Inter-annual ozone variations at European high latitudes studied by ozone lidar and ozone sondes

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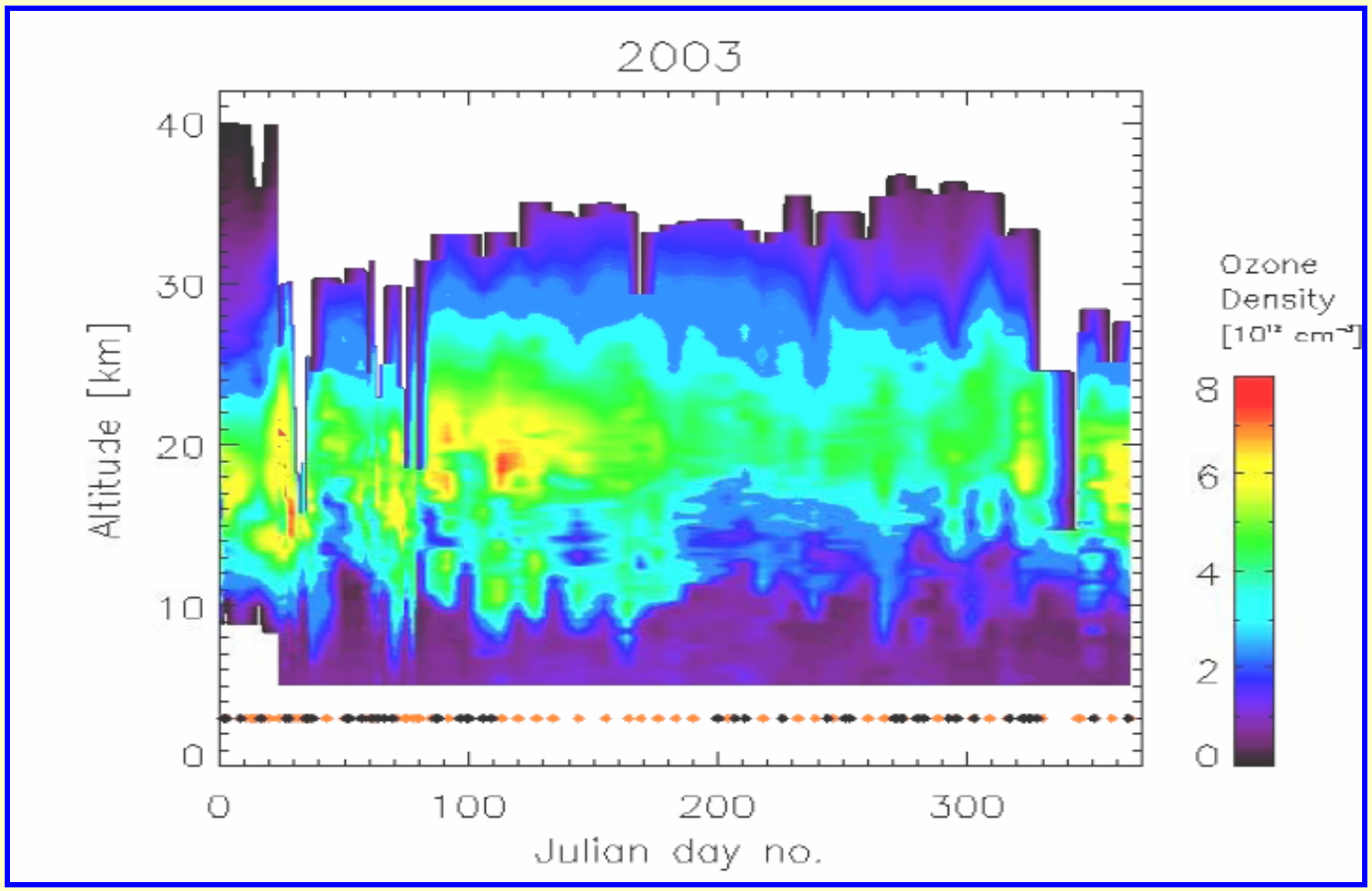
Objectives



NILU annual report 2003, OR53/2004

Second ozone maximum was found in annual averaged ozone sonde data by: R. Kivi et. Al, JGR, 112, D08306, 2007

Objectives

1. Does a second ozone maximum exist every year?
2. If it is so, than which seasonality has it?
3. What are the reasons for the build up of this maximum?

