5th 6th 7th
1. O_3 is formed in the tropical mid-stratosphere via Chapman cycle
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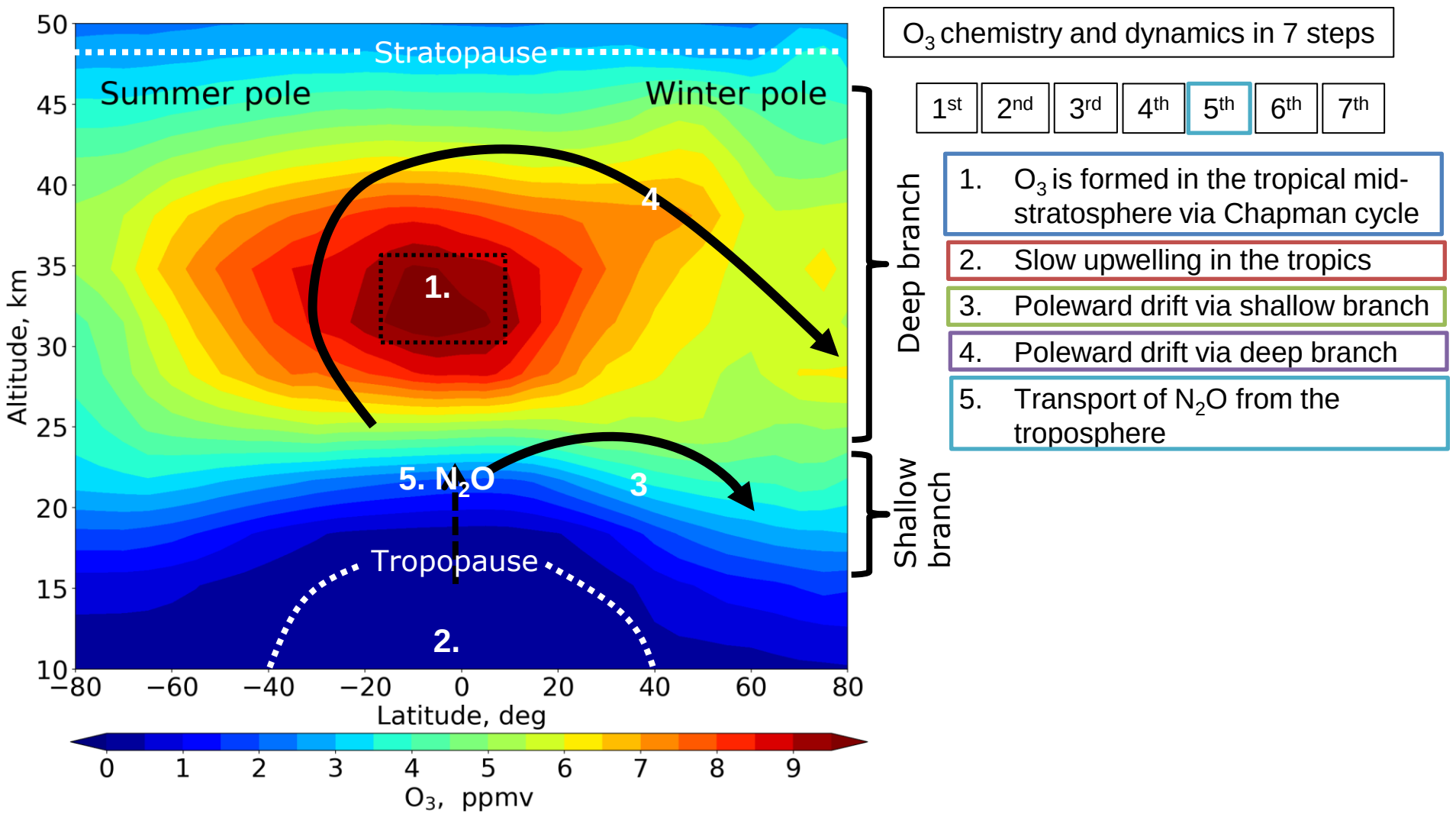
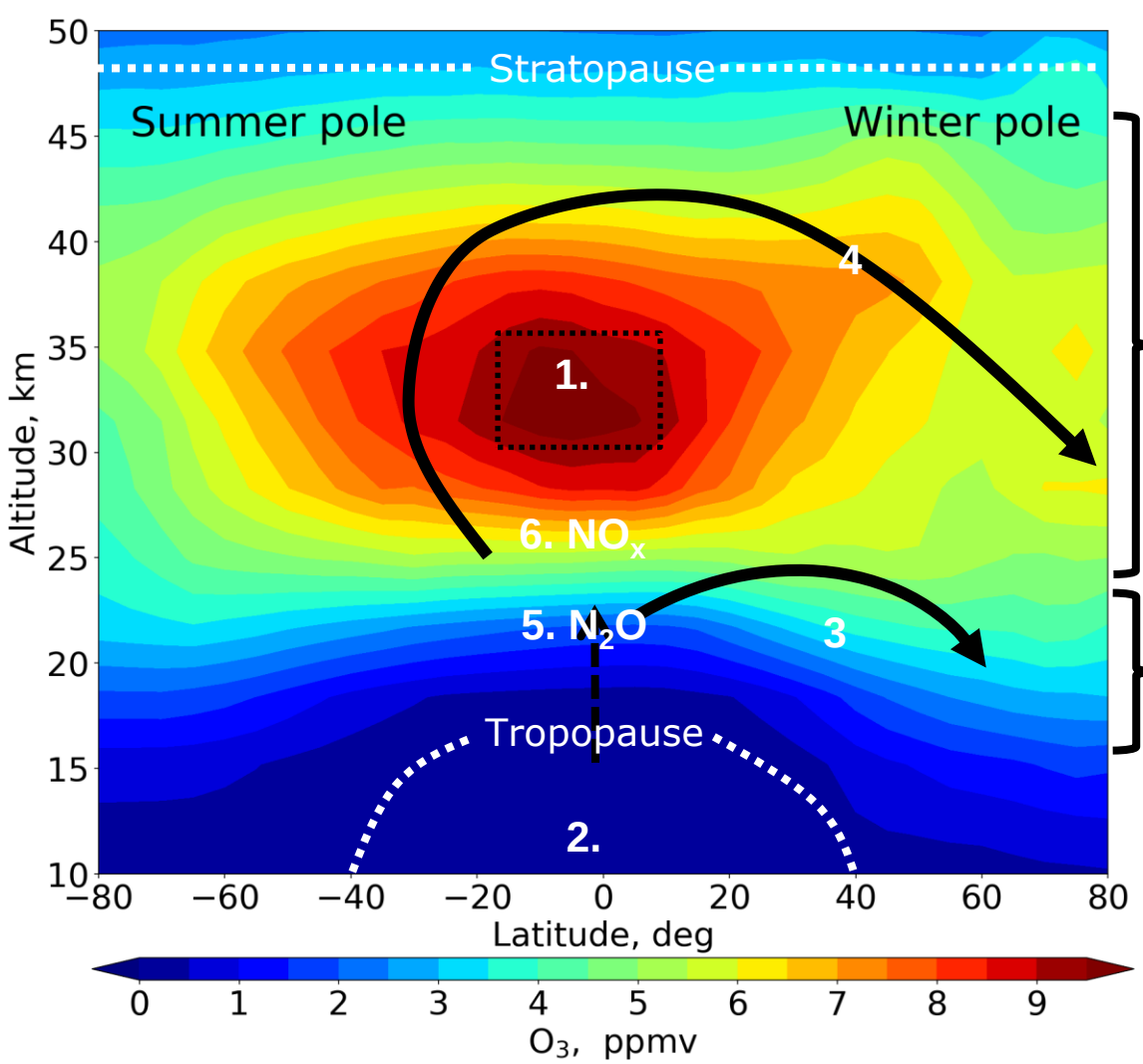
3. Poleward drift via shallow branch
4. Poleward drift via deep branch



O_3 chemistry and dynamics in 7 steps

1st | 2nd | 3rd | 4th | **5th** | 6th | 7th

1. O_3 is formed in the tropical mid-stratosphere via Chapman cycle
2. Slow upwelling in the tropics
3. Poleward drift via shallow branch
4. Poleward drift via deep branch
5. Transport of N_2O from the troposphere



O_3 chemistry and dynamics in 7 steps

1st | 2nd | 3rd | 4th | 5th | 6th | 7th

Deep branch

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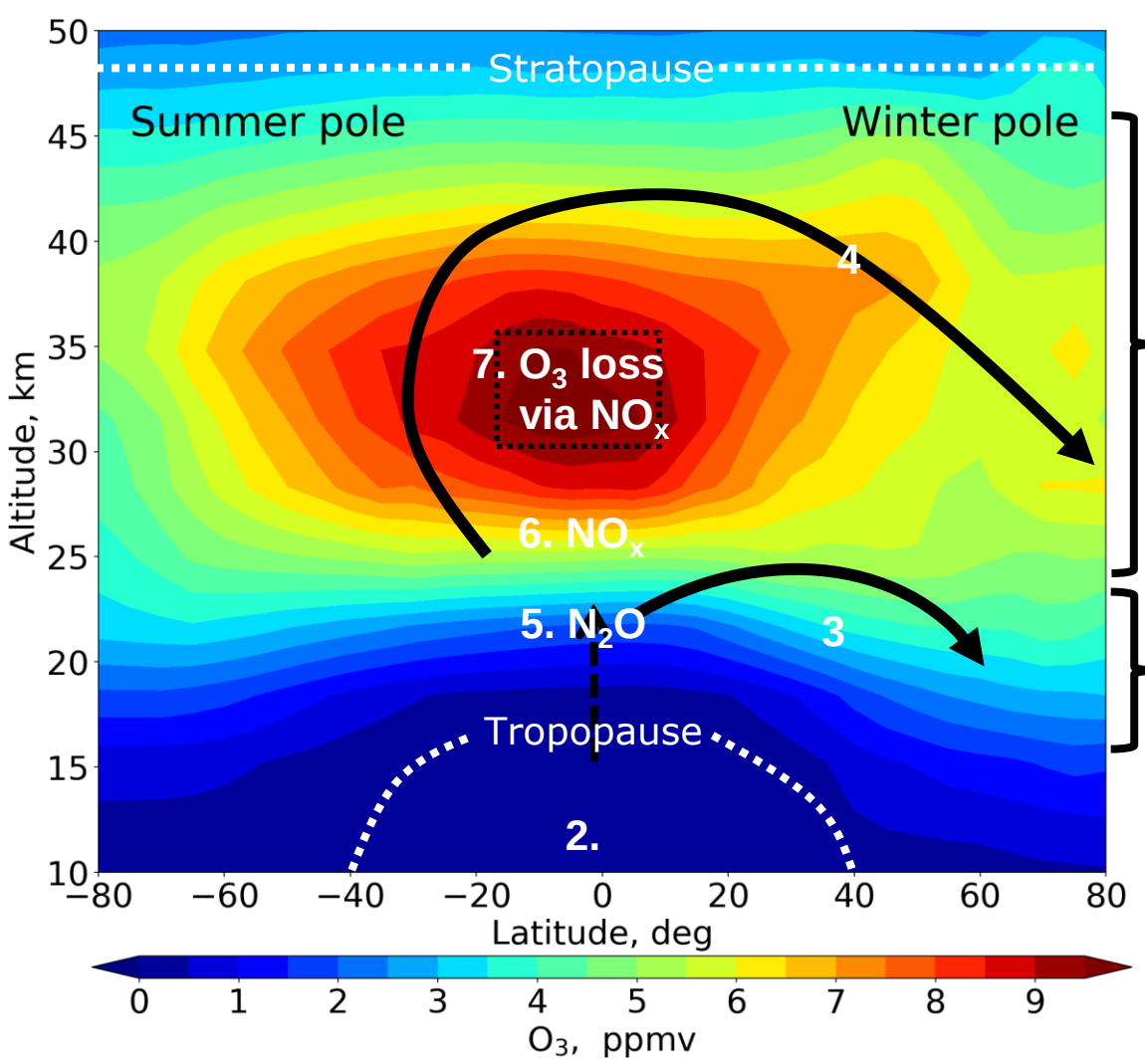
3. Poleward drift via shallow branch
4. Poleward drift via deep branch
5. Transport of N_2O from the troposphere

Shallow branch

6. Formation of NO_x (NO+NO2):
   $N_2O + O(^1D) \rightarrow 2\ NO$



O_3 chemistry and dynamics in 7 steps

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Deep branch

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4. Poleward drift via deep branch
5. Transport of N_2O from the troposphere

Shallow branch

6. Formation of NO_x (NO+NO2):
   $N_2O + O(^1D) \rightarrow 2\ NO$
7. O_3 destruction via NO_x:
   $NO + O_3 \rightarrow NO_2 + O_2$
   $NO_2 + O \rightarrow NO + O_2$

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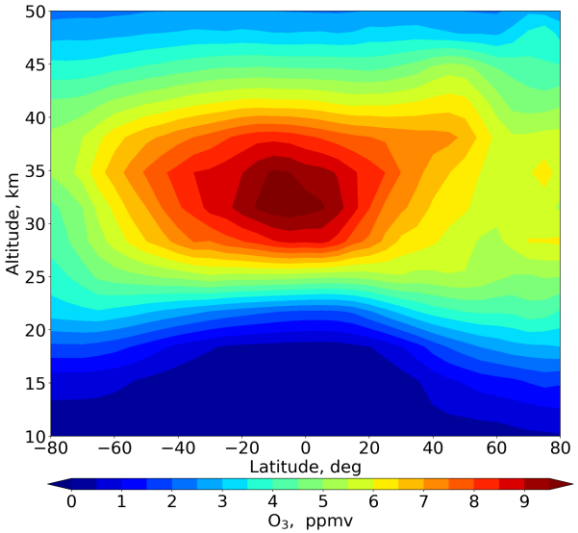
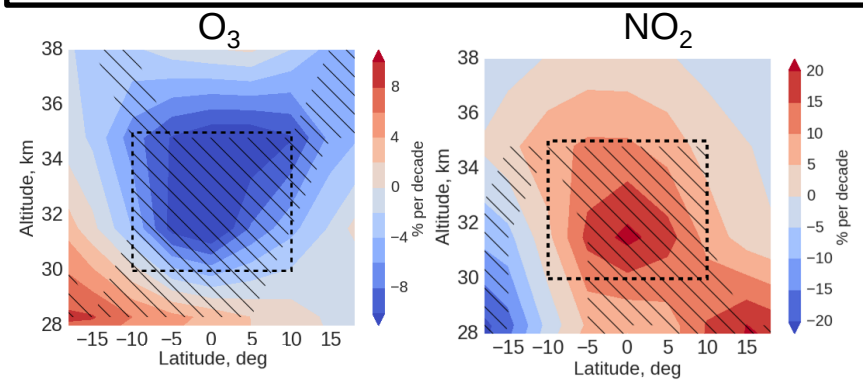
O_3 changes in the tropical mid- stratosphere



