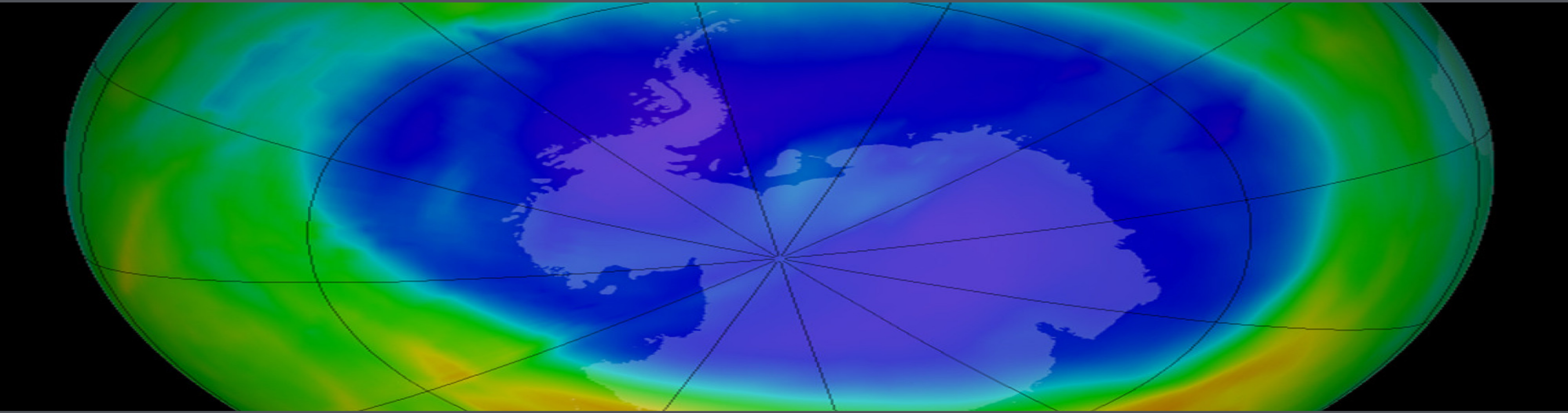
2nd LOTUS Workshop, WMO
17-19 September 2018

OPTIMISATION OF PWLT FITTING OF POROUS OZONE TIMESERIES WITH LOESS-SOS AND MC-SSA (+WAVELETS)



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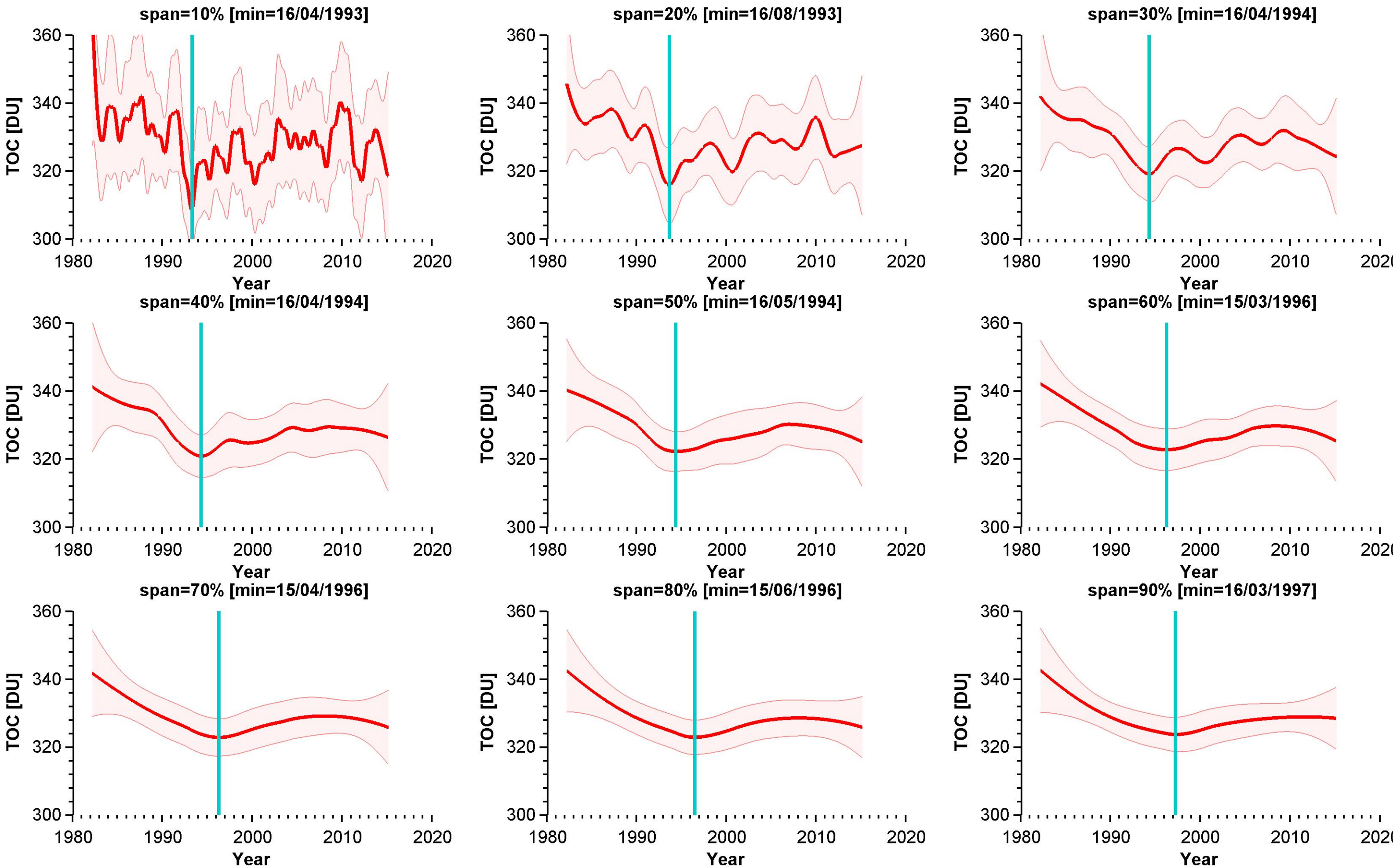
OVERVIEW