Data use

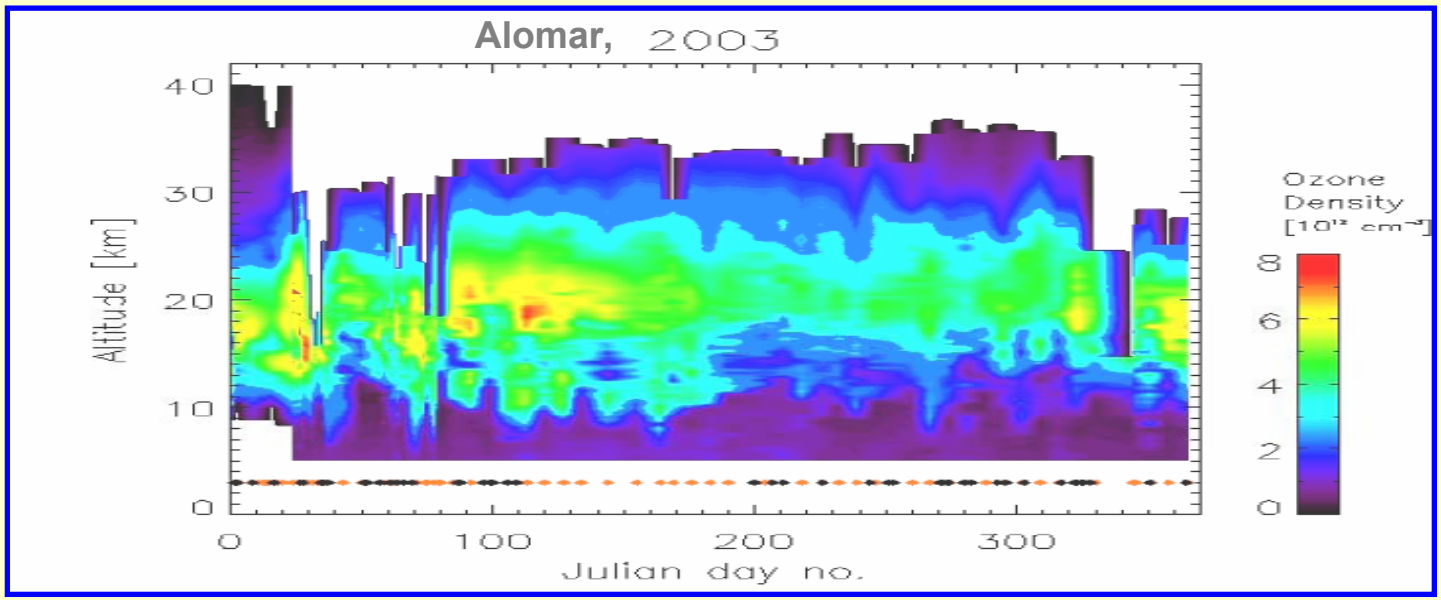
ALOMAR (69°N, 16°E) ozone lidar data sets, 1994-2004