Galytska et al., ACP, 2019

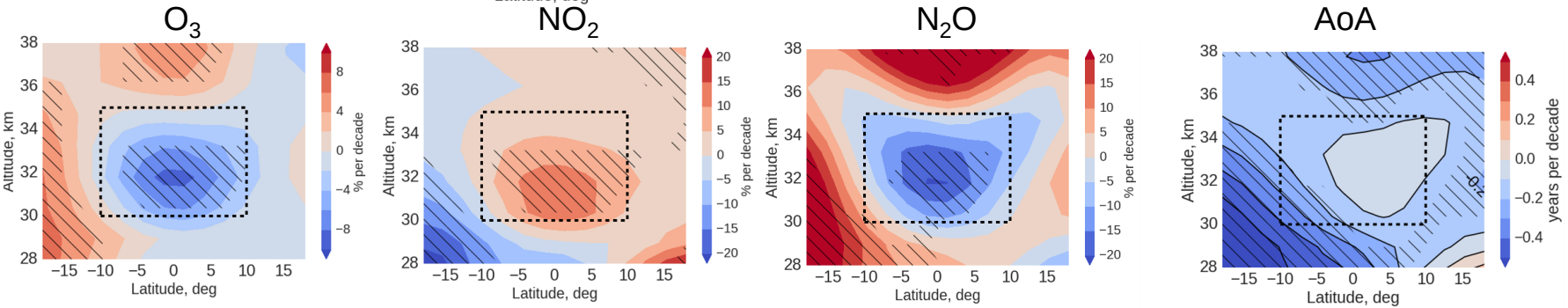
Observed and modelled changes in the tropical mid-stratosphere during 2004-2012

SCIAMACHY



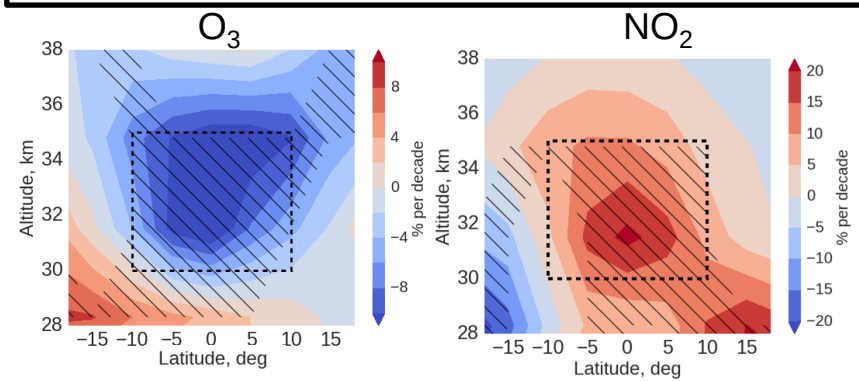
Increase of NO_2 causes O_3 decline in the tropical mid-stratosphere.

TOMCAT



Observed and modelled changes in the tropical mid-stratosphere during 2004-2012

SCIAMACHY



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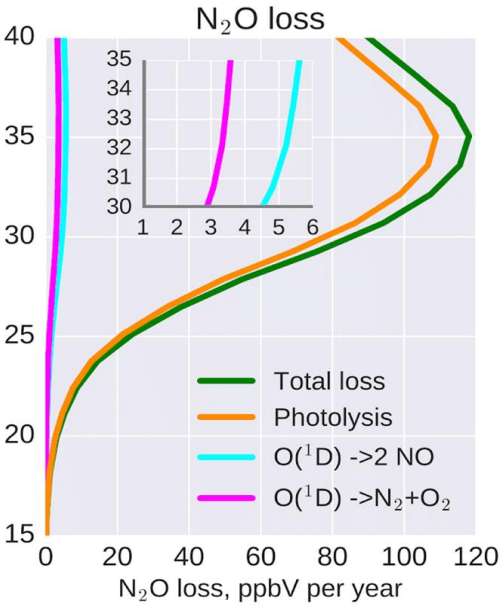


Negative N_2O changes could be driven by:

(1) Increase of *hV*

$N_2O + hV \rightarrow N_2 + O(^1D)$

Does not explain the increase of NO_x

(2) Increase of $O(^1D)$

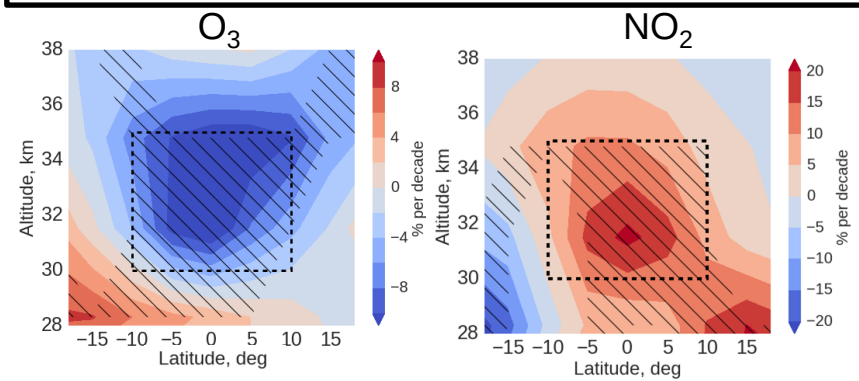
$N_2O + O(^1D) \rightarrow 2\ NO$

$O(^1D)$ destroys only ~ 5% of all N_2O

(3) BDC slow-down (suggested by *Nedoluha et al., 2015*) or positive AoA trend

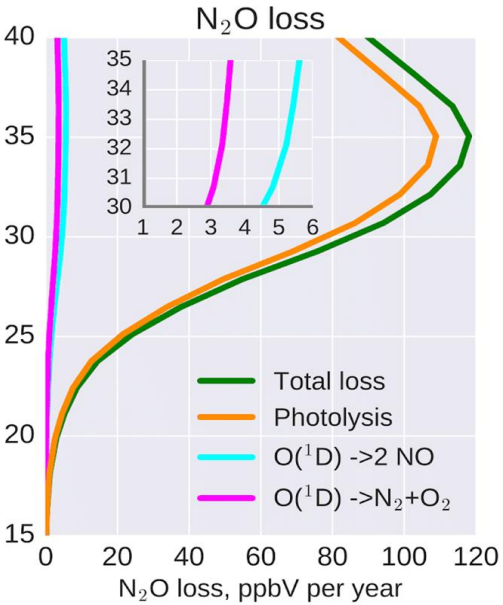
Observed and modelled changes in the tropical mid-stratosphere during 2004-2012

SCIAMACHY



Increase of NO_2 causes O_3 decline in the tropical mid-stratosphere.

TOMCAT



Negative N_2O changes could be driven by:

(1) Increase of *hV*

$N_2O + hV \rightarrow N_2 + O(^1D)$

Does not explain the increase of NO_x

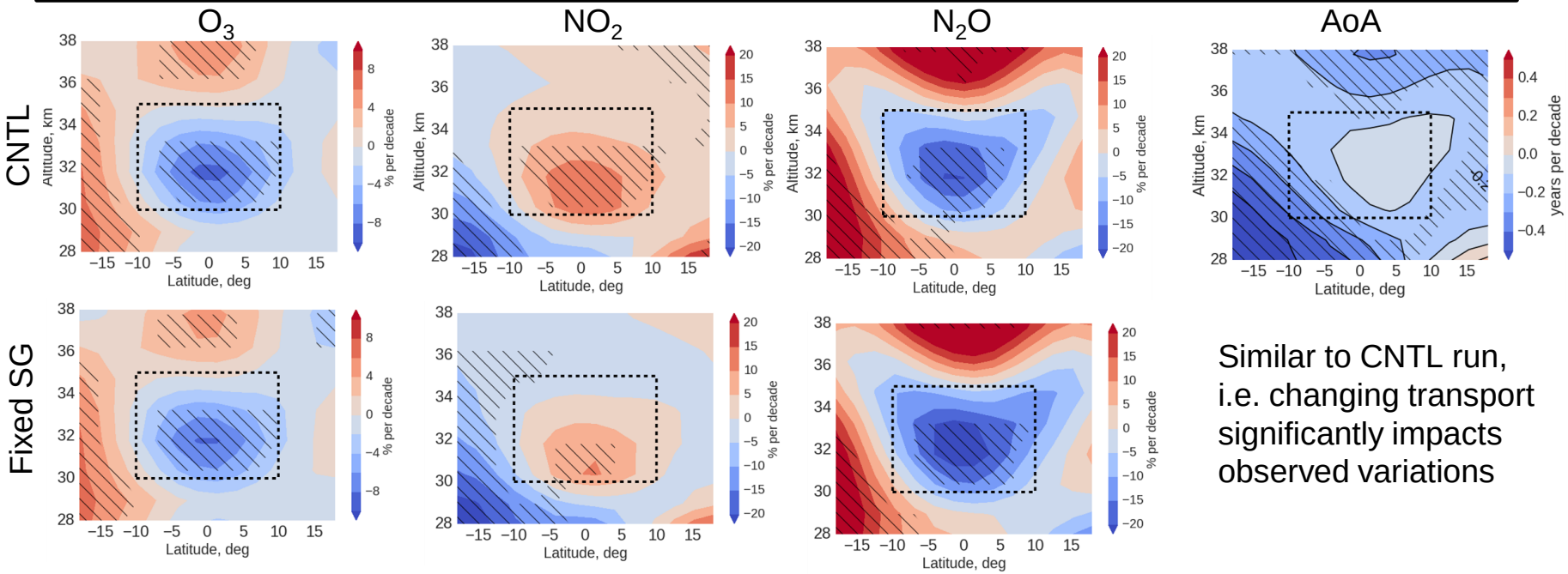
(2) Increase of $O(^1D)$

$N_2O + O(^1D) \rightarrow 2\,NO$

$O(^1D)$ destroys only ~ 5% of all N_2O

(3) BDC slow-down (suggested by *Nedoluha et al., 2015*) or positive AoA trend

Observed and modelled changes in the tropical mid-stratosphere during 2004-2012



Similar to CNTL run, i.e. changing transport significantly impacts observed variations

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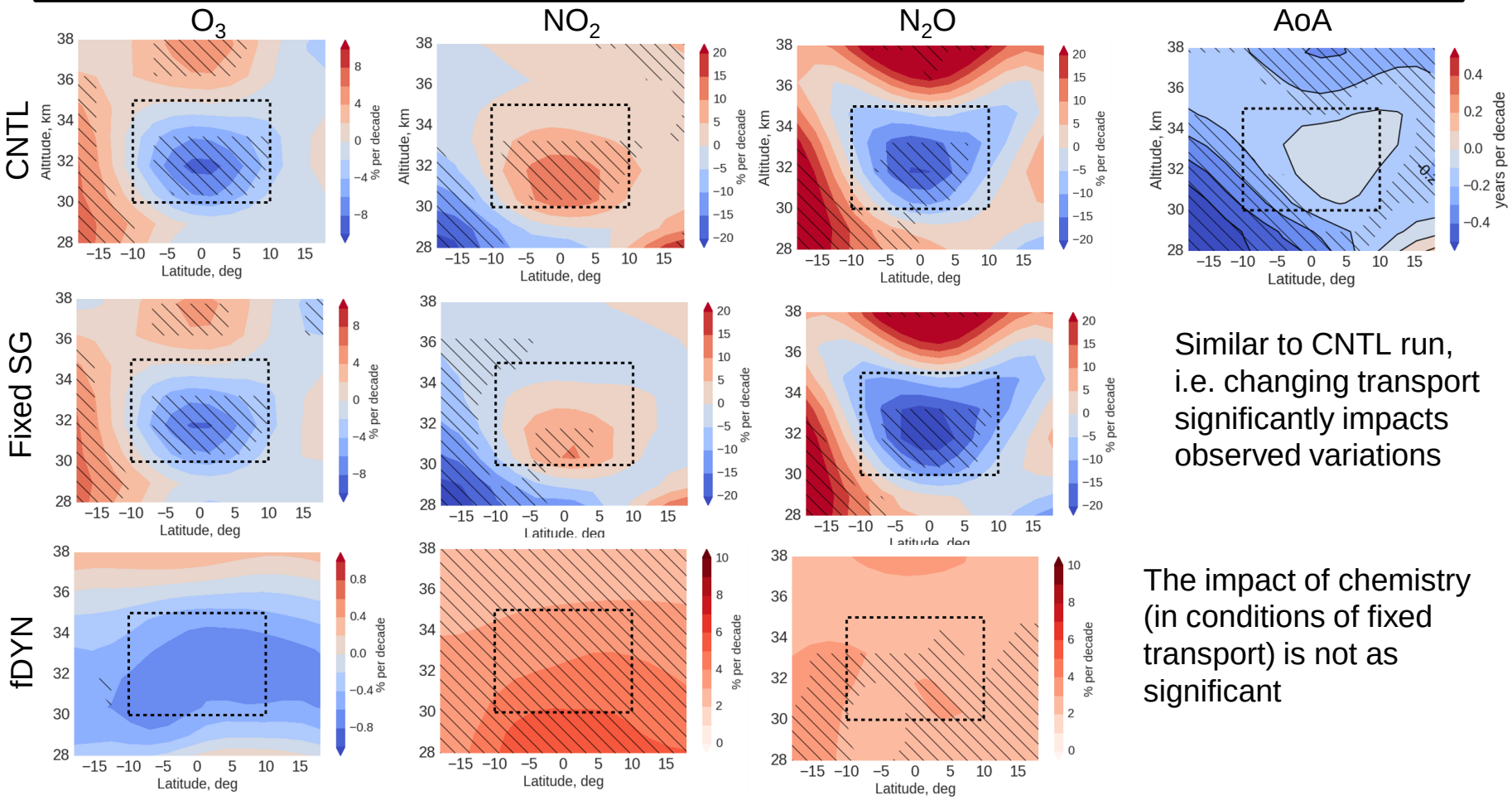

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The impact of chemistry (in conditions of fixed transport) is not as significant