- Two data-driven, proxy-free models (for discussion):

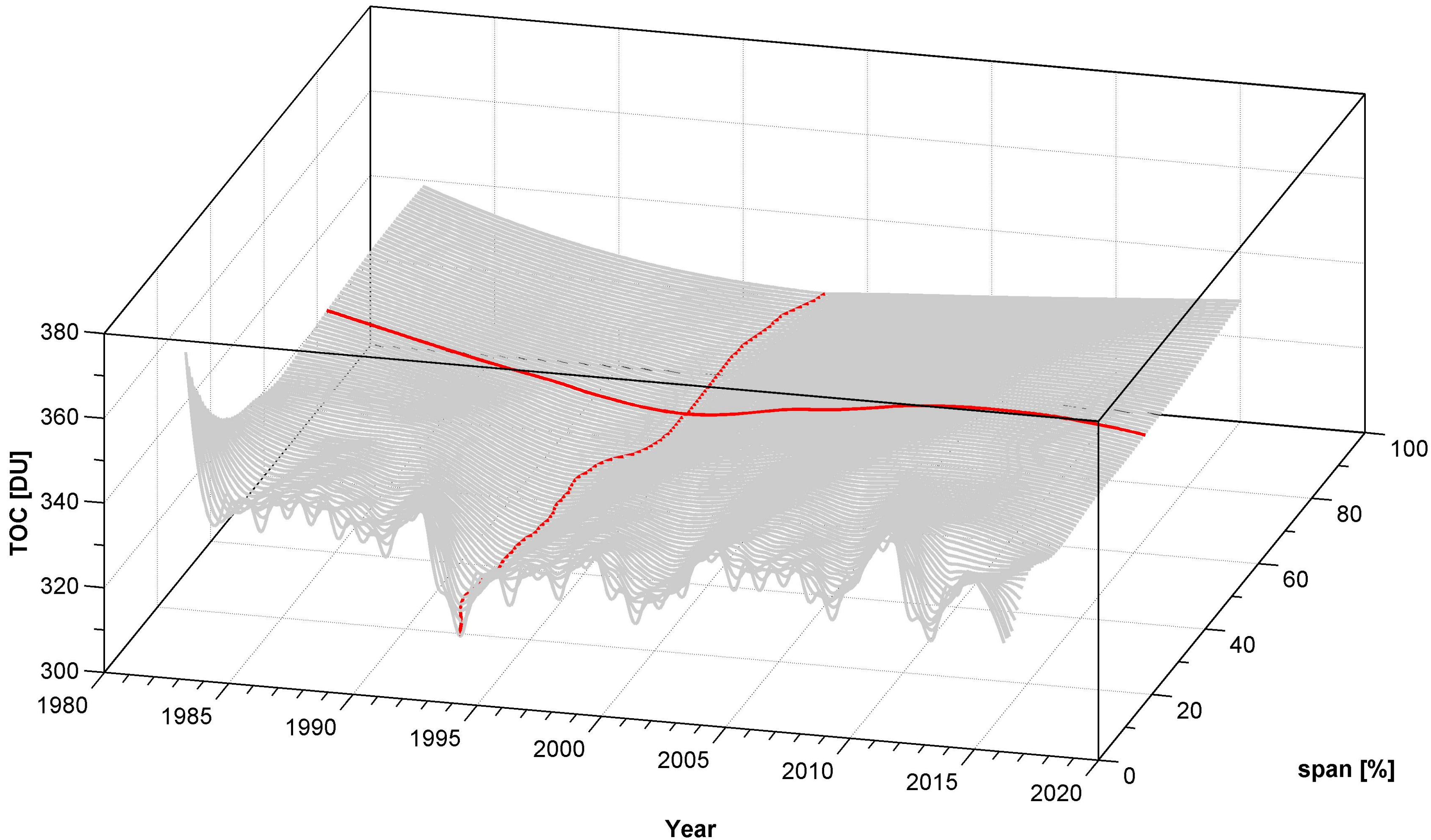
  1. Gap-filling of **porous** ozone timeseries & nonlinear versus linear (**LOESS** versus **PWLT**) trends
  2. Distribution (month, zonal latitude, altitude) of **statistically-significant cycles** in global profile ozone using **wavelets**