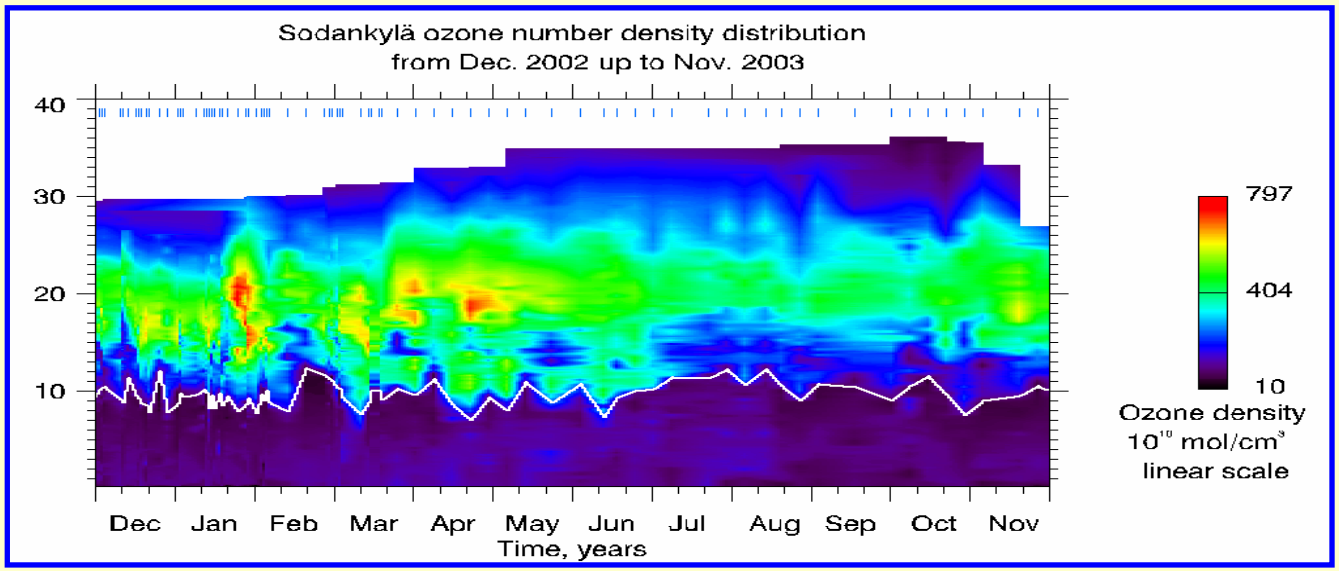
- Altitude, temperature, ozone density
  air density, potential temperature,
  profiles mainly during measurement campains

Sodankylä (67°N, 27°E) and Ny Ålesund (79°N, 12°E) ozone sondes, 1994-2004

- Geopotential height, temperature, pressure, ozone partial pressure, horizontal wind direction and speed, relative humidity
  40 up to 90 profiles per year

Data use


Alomar, 2003
Altitude [km]
40
30
20
10
0
0
100
200
300
Julian day no.
Ozone
Density
8
6
4
2
0


Sodankylä ozone number density distribution
from Dec. 2002 up to Nov. 2003
40
30
20
10
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Time, years
797
404
10
Ozone density
linear scale

Data processing

1. Construction of plots of the yearly temperature distributions, temperature differences of the annual means and temperature gradients
2. Calculation of the tropopause heights (based on the WMO-definition)
3. Plots of the potential temperature $\theta = T (p_0/p)^{\kappa}$, the vertical gradient $\delta\theta/\delta z$ and the squared Brunt Väisälä frequency $N_B^2 = g/\theta * \delta\theta/\delta z$
4. Construction of plots of yearly ozone distributions and of ozone differences

Data processing

5. Application of the Tropopause based (TB) climatology

   a) altitude related to the tropopause height z_{TP} : $z_r \rightarrow z - z_{TP}$