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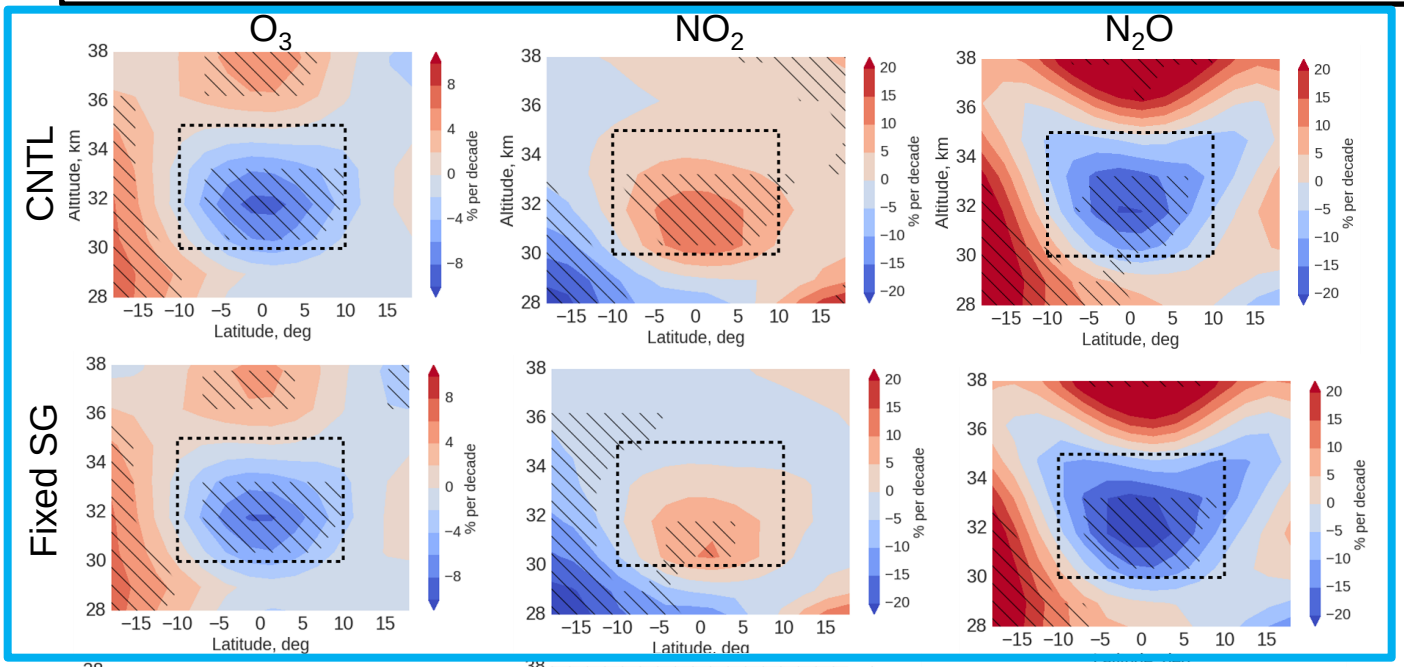

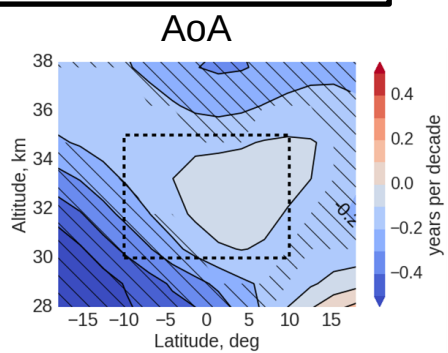

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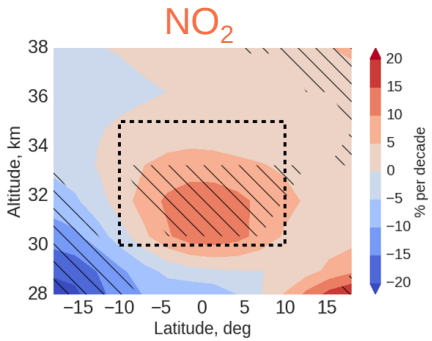
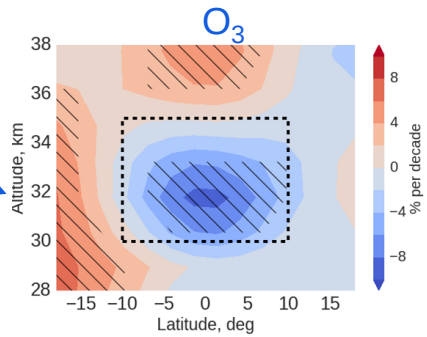
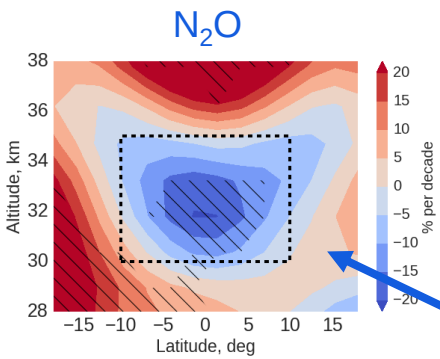
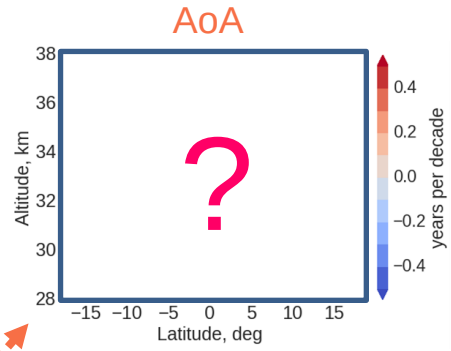
What is the assumption of O_3 changes ?









Less O_3

More NO_x

More NO_x is produced via $N_2O + O(^1D)$

Longer N_2O residence time

Less N_2O is transported

Slowdown of tropical upwelling

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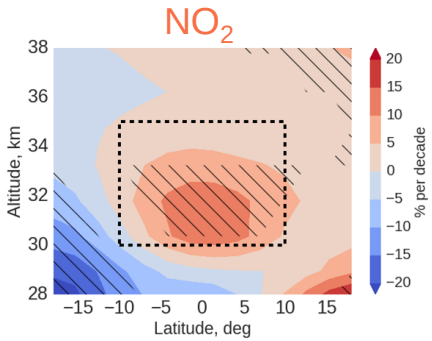

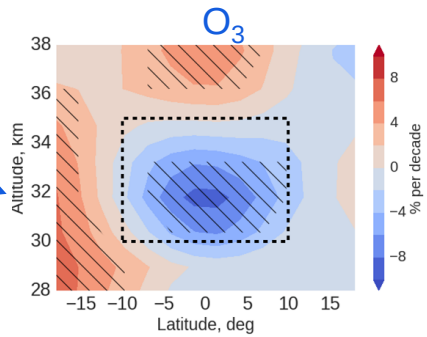

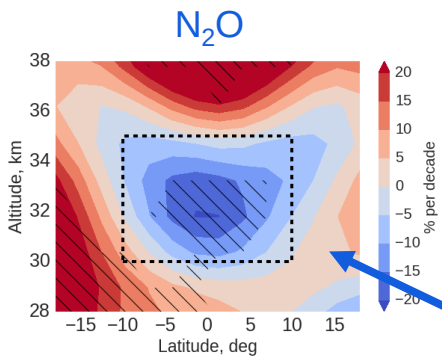

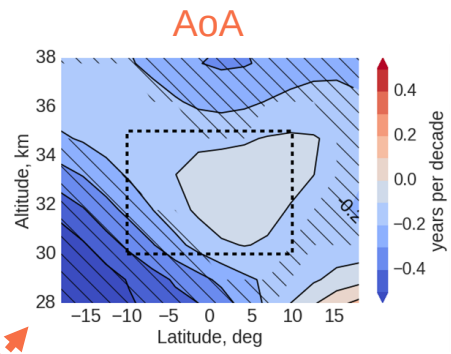

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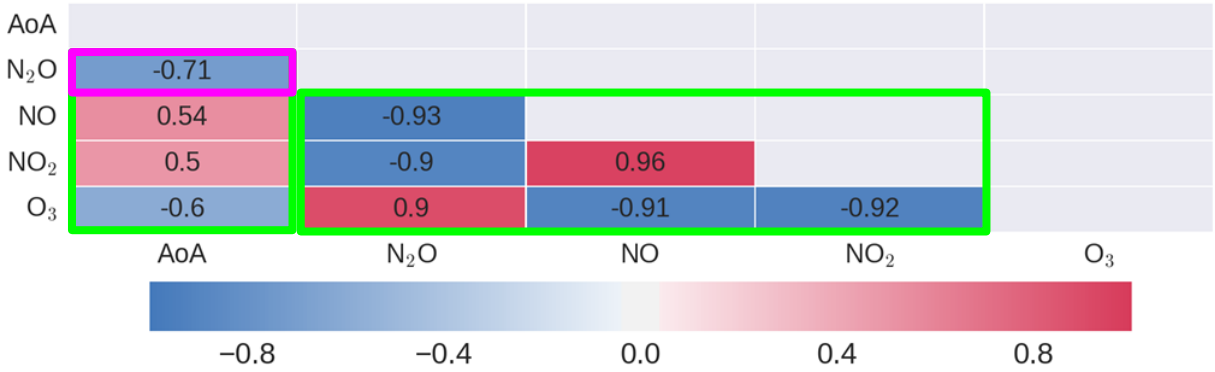
Correlation features in the tropical mid-stratosphere: AoA, N_2O, NO_x, O_3



Based on monthly mean TOMCAT data during 2004-2012

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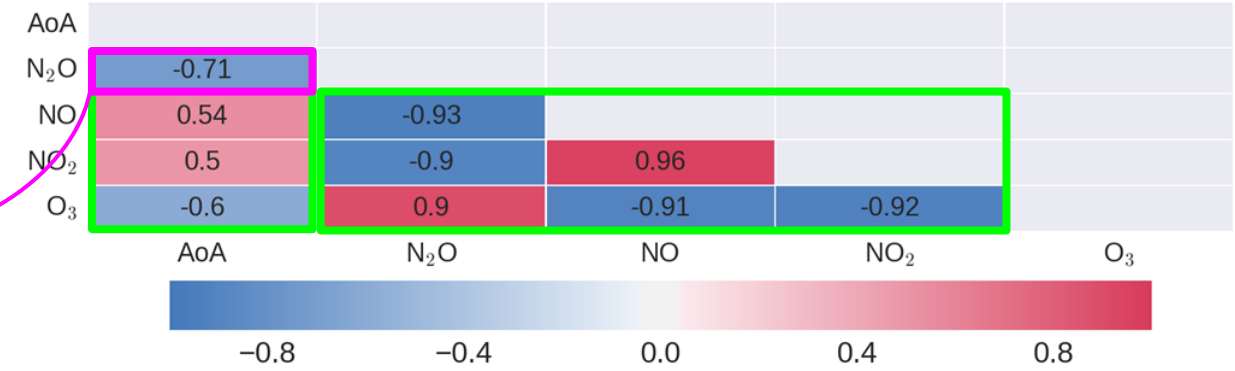

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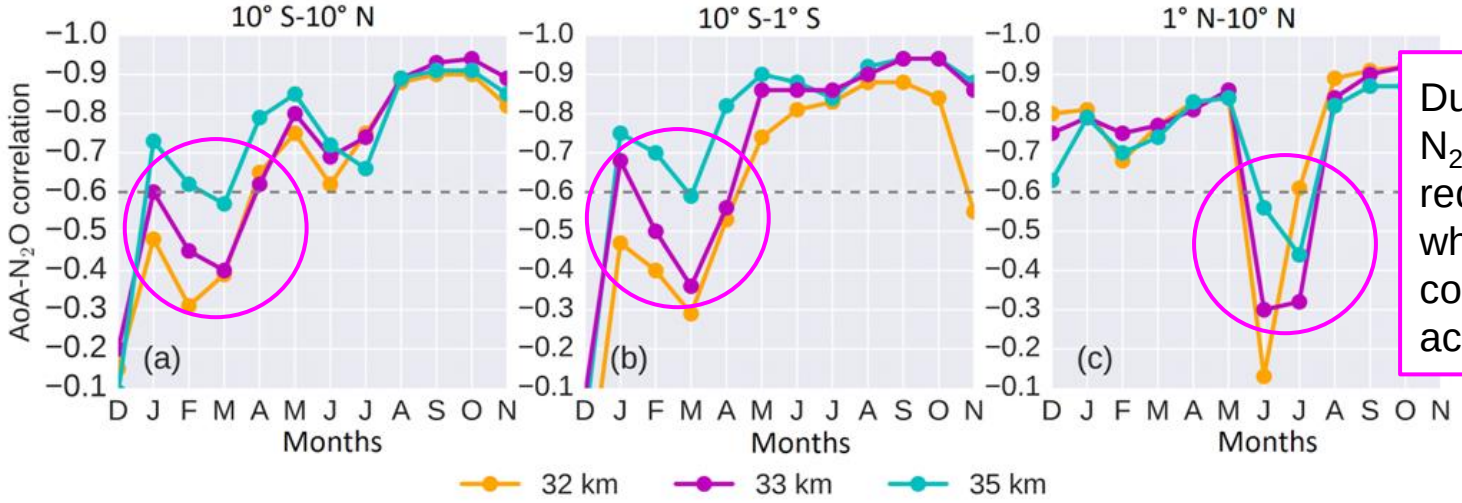
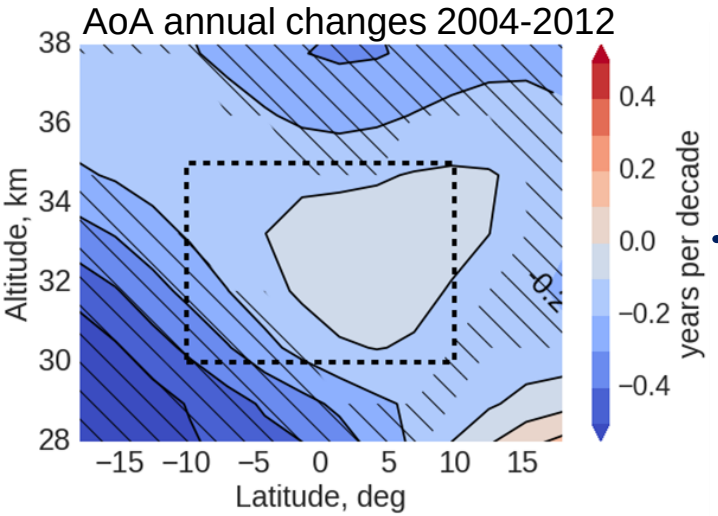
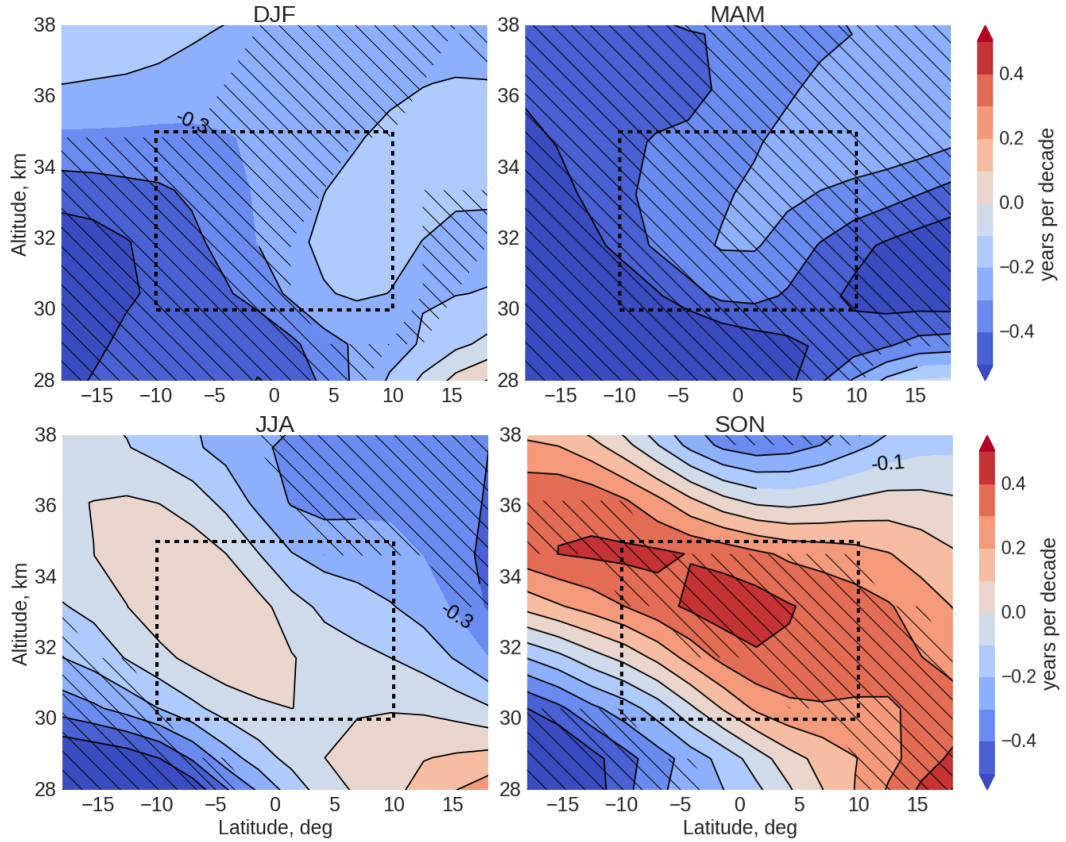


During local summers N_2O-AoA correlation reduces significantly, which can be connected to low wave activity.