STEP 1: Use LOESS + KPSS test for stationary to detect nonlinear trend

- Aim → to make **porous** timeseries stationary & extract nonlinear trend
- How? → use **LOESS** (=LOcal regrESSion) varying the smoothing parameter & applying a Kwiatkowski–Phillips–Schmidt–Shin (**KPSS**) test (null hypothesis = data is stationarity around a deterministic trend)
- By-product → the process converges on location of turnaround in PWLT


span=10% [min=16/04/1993]
span=20% [min=16/08/1993]
span=30% [min=16/04/1994]
span=40% [min=16/04/1994]
span=50% [min=16/05/1994]
span=60% [min=15/03/1996]
span=70% [min=15/04/1996]
span=80% [min=15/06/1996]
span=90% [min=16/03/1997]
TOC [DU]
300
320
340
360
Year
1980
1990
2000
2010
2020

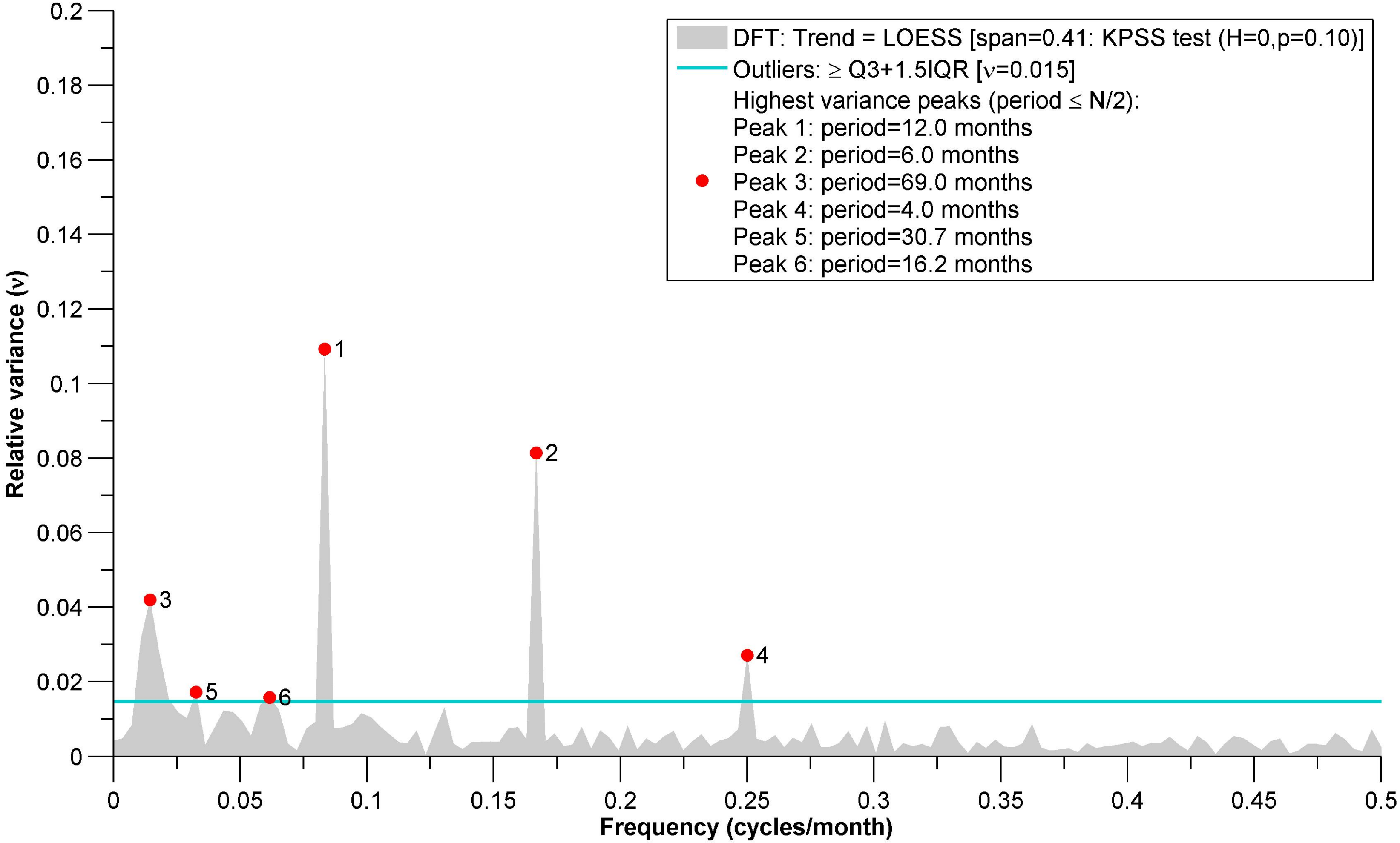
Thessaloniki : Bootstrap trend surface (LOESS) [optimal minimum=09/1996 span=63%]