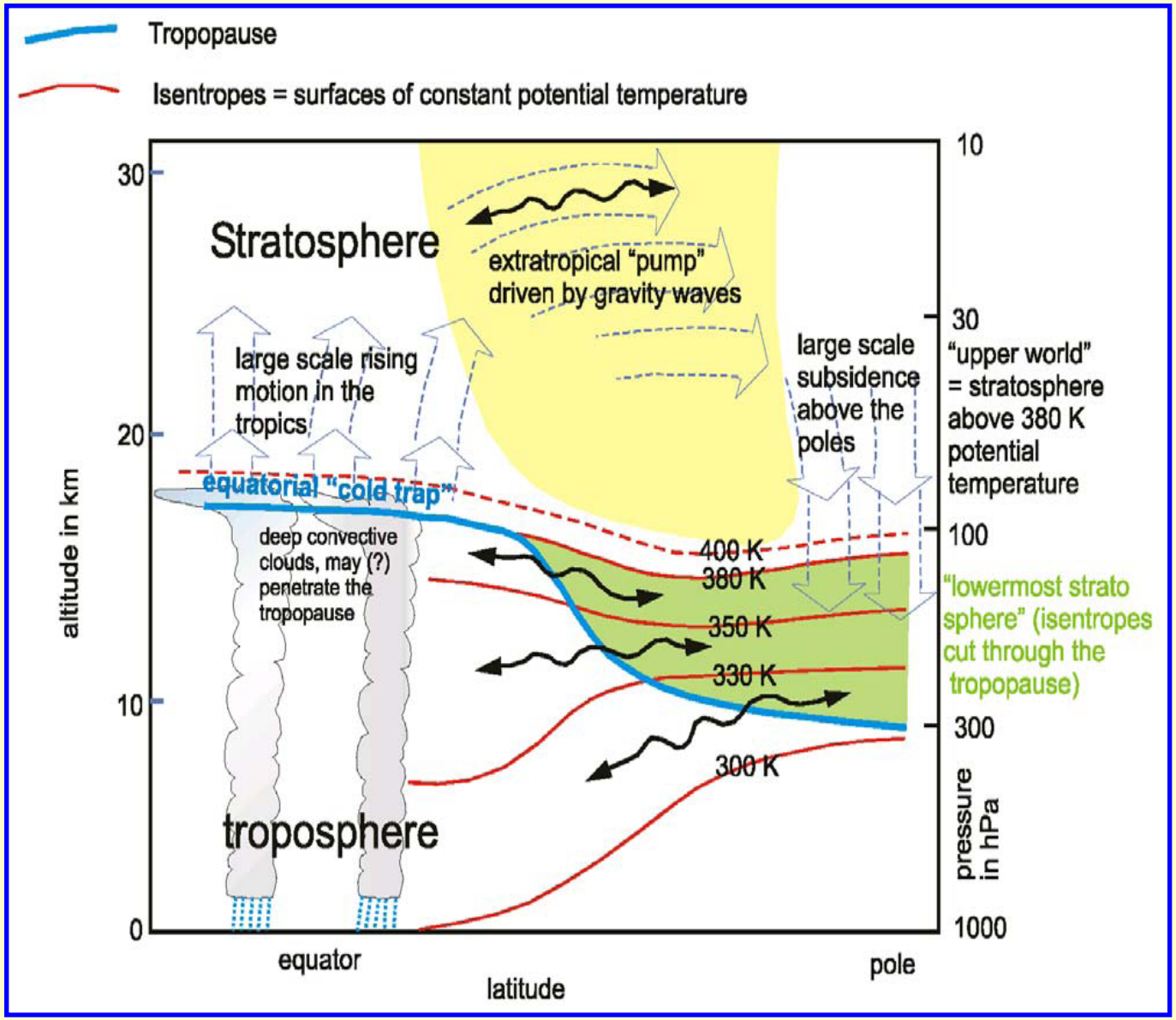
   b) addition of a mean tropopause:

   $$z' = z - z_{TP} + \text{mean}(z_{TP})$$

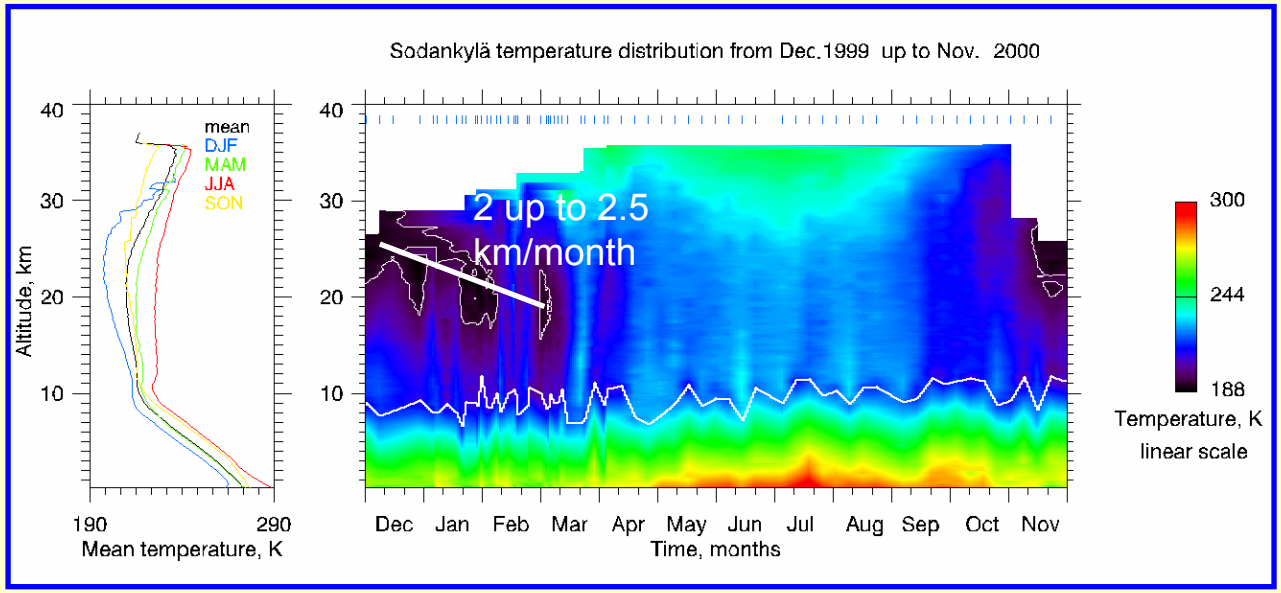
   c) calculation of averaged physical measures x(z') (temperature, ozone, N_B)