TOMCAT AoA seasonal changes 2004-2012

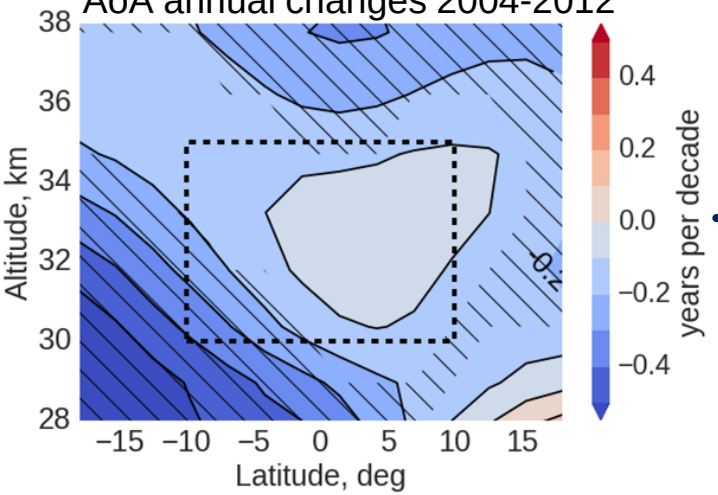


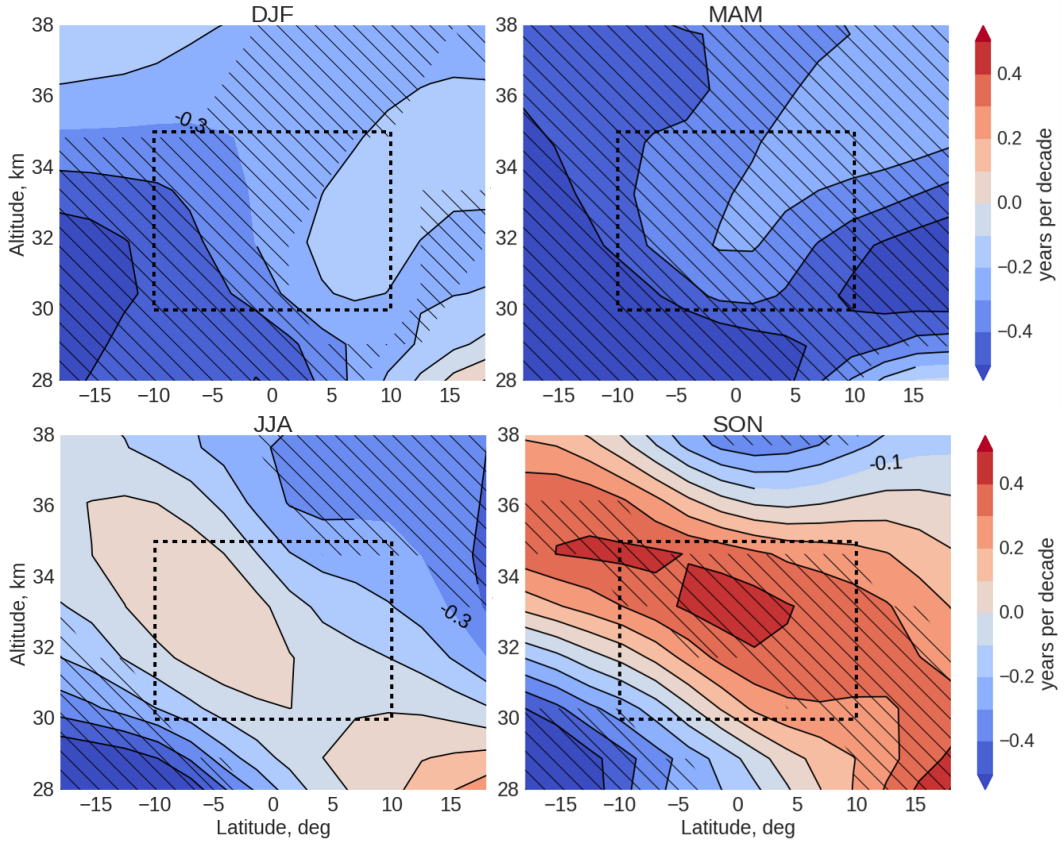


TOMCAT AoA seasonal changes 2004-2012

DJF and MAM → the transport is speeding up significantly

AoA annual changes 2004-2012





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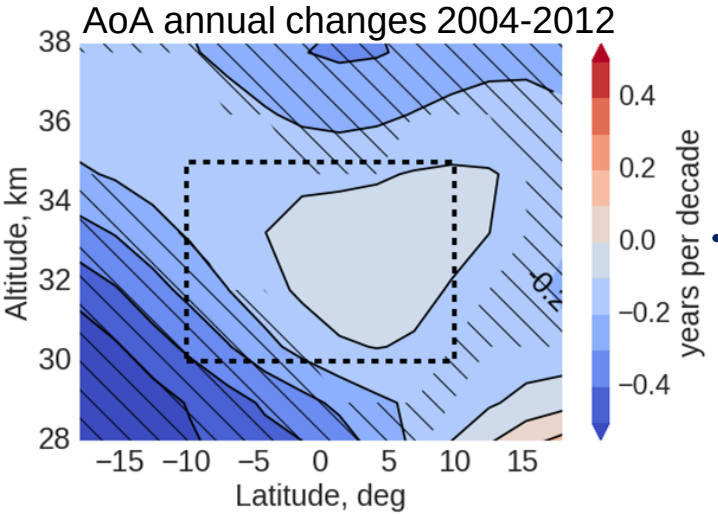

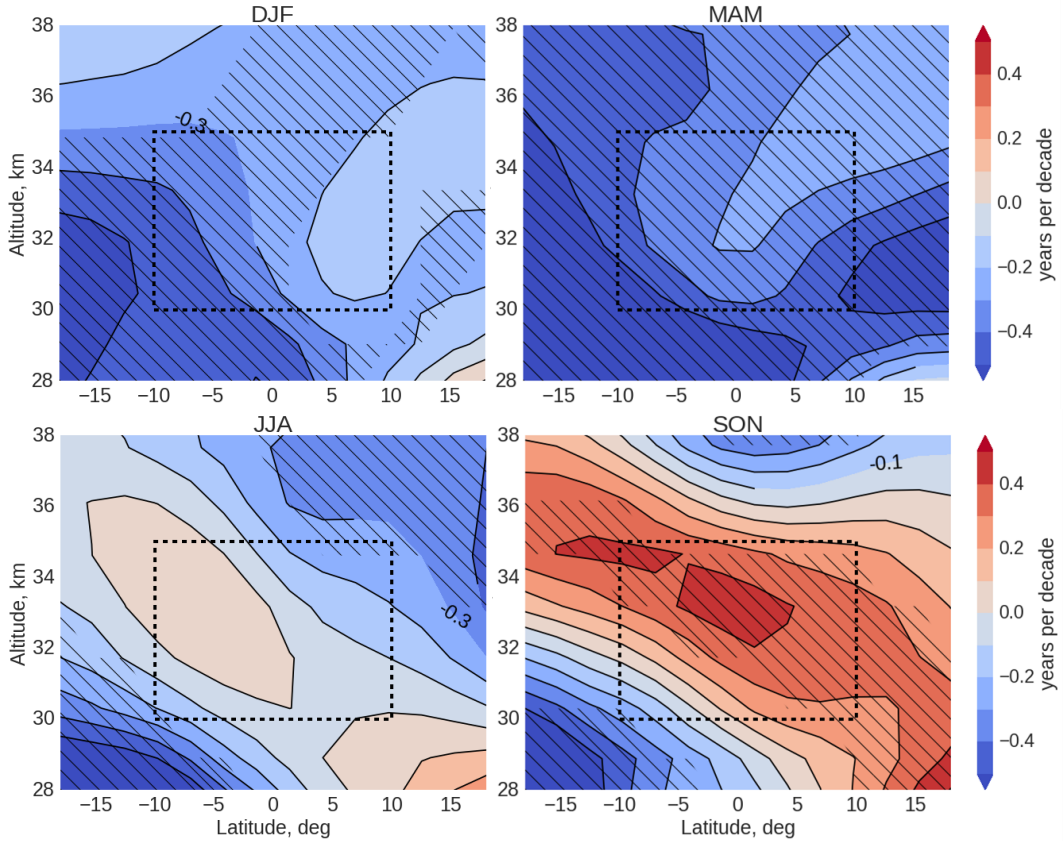

SON → the transport is slowing down significantly

TOMCAT AoA seasonal changes 2004-2012

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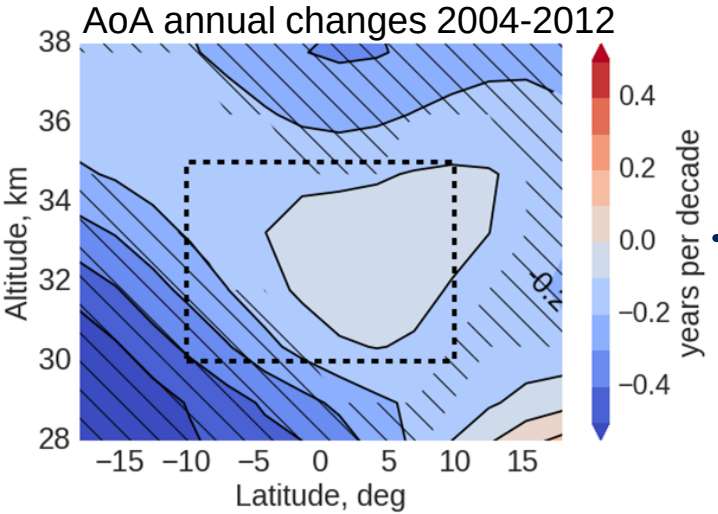