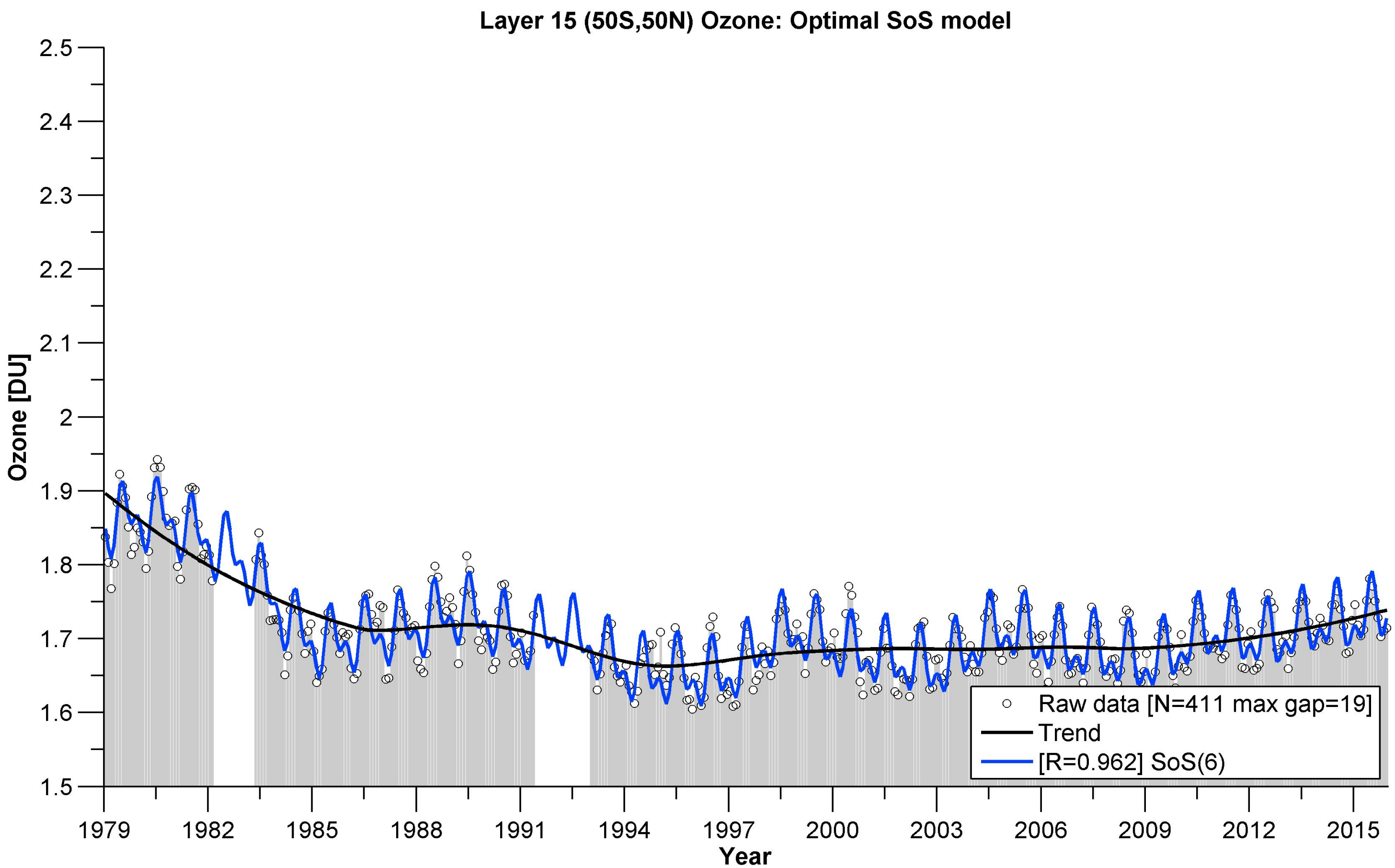
STEP 2: Fit sum of sines (SOS) model to largest gap-free segment

- Calculate the discrete Fourier transform (line spectrum) of the largest gap-free segment
- This requires that the timeseries is stationary (i.e. centered) → hence STEP 1
- Highest variance peaks → prior information about dominant cycles in the data
- Set an outlier threshold on the relative variance of peaks and extract the 8 most dominant cycles → prior information about variability in gap segments
- Construct Fourier series