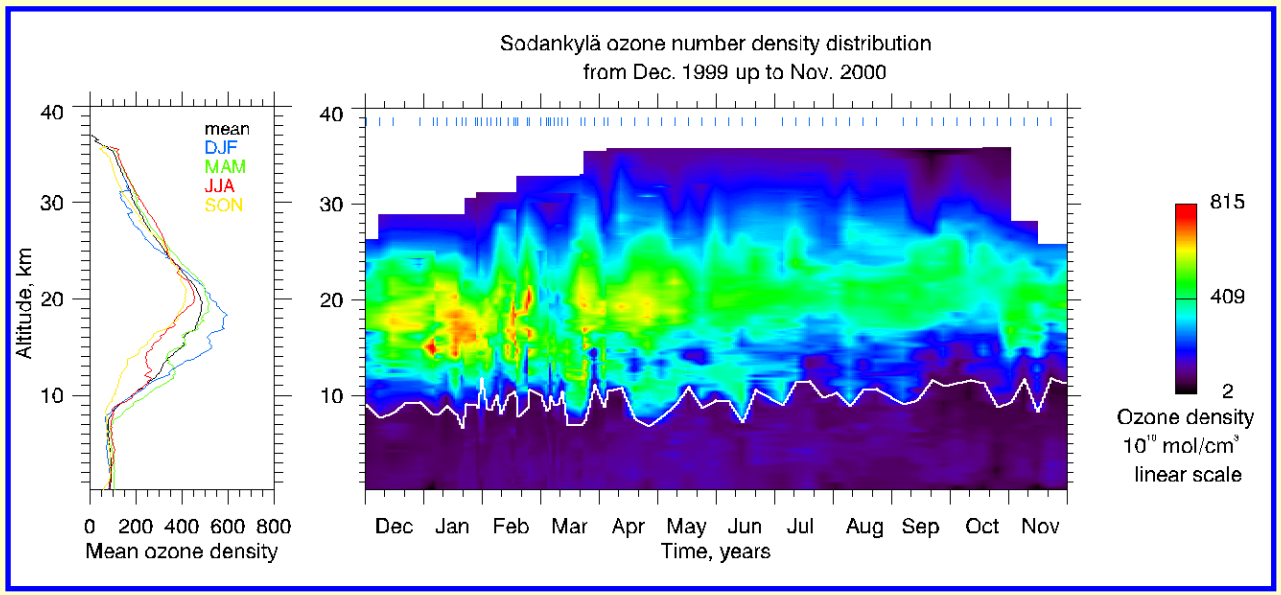
Birner,T., JGR, 111, D04104, 2006

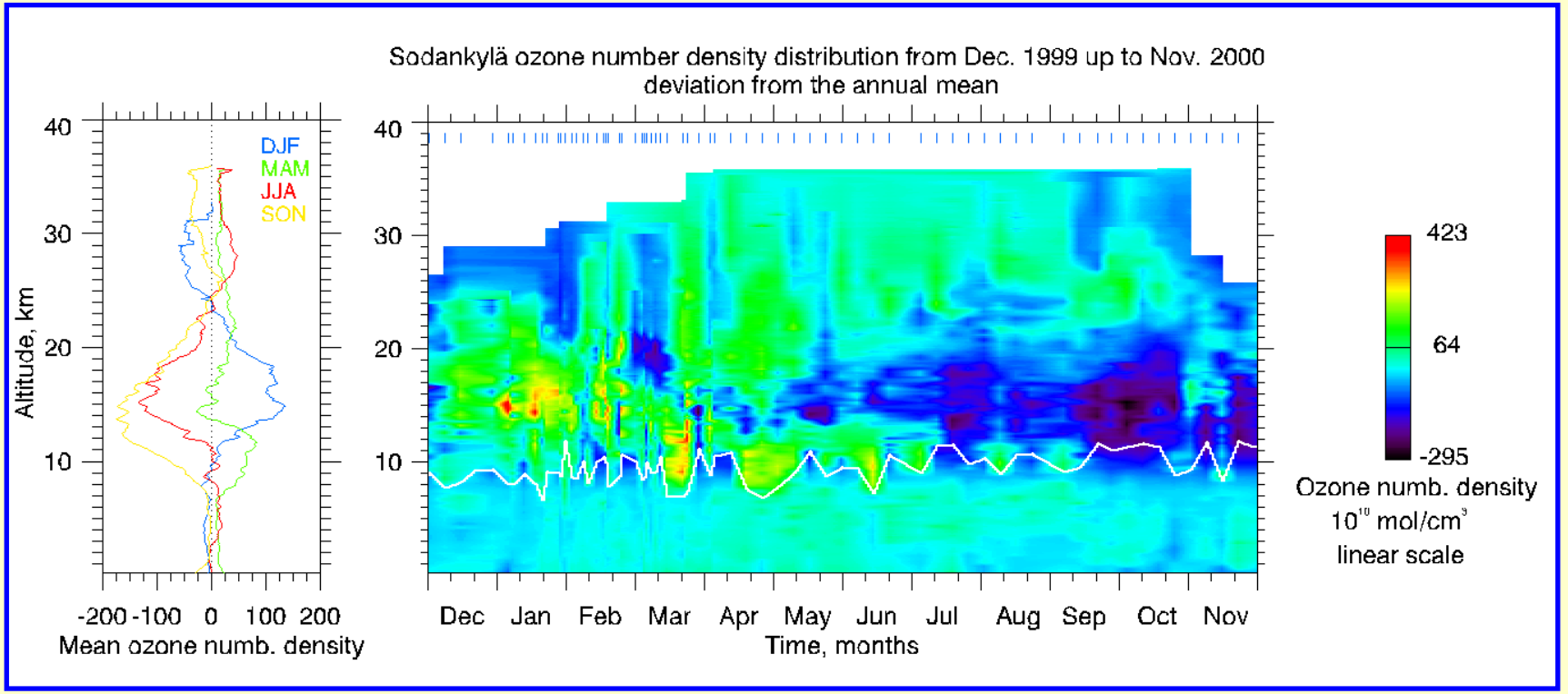
Brewer-Dobson Circulation and STE



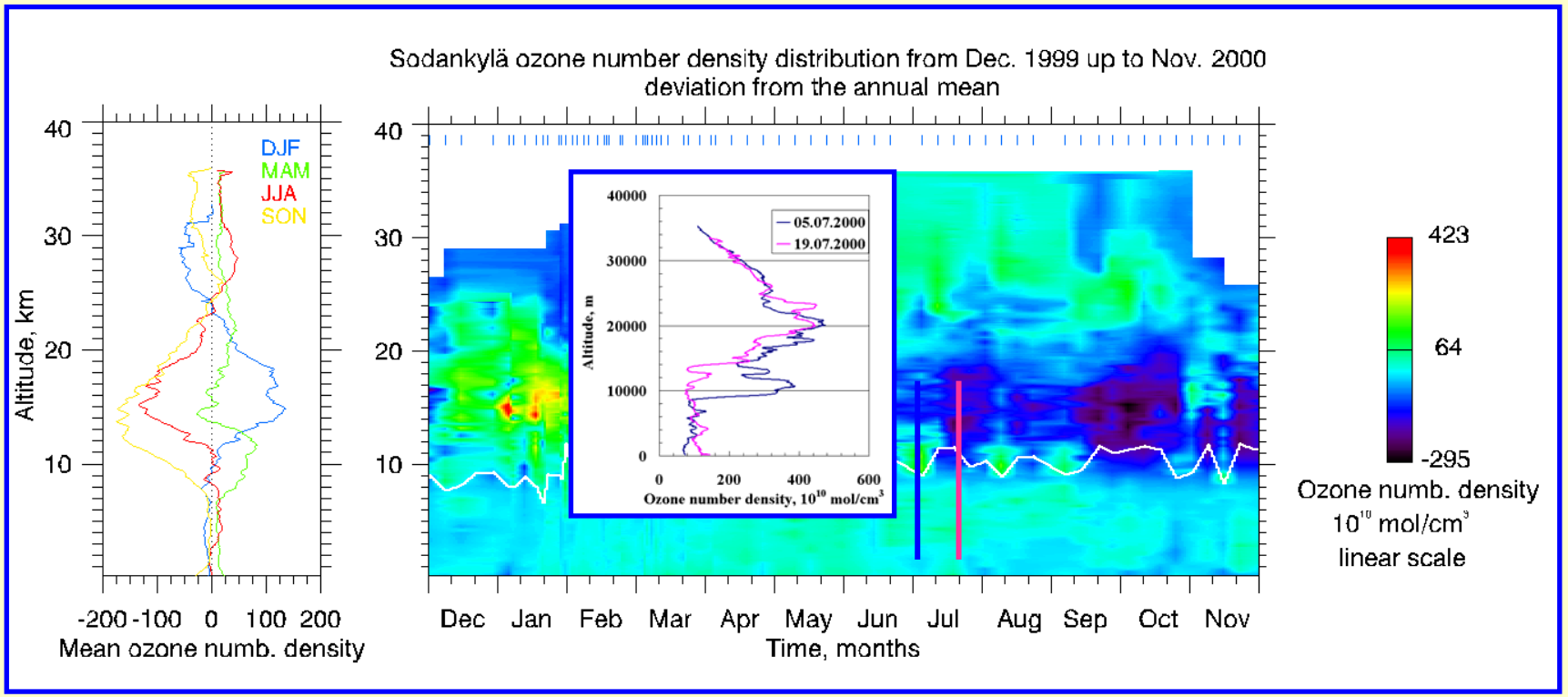
Results


Sodankylä temperature distribution from Dec.1999 up to Nov. 2000
mean
DJF
MAM
JJA
SON
Altitude, km
40
30
20
10
190
290
Mean temperature, K
2 up to 2.5
km/month
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Time, months
300
244
188
Temperature, K
linear scale