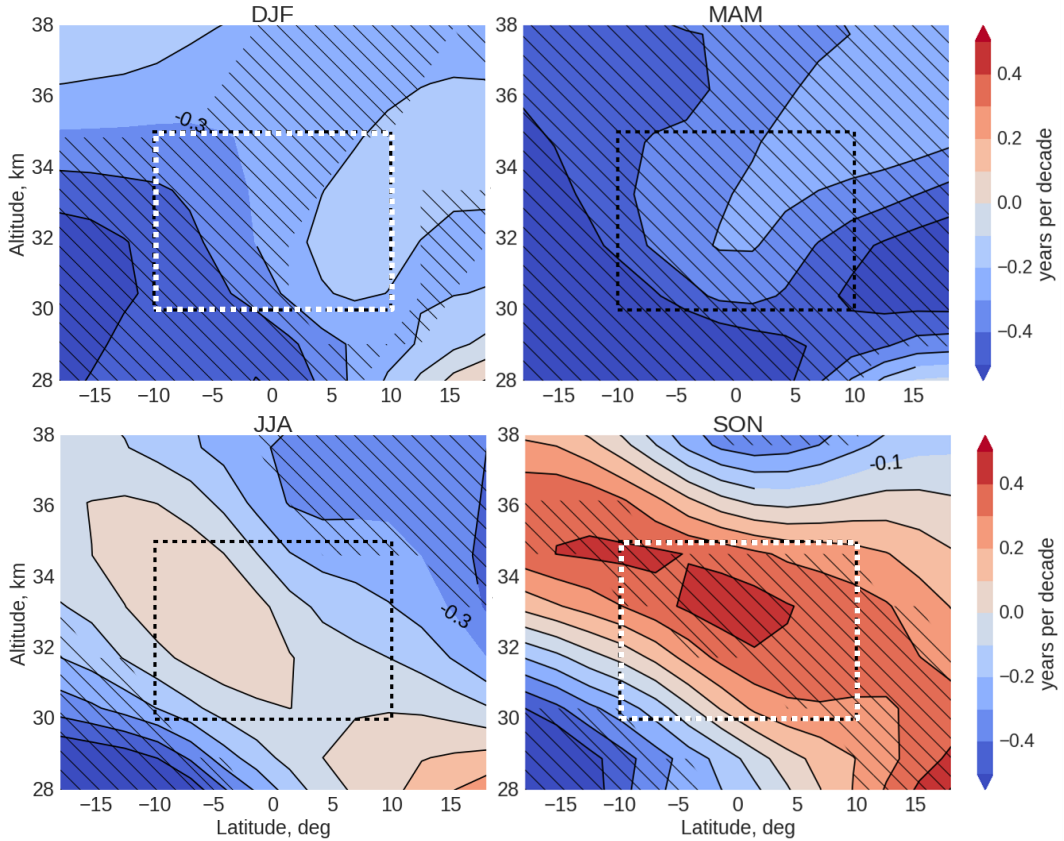

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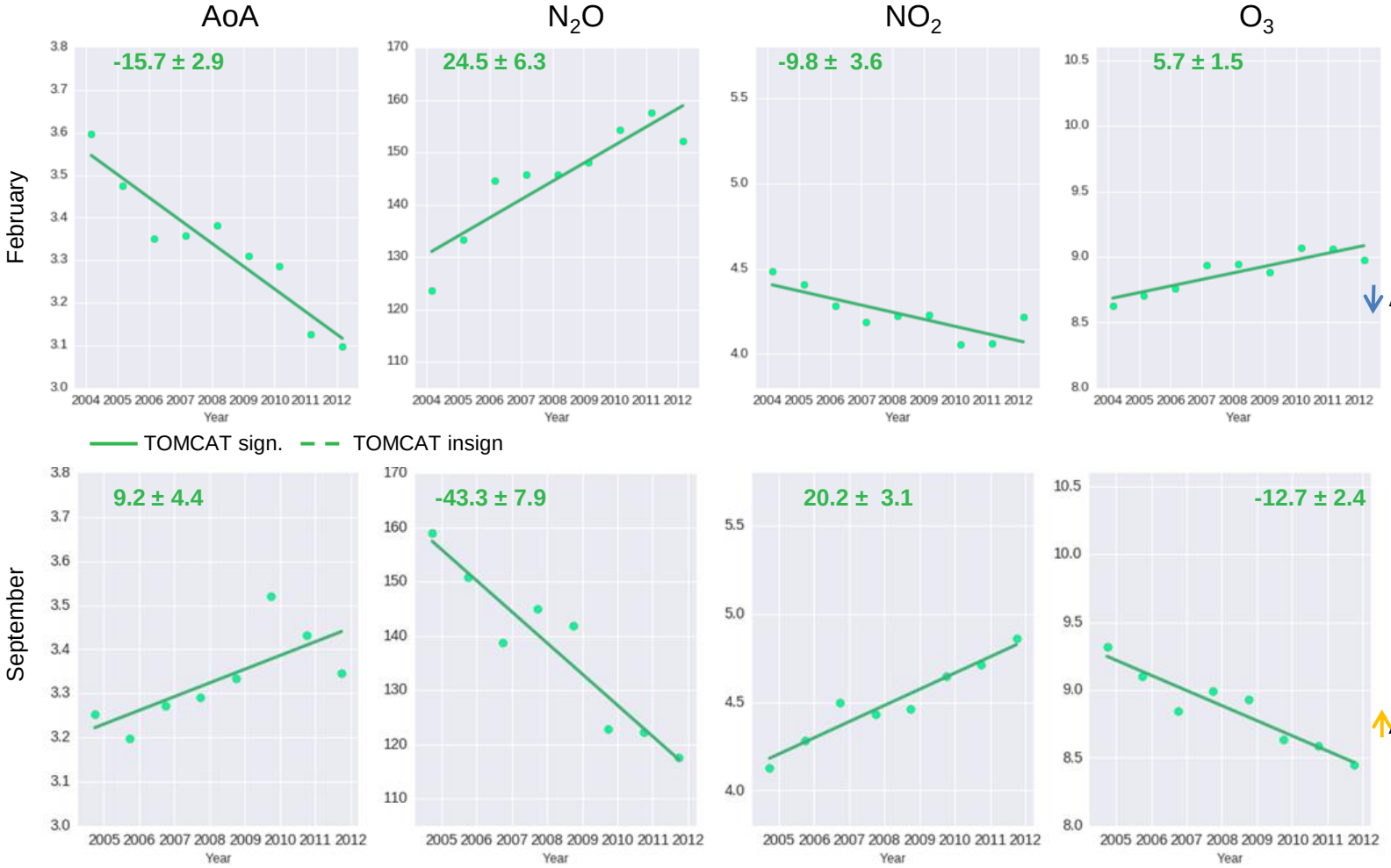
What do changes (2004-2012) in tropical stratosphere at 30-35 km say?



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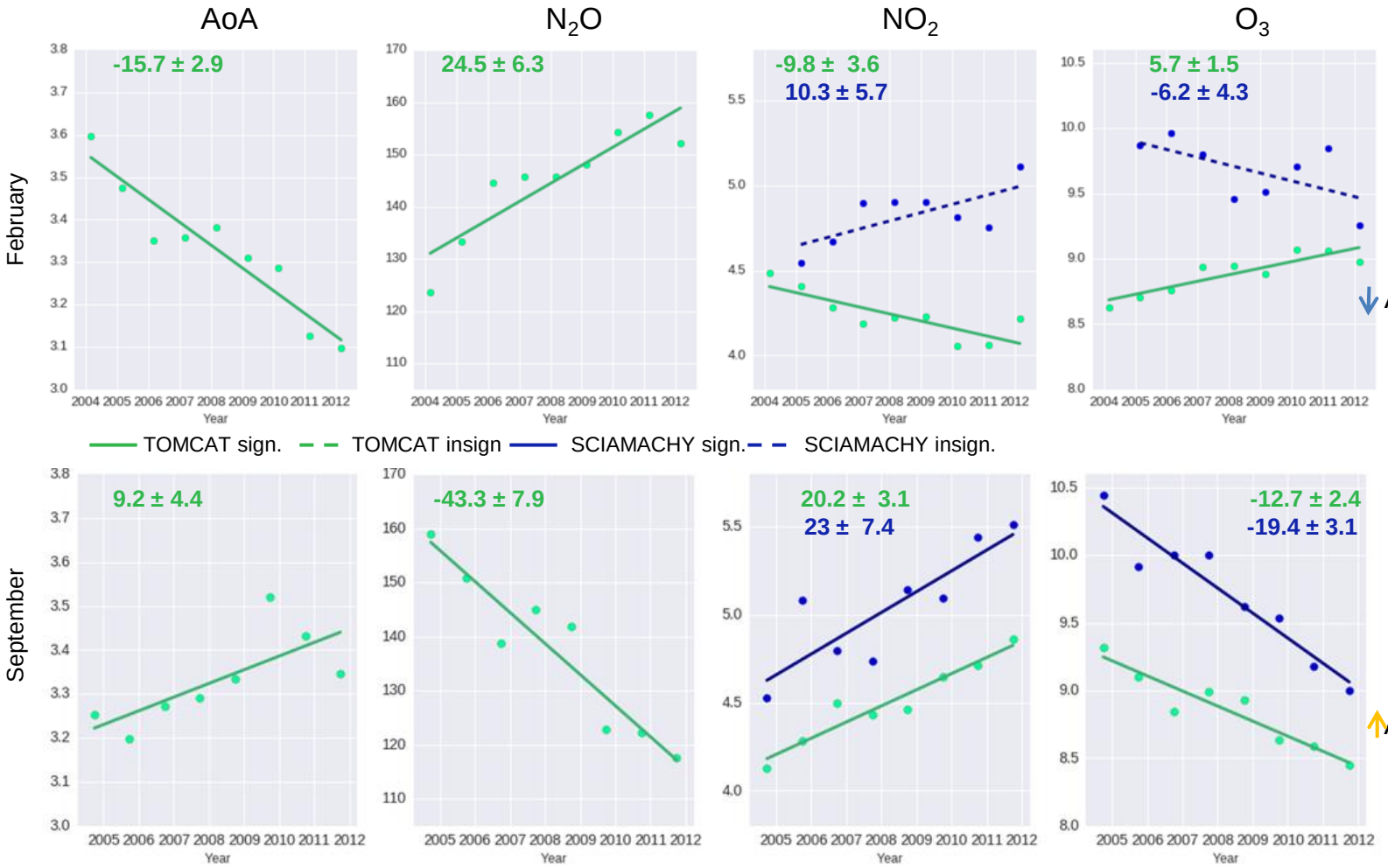

Similar conditions are observed in January.

↓AoA ↑N_2O ↓NO_2 ↑O_3

Similar conditions are observed in October.

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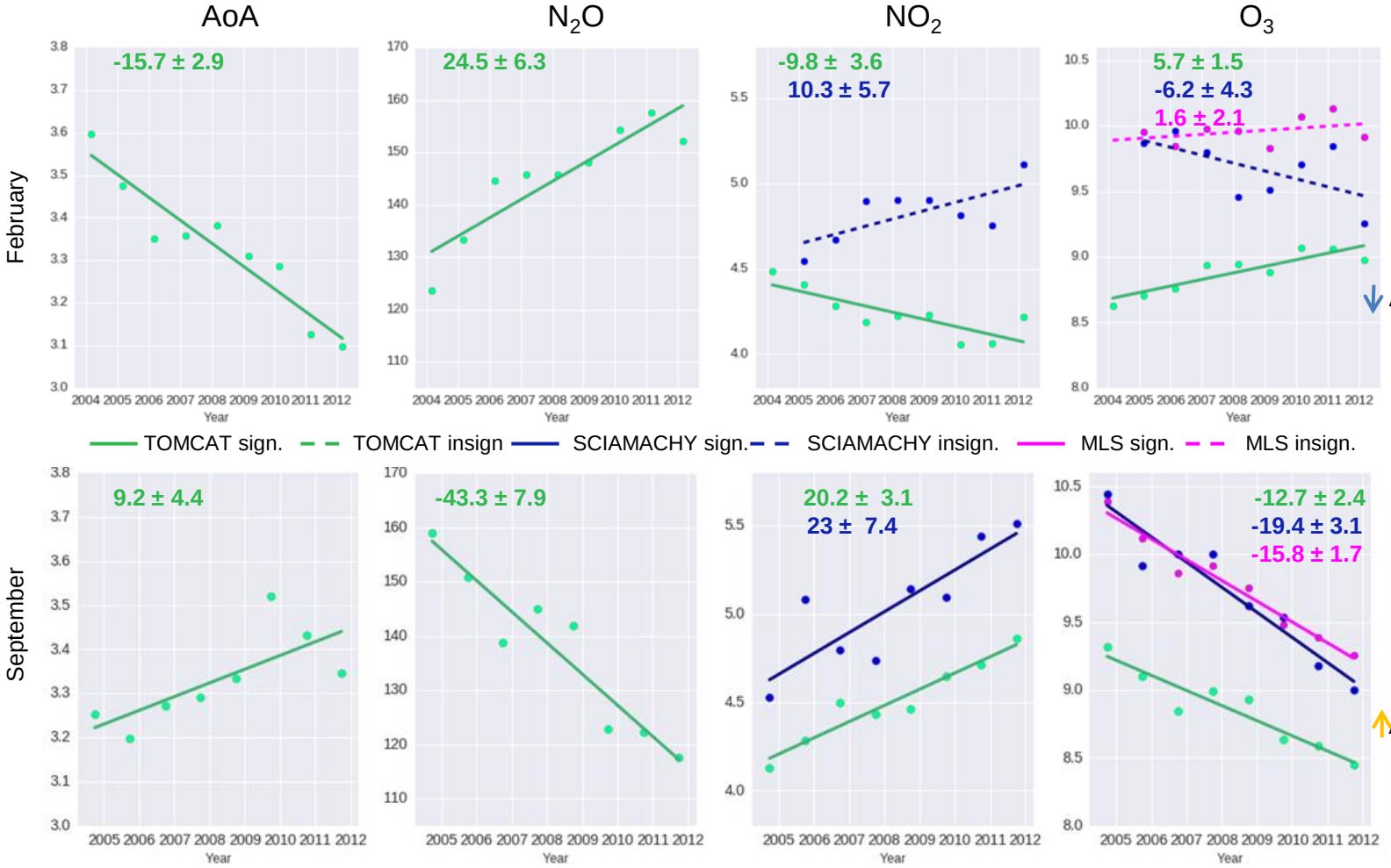

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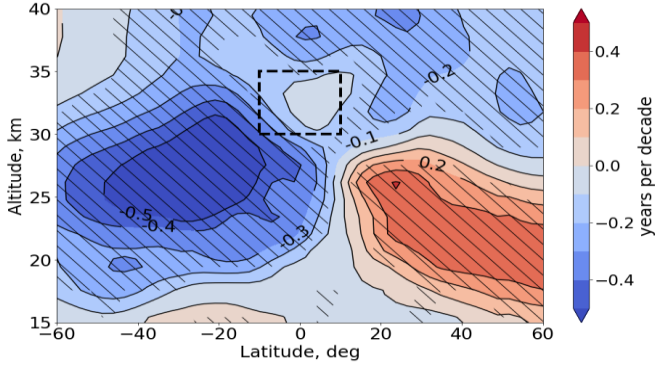
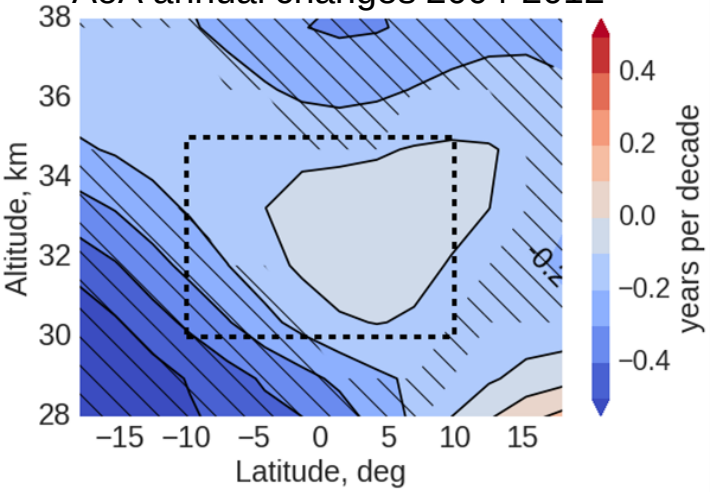
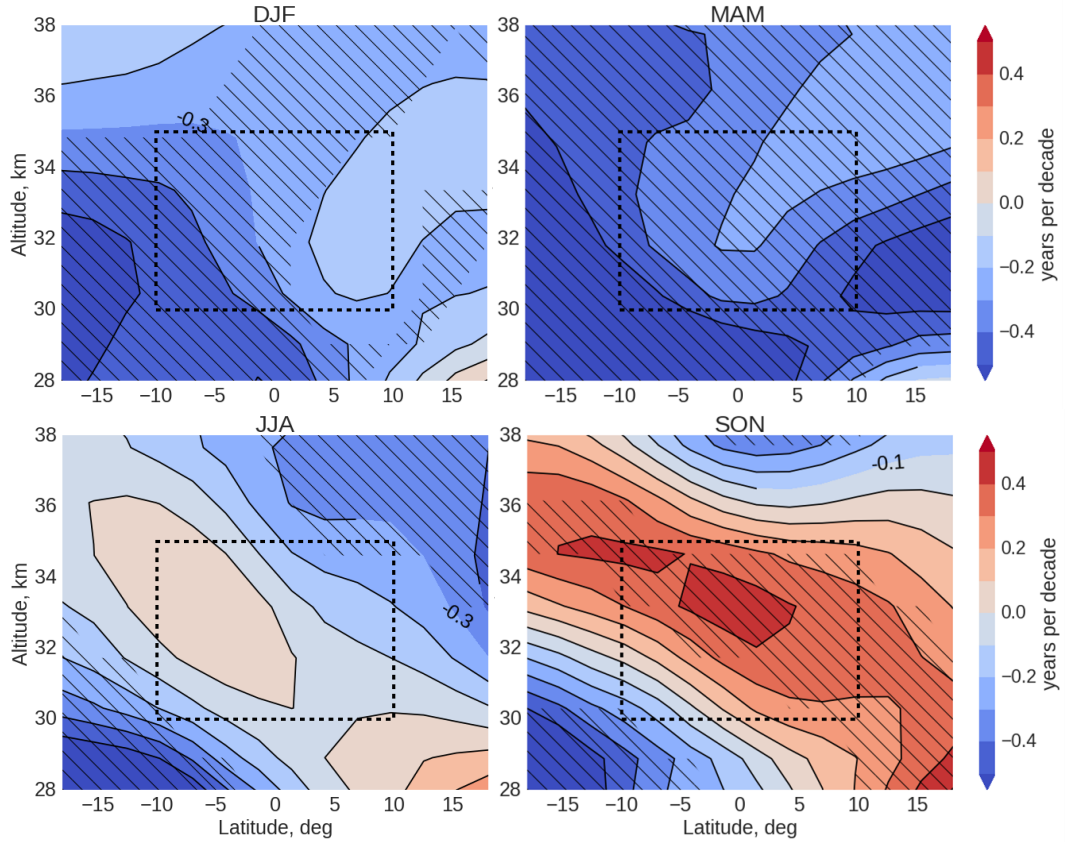
TOMCAT ERA-Interim AoA seasonal changes 2004-2012



AoA annual changes 2004-2012





Do other models/reanalyses show similar seasonal AoA changes?