Layer 15 (50S,50N) Ozone: Fourier line spectrum of stationary time series



STEP 3: Gap-fill with LOESS + SOS



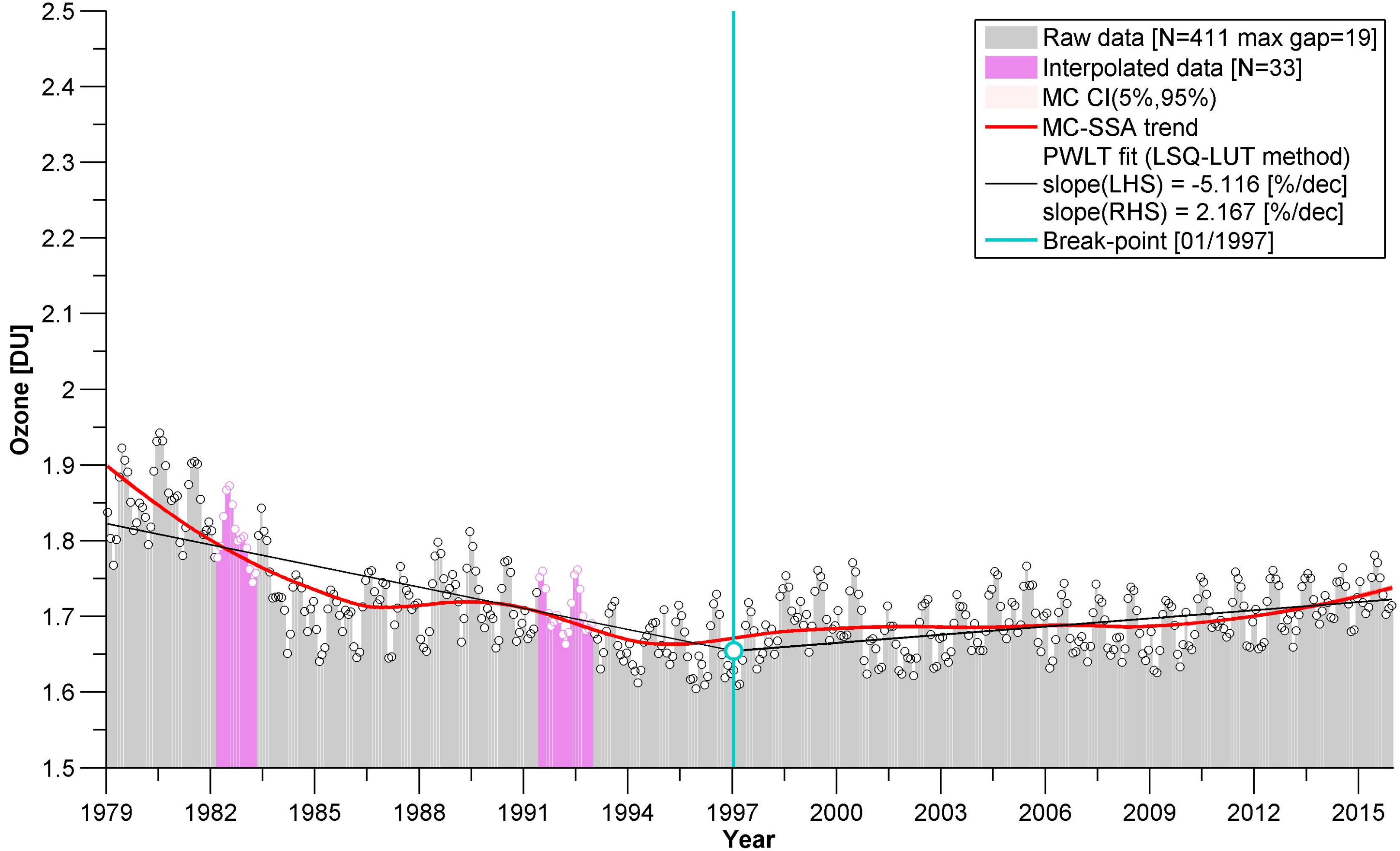
STEP 4: Construct (5%,95%) CI around LOESS trend using MC-SSA

- SSA = Singular Spectrum Analysis [Broomhead & King, 1986, *Physica D* 20:217-236]
- MC-SSA = Monte-Carlo SSA [Allen & Smith, 1996, *J Climate* 9(12):3373–3404] → allows bootstrapping (2000 iterations) of SSA to construct CI around the median SSA trend = LOESS trend
- This is the estimated uncertainty of the nonlinear trend fit to the gap-filled data

STEP 5: Regress PWLT on LOESS trend

- We set January 1997 as the PWLT turnaround point
- Regress PWLT on MC-SSA trend using nonlinear least squares optimisation

Layer 15 (50S,50N) Ozone: SSA versus PWLT fitting



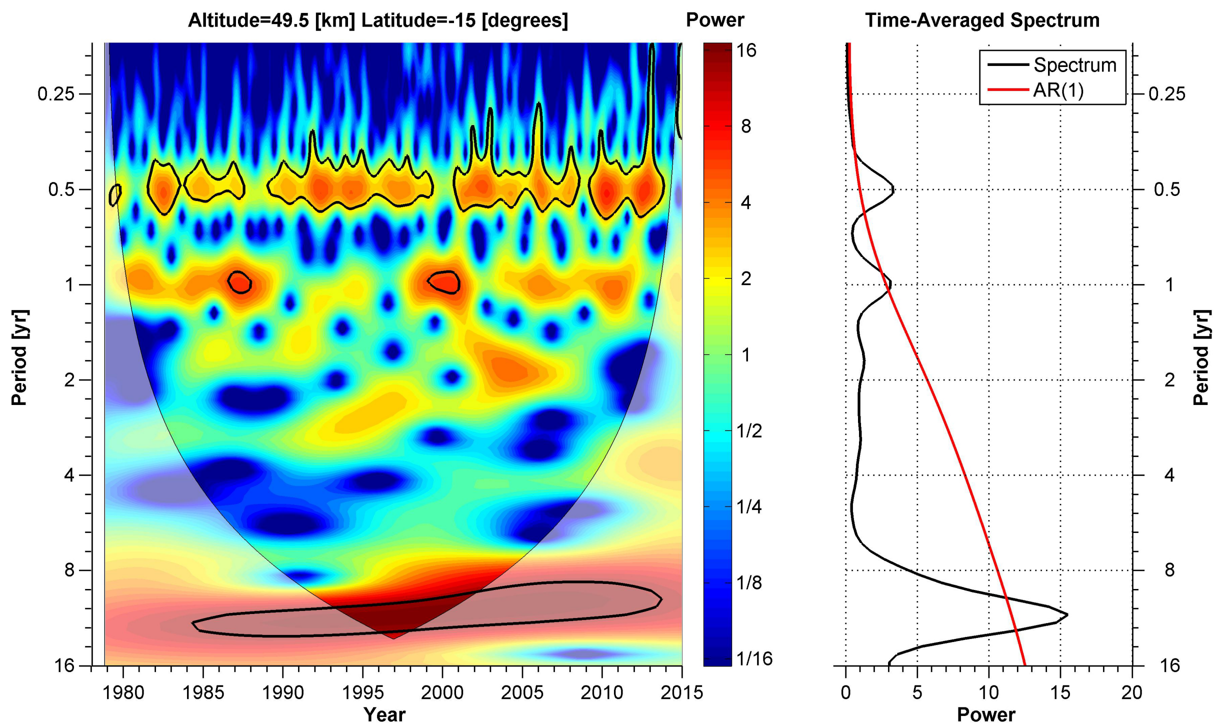
Trend < 1997 [%/decade]				
Layer/ Band	35S - 50S	35N - 50N	50S - 50N	20S - 20N
8	-2.69	-4.52	-1.56	-0.01
9	-1.71	-3.88	-1.66	-0.92
10	-0.91	-2.70	-1.74	-1.66
11	-1.12	-1.78	-1.25	-1.24
12	-2.91	-2.68	-1.70	-1.04
13	-5.91	-5.60	-4.11	-2.96
14	-7.74	-7.79	-5.78	-4.37
15	-6.83	-6.67	-5.07	-3.91
16	-4.24	-3.54	-3.22	-2.90