AoA tests with Belgian CTM BASCOE
Chabrillat et al., ACP, 2018

AoA tests with CLaMS
Ploeger et al., ACPD, 2019

Comparison of mean age of air in five reanalyses using the BASCOE transport model

Simon Chabrillat[1], Corinne Vigouroux[1], Yves Christophe[1], Andreas Engel[2], Quentin Errera[1], Daniele Minganti[1], Beatriz M. Monge-Sanz[3], Arjo Segers[4], and Emmanuel Mahieu[5]
[1]Royal Belgian Institute for Space Aeronomy, BIRA-IASB, Brussels, Belgium
[2]Institute for Atmospheric and Environmental Science, Goethe University Frankfurt, Frankfurt, Germany
[3]European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading, UK
[4]TNO, Department of Climate, Air and Sustainability, P.O. Box 80015, Utrecht, the Netherlands
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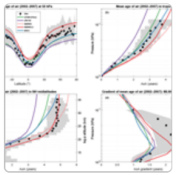

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Felix Ploeger[1,2], Bernard Legras[3], Edward Charlesworth[1], Xiaolu Yan[1], Mohamadou Diallo[1], Paul Konopka[1], Thomas Birner[4], Mengchu Tao[1], Andreas Engel[5], and Martin Riese[1]
[1]Institute for Energy and Climate Research: Stratosphere (IEK-7), Forschungszentrum Jülich, Jülich, Germany
[2]Institute for Atmospheric and Environmental Research, University ofWuppertal,Wuppertal, Germany
[3]Laboratoire de Météorologie Dynamique, UMR8539, IPSL, UPMC/ENS/CNRS/Ecole Polytechnique, Paris, France
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- **ERA-Interim**
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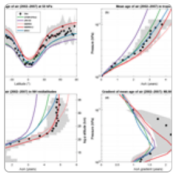

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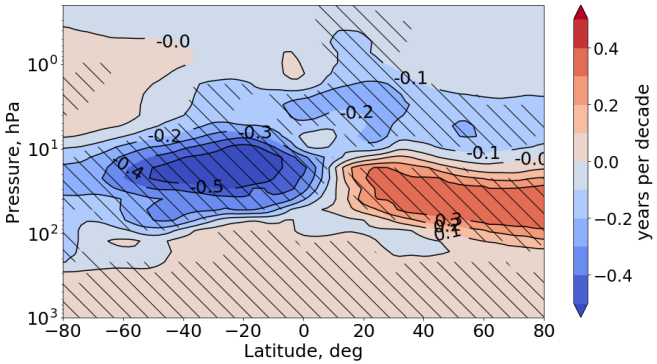

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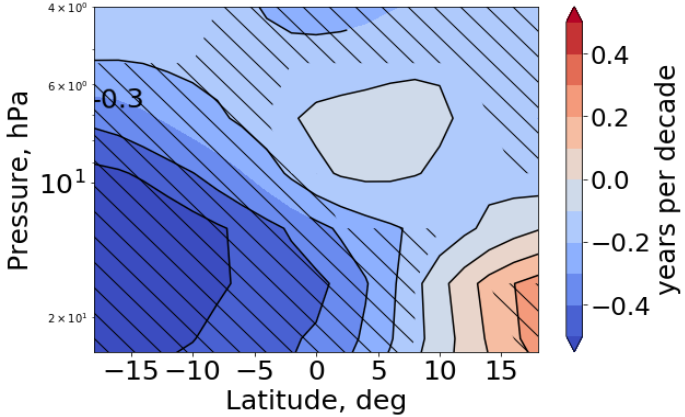
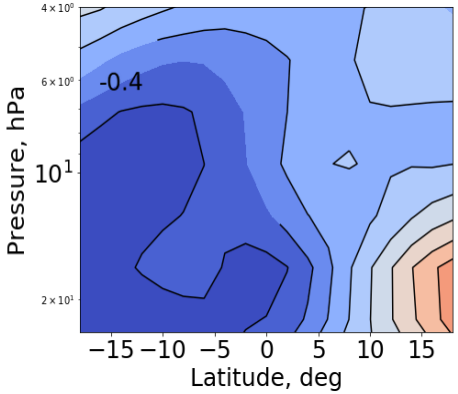
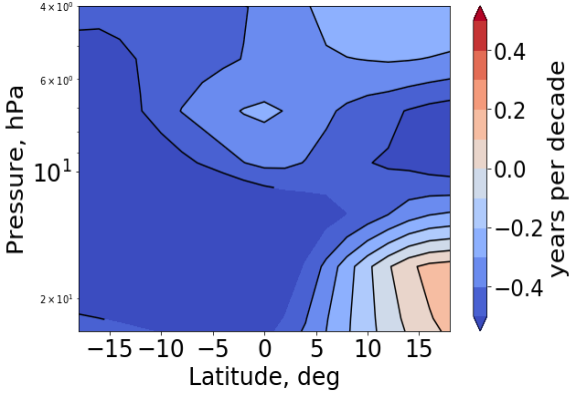


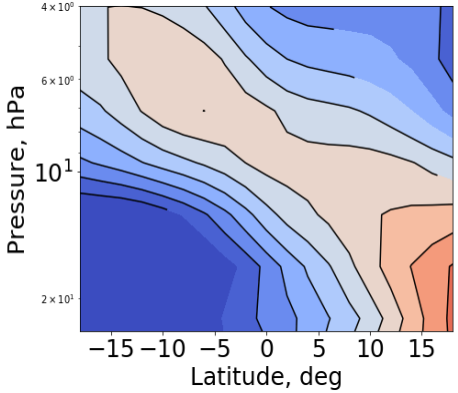
DJF



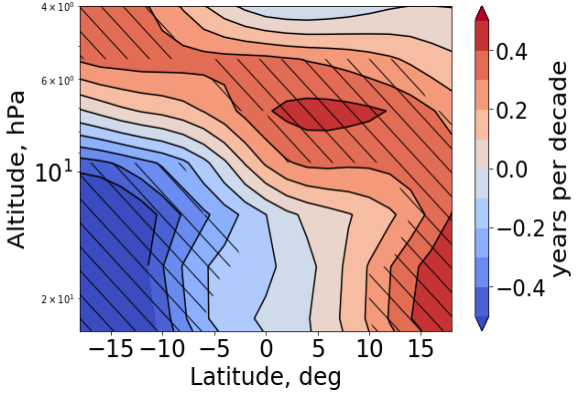
MAM



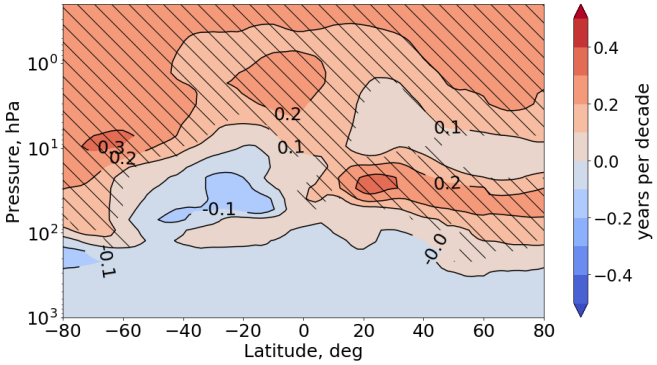
JJA



SON



BASCOE JRA-55 AoA seasonal changes 2004-2012



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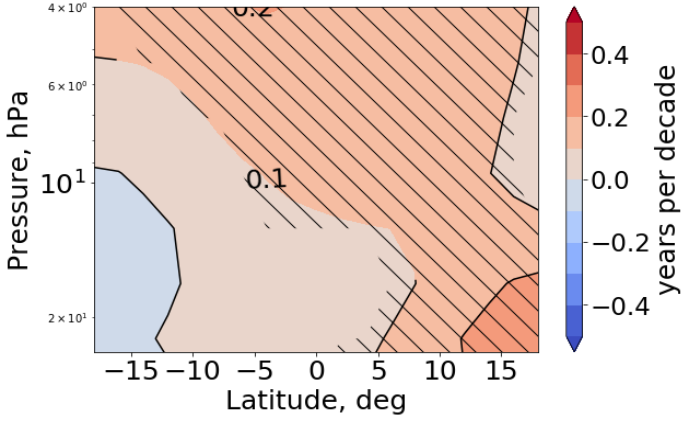

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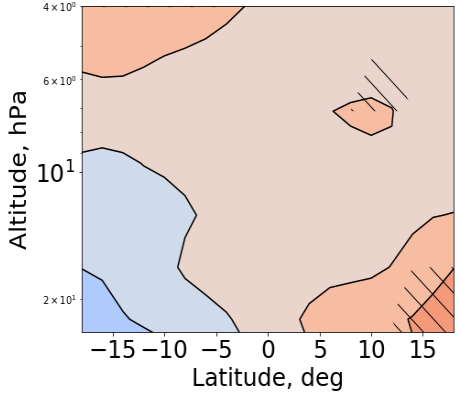

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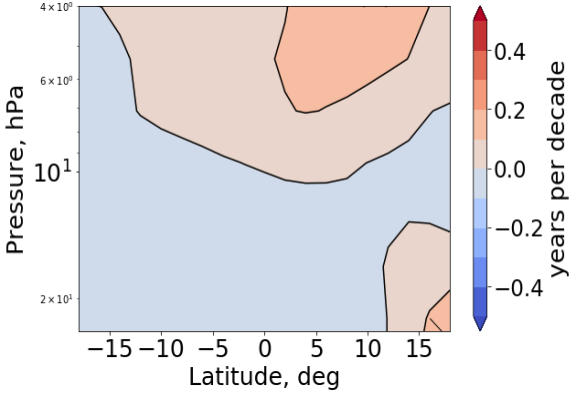

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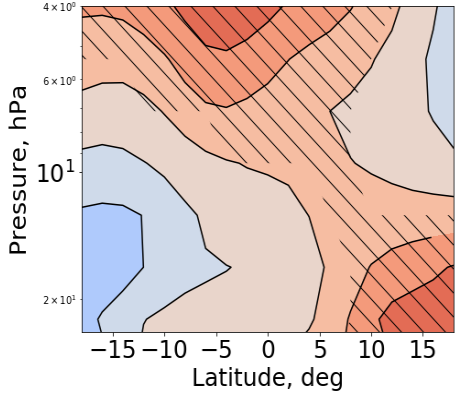
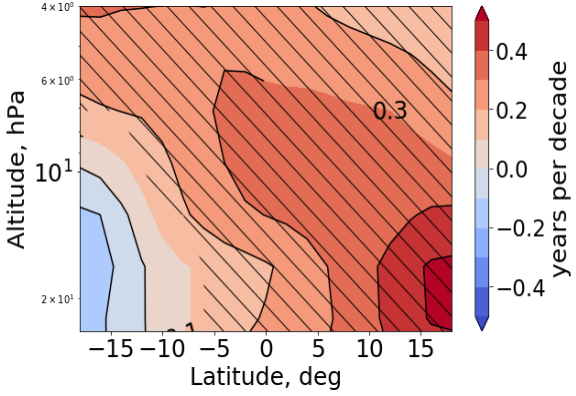
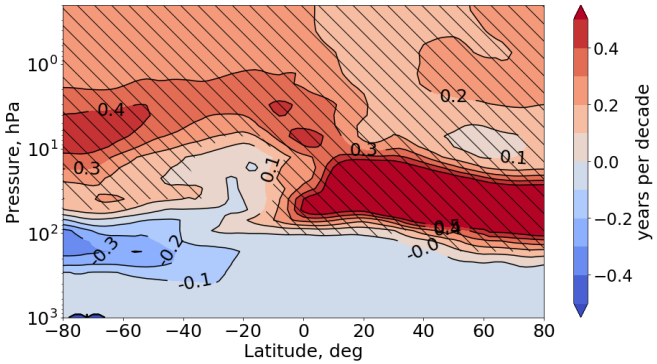


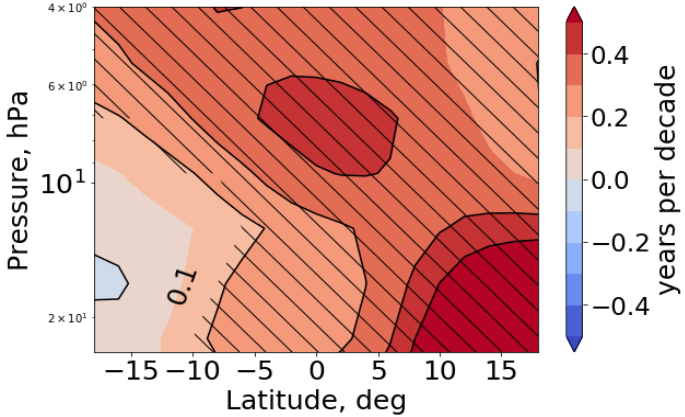
SON



BASCOE MERRA AoA seasonal changes 2004-2012



AoA annual changes 2004-2012



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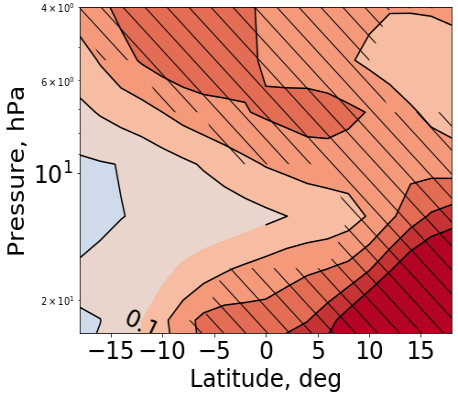
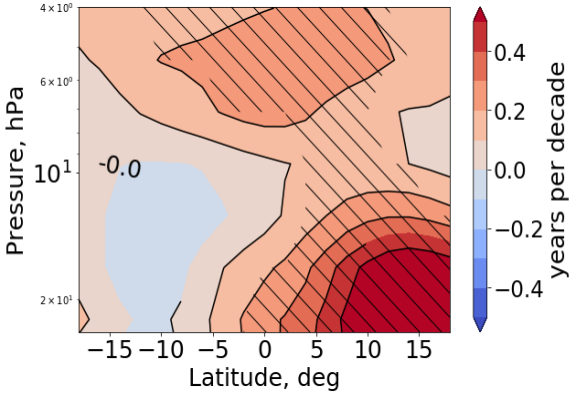


MAM



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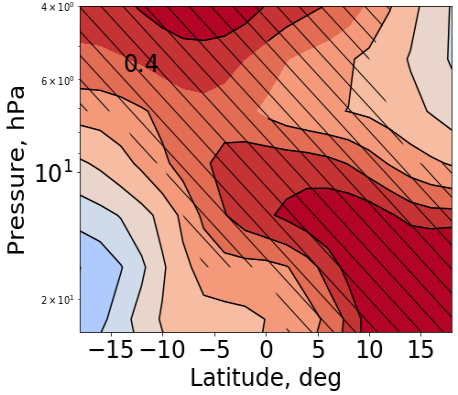

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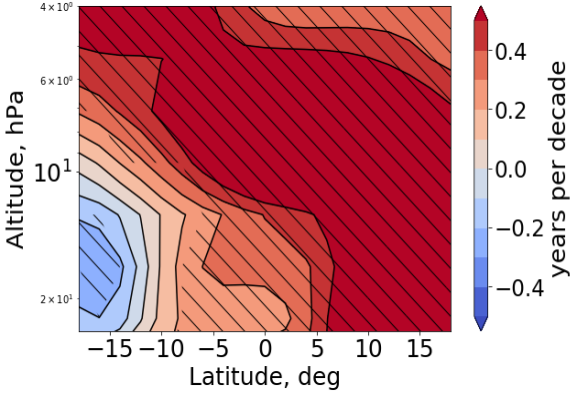
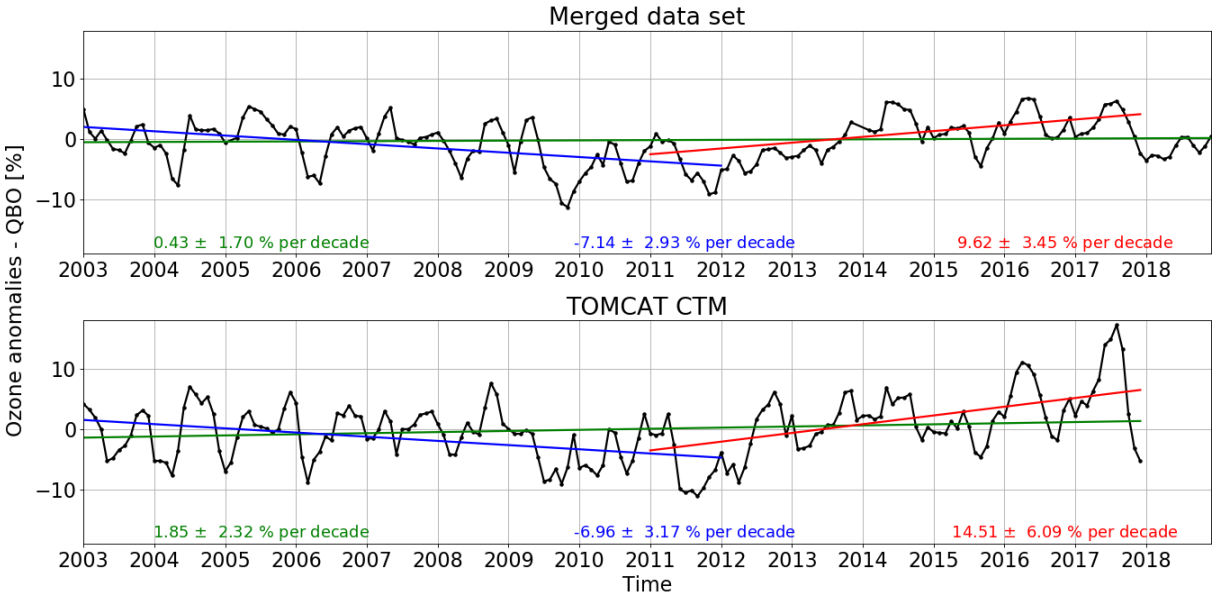
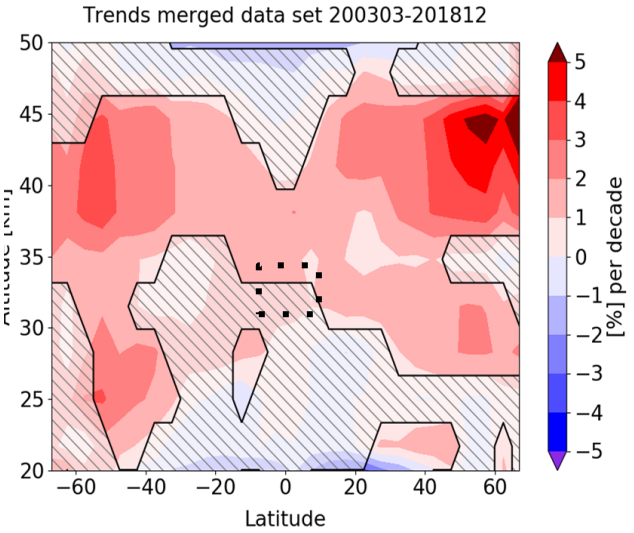


O_3 changes in the tropical mid-stratosphere during 2003-2018

SCIAMACHY + OMPS merged data set (*Arosio et al., AMT, 2019)*

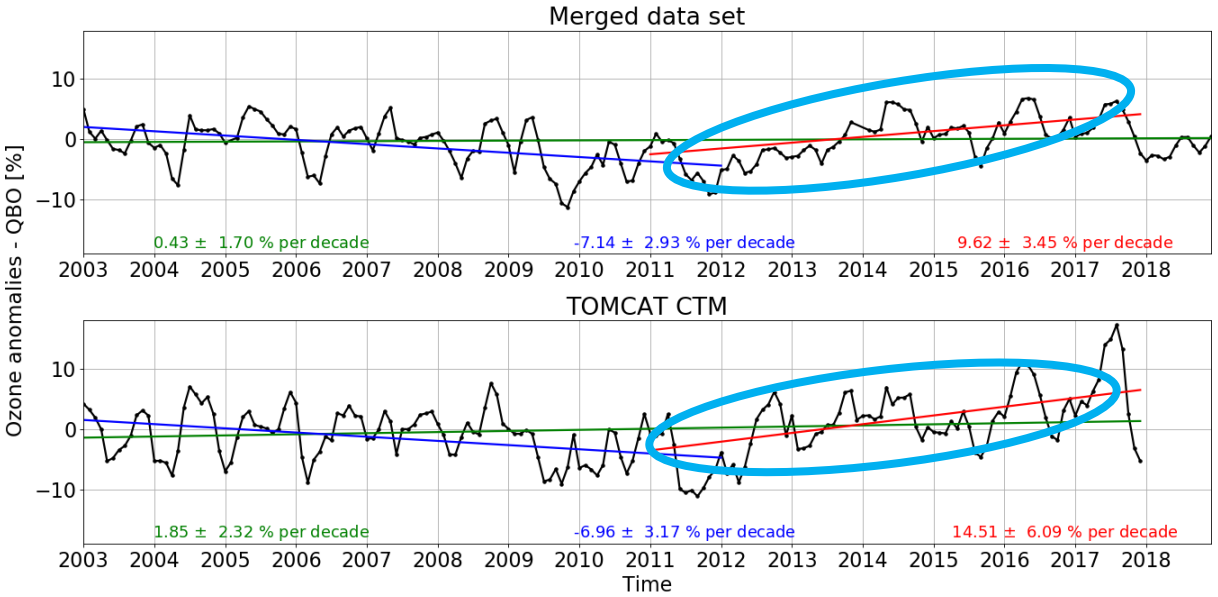


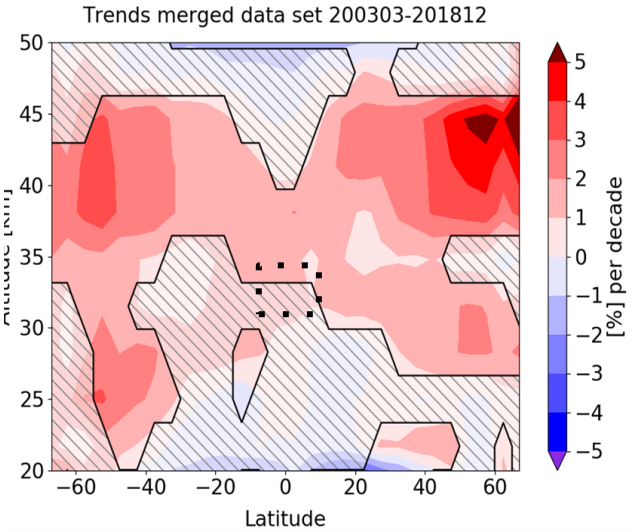


From the presentation of **C. Arosio**, ATMOS, Salzburg, Austria, November 2018

O_3 changes in the tropical mid-stratosphere during 2003-2018

SCIAMACHY + OMPS merged data set (*Arosio et al., AMT, 2019)*



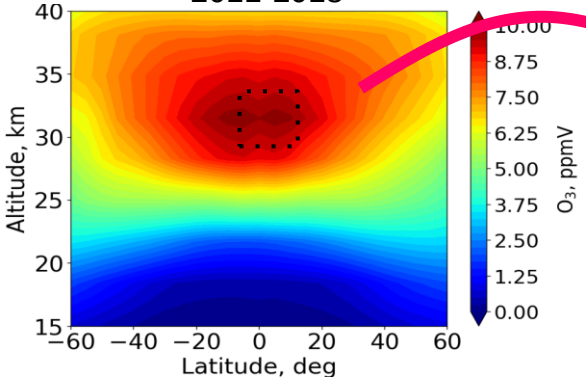


* From the presentation of **C. Arosio**, ATMOS, Salzburg, Austria, November 2018

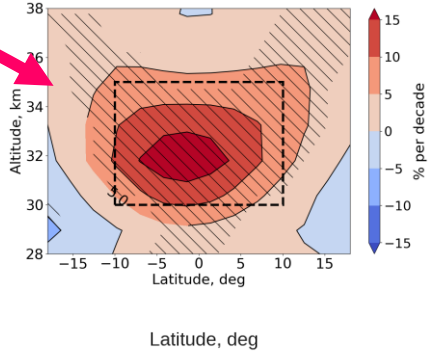
What are the O_3 changes during 2011-2018?

TOMCAT

O_3 from SCIAMACHY + OMPS
2011-2018



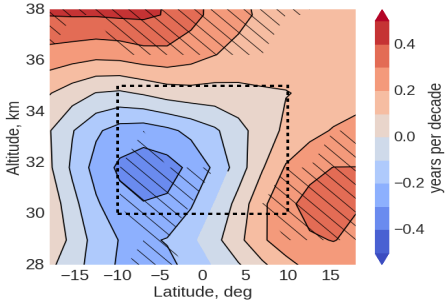
O_3 changes 2011-2018



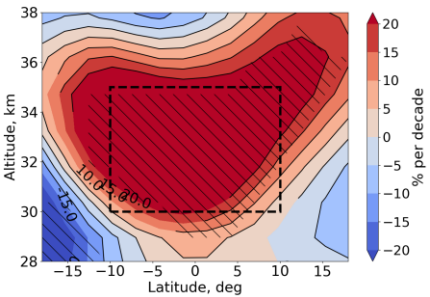
TOMCAT

2011-2018

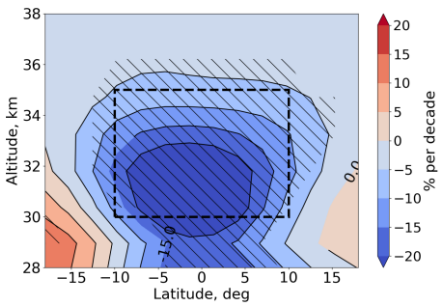
AoA



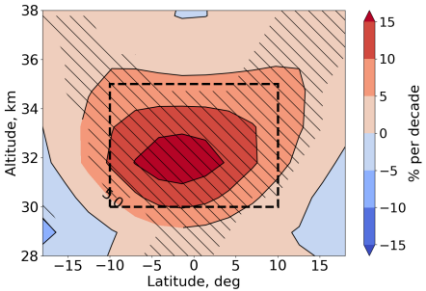
N_2O



NO_2



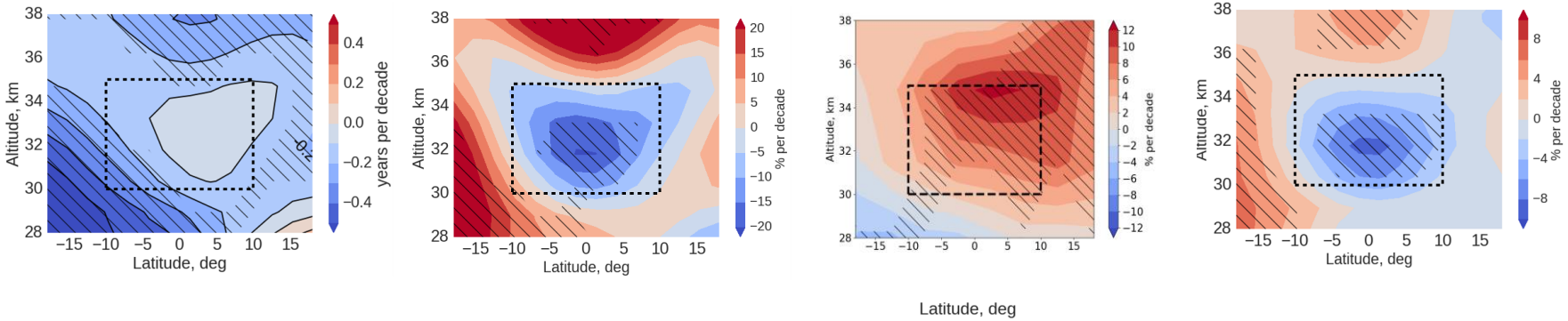
O_3



What are the O_3 changes during 2004-2018?