Trend > 1997 [%/decade]				
Layer/ Band	35S - 50S	35N - 50N	50S - 50N	20S - 20N
8	-1.13	-0.40	-0.89	-0.96
9	-1.41	-0.25	-0.44	-0.23
10	-0.06	1.17	1.04	1.26
11	2.00	2.51	2.41	2.41
12	2.75	2.53	2.22	1.89
13	1.91	1.71	0.90	0.31
14	1.17	1.44	0.62	0.12
15	1.73	2.62	2.12	2.04
16	3.18	4.16	3.82	4.00

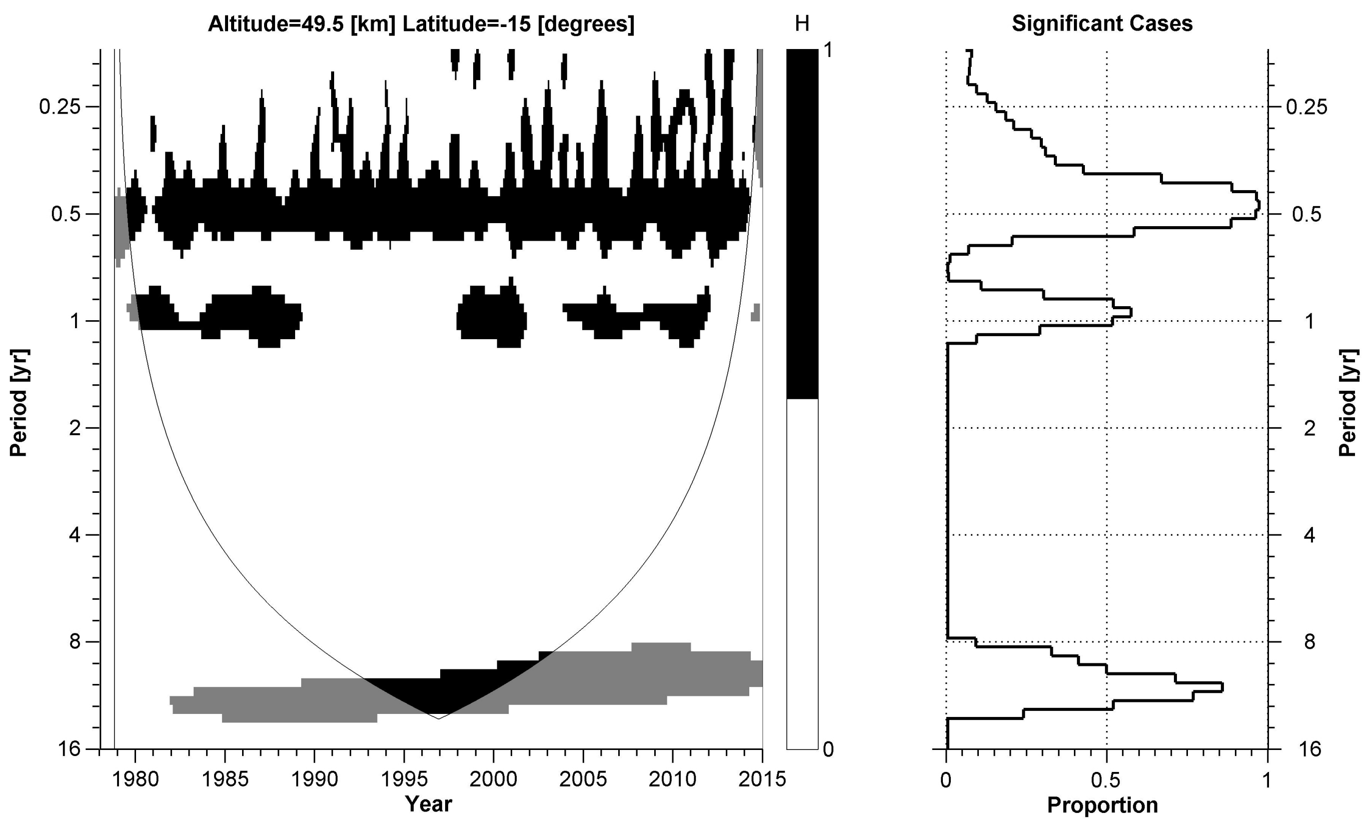
Wavelet method

For each (zonal latitude,altitude) timeseries we calculate the wavelet power spectrum using the continuous wavelet transform (CWT) ("Mortlet wavelet")