2004-2012

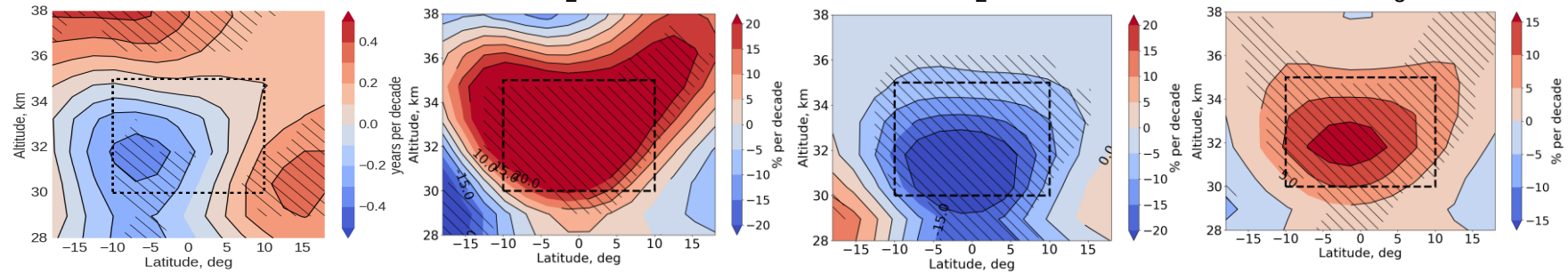
TOMCAT



2011-2018

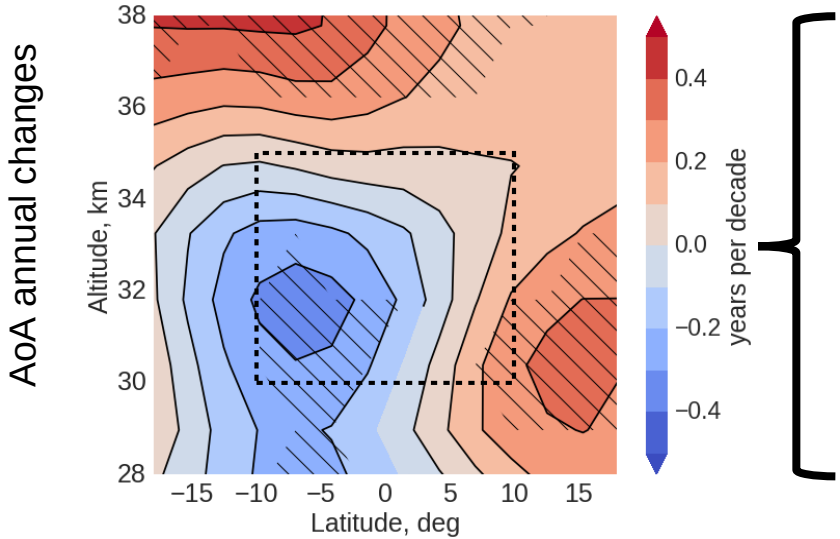
AoA	N_2O	NO_2	O_3

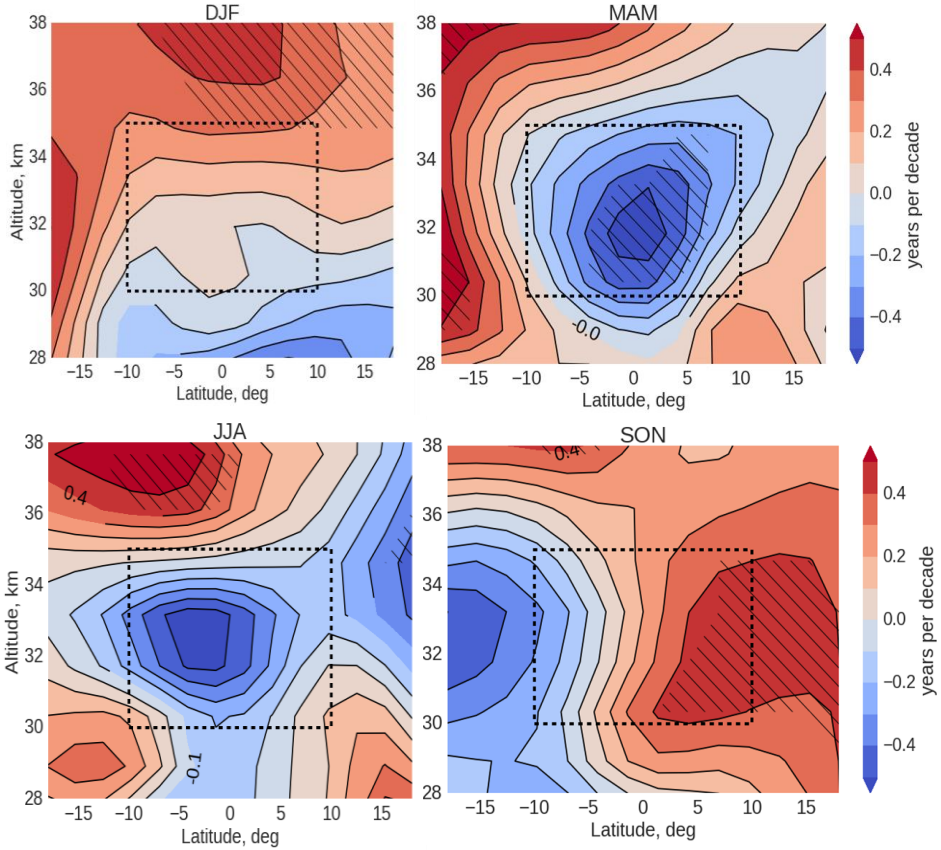
TOMCAT



TOMCAT AoA seasonal changes during 2011-2018

MAM → the transport is speeding up significantly

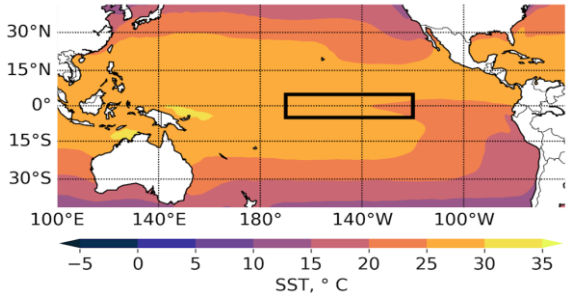


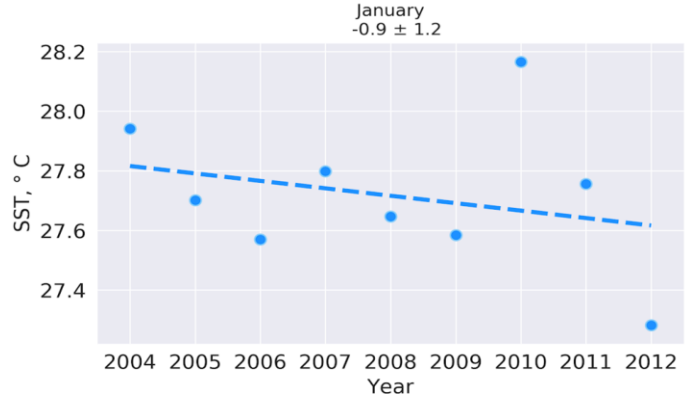


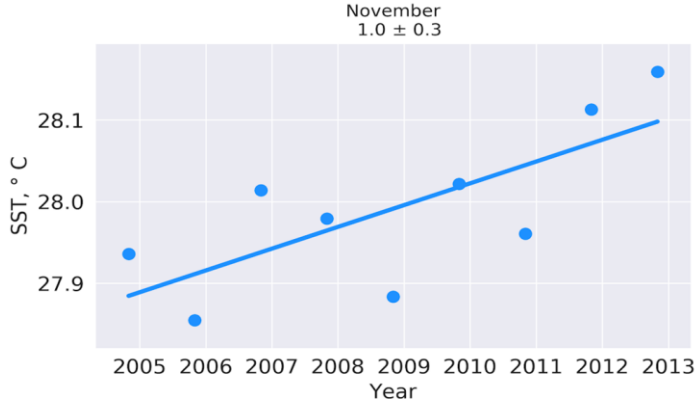
SON → the transport is slowing down (not as significant as during 2004-2012)

What drives seasonal AoA changes in the tropical mid-stratosphere?

SST (NOAA)

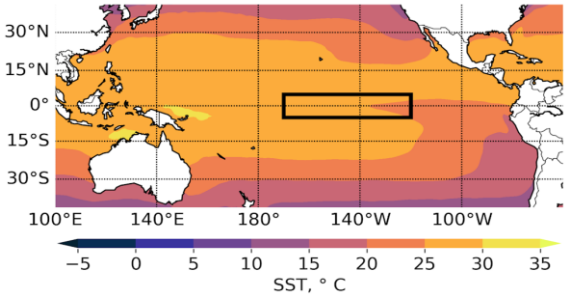


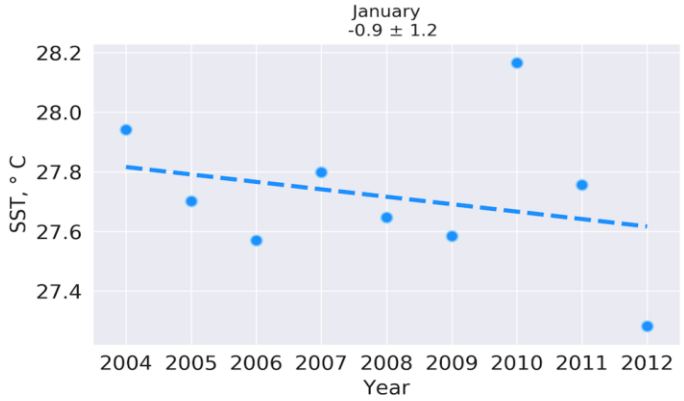


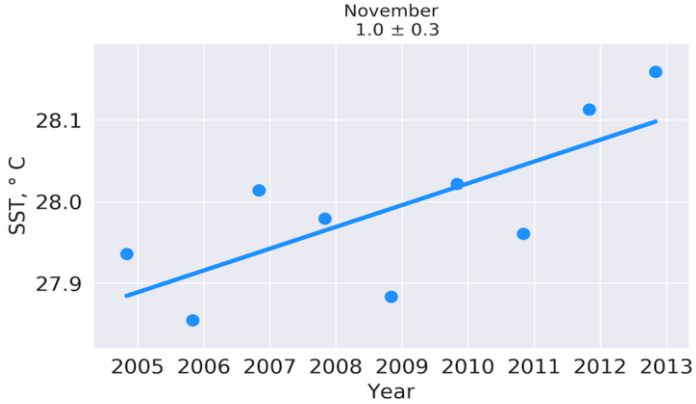


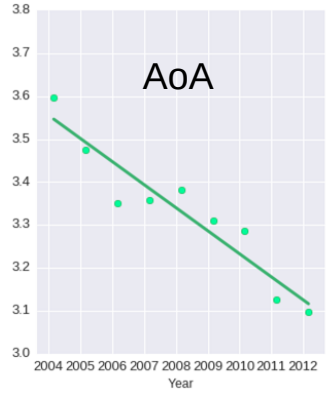
What drives seasonal AoA changes in the tropical mid-stratosphere?

SST (NOAA)



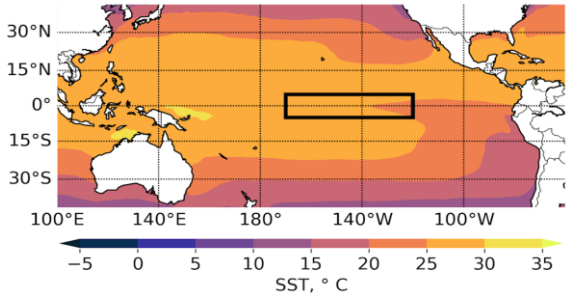


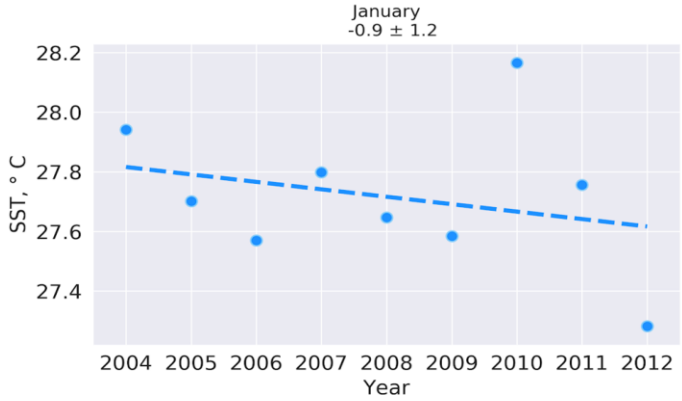


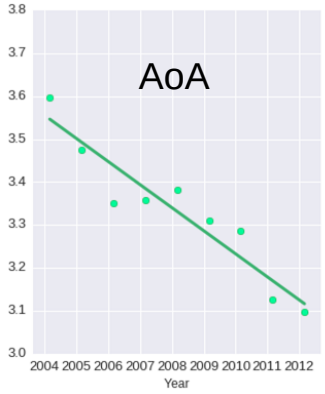


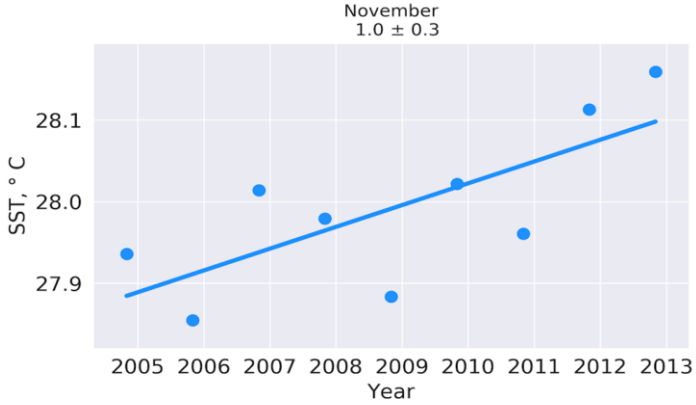
What drives seasonal AoA changes in the tropical mid-stratosphere?

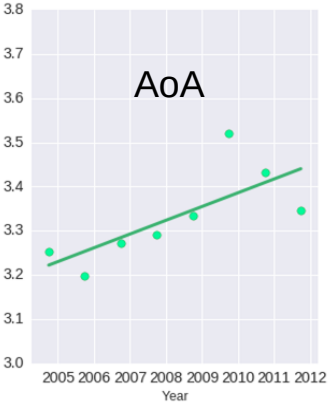
SST (NOAA)











OUTLINE

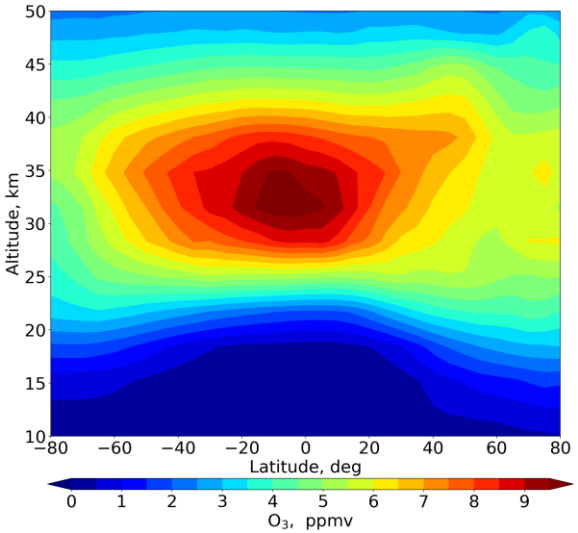
1. Scientific issue and previous findings

2. O_3 chemistry and stratospheric dynamics in 7 steps

3. Interpretation of observed and modelled changes during 2004-2012

➢ 4. Conclusions and outlook

O_3 changes in the tropical mid- stratosphere



Galytska et al., ACP, 2019

Conclusions

- The major driver of O_3 changes in the tropical mid-stratosphere during 2004-2012 is the seasonal variability of stratospheric dynamics;
- **Decline** of O_3 is due to the transport **slow-down** during **September, October**.
- **Recovery** of O_3 is due to the transport **speed-up** in **January, February**.
- ERA-Interim, JRA, MERRA agree on AoA seasonal variability.
- Positive O_3 changes during 2011-2018 are associated with overall speed-up of the transport in the tropical mid-stratosphere.
- What drives AoA seasonal variability?