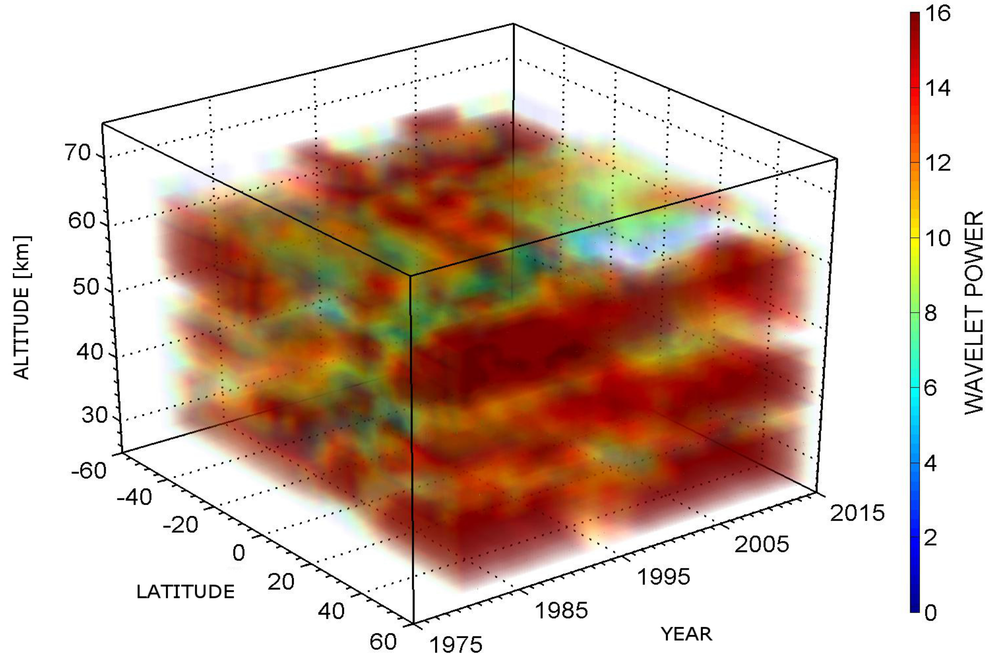
We also fit the timeseries with an AR(1) process and calculate its spectrum.



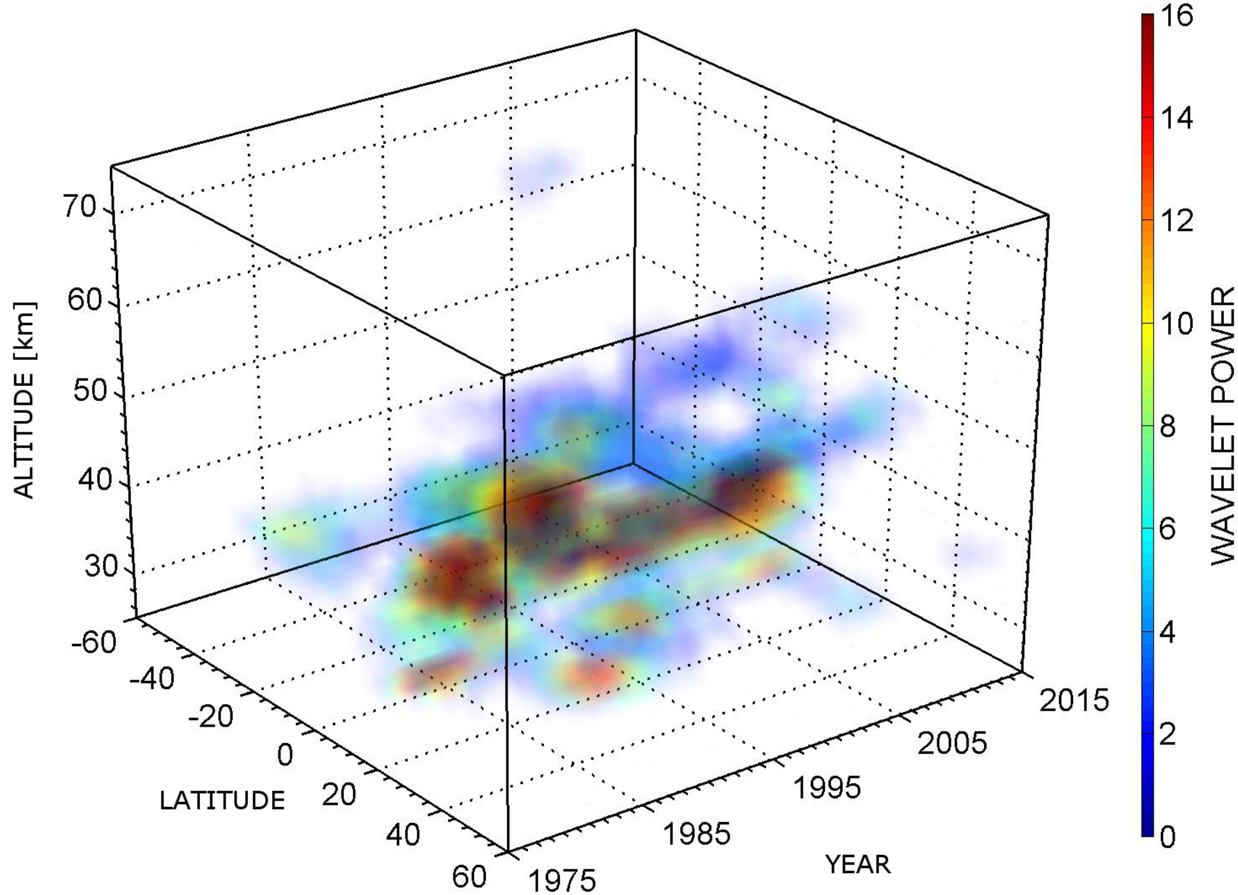
For each (zonal latitude , altitude) timeseries we calculate the wavelet spectrum and perform an AR(1) “red noise” test to detect statistically significant cycles in each month:



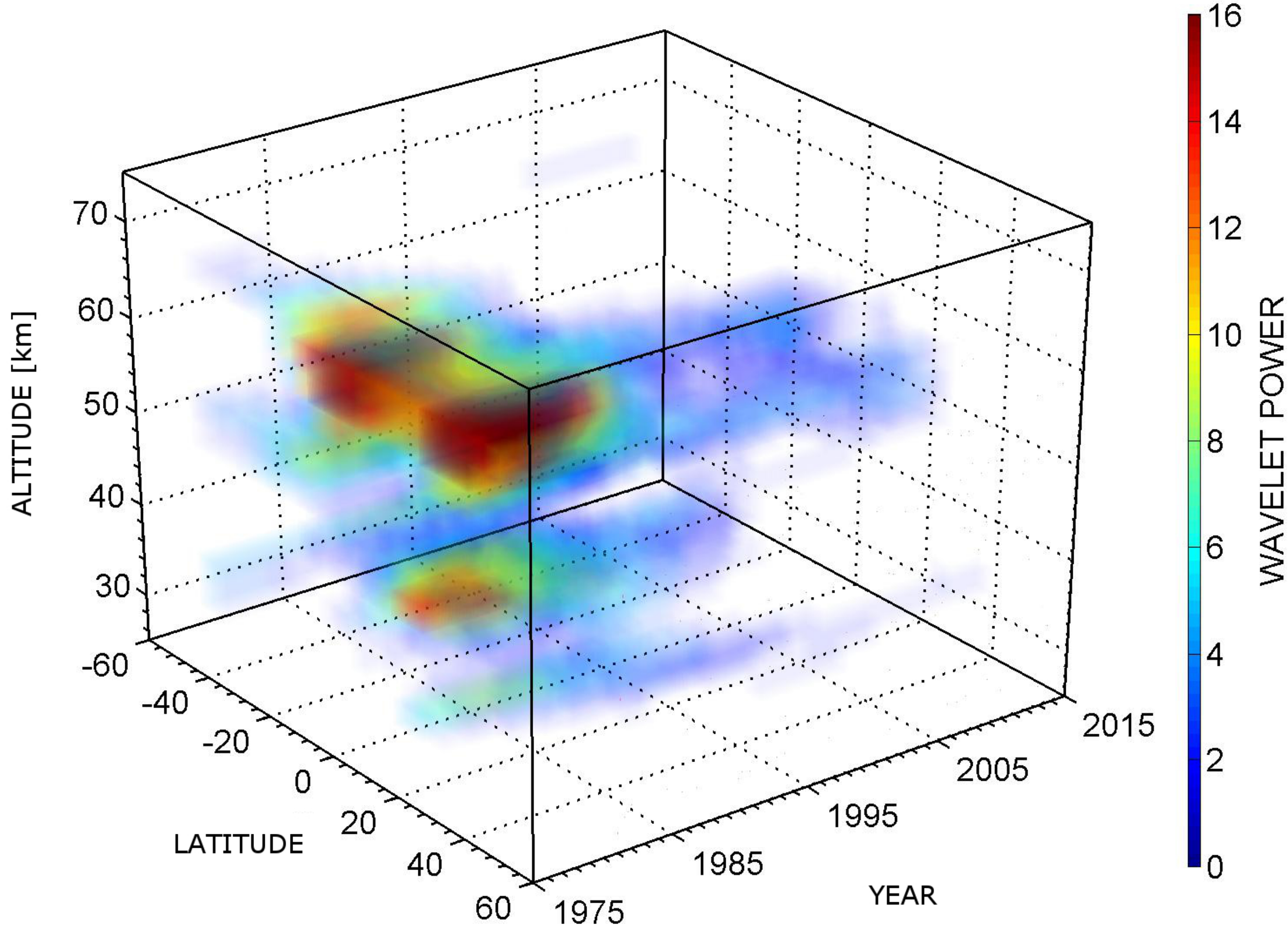
We then generate 4D “ozone cubes” (time, latitude, altitude, wavelet power) for each period [3 months – 16 years] to assess the spatio-temporal distribution of statistically-significant oscillations:



1.03 years (“Annual Cycle”)



2.32 years ("QBO")



ALTITUDE [km]
70
60
50
40
30
-60
-40
-20
0
20
40
60
LATITUDE
1975
1985
1995
2005
2015
YEAR
WAVELET POWER
16
14
12
10
8
6
4
2
0

6.94 years (?)

THOUGHTS

- LOESS-SOS gap-filling method:
  - How realistic is the gap-filled data?
  - IDEA: Create gaps in full timeseries and test?
  - Can we measure the uncertainty introduced by the gap-filling procedure?
  - What is the limit of applicability in terms of porosity?
- Wavelet method:
  - Is knowing where different cycles exist helping?
  - Can it feed into other modeling approaches (e.g. DLMs)?

Many thanks for listening