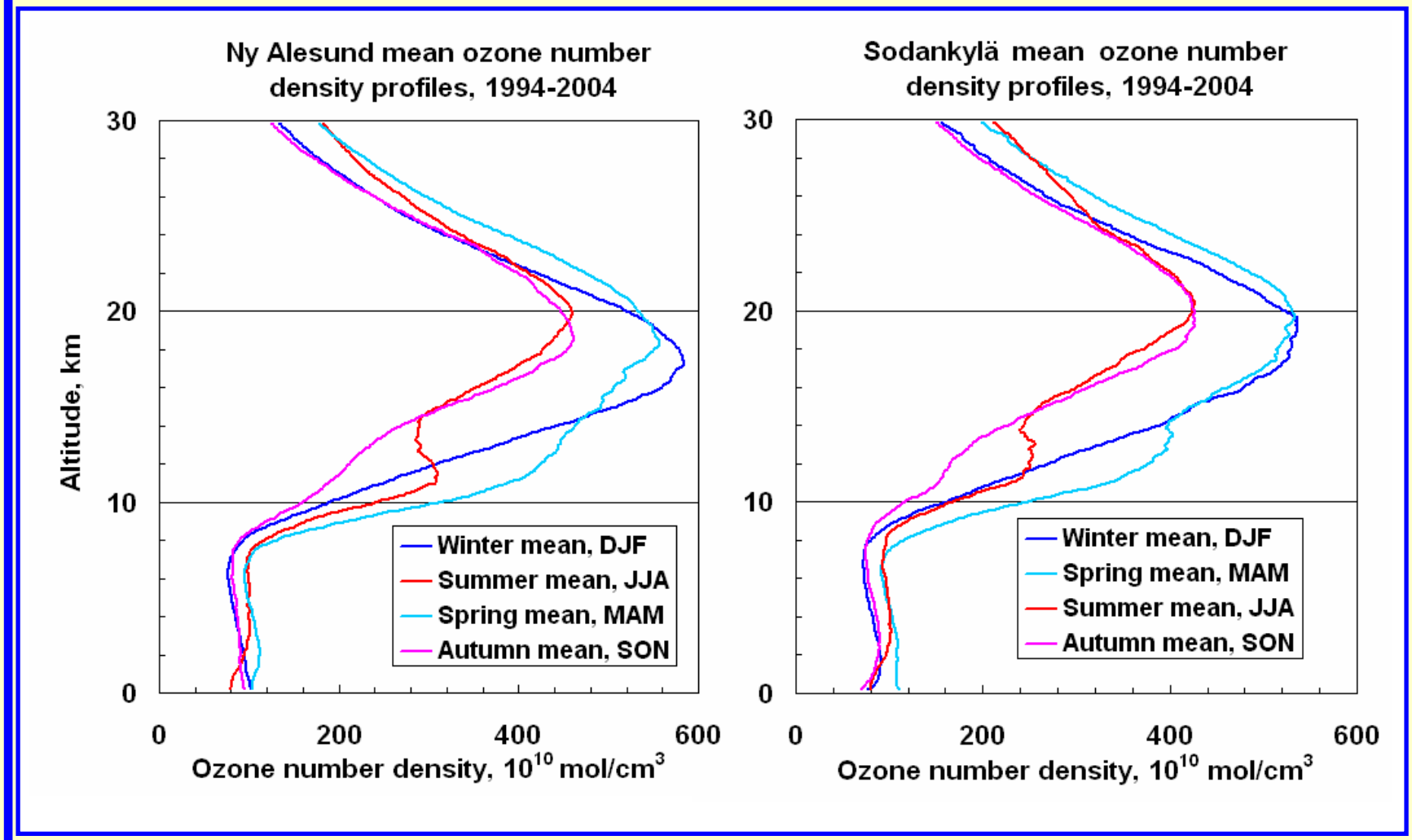

Sodankylä ozone number density distribution
from Dec. 1999 up to Nov. 2000
mean
DJF
MAM
JJA
SON
Altitude, km
40
30
20
10
0 200 400 600 800
Mean ozone density
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Time, years
815
409
2
Ozone density
10^10 mol/cm^3
linear scale


Sodankylä ozone number density distribution from Dec. 1999 up to Nov. 2000
deviation from the annual mean
Altitude, km
40
30
20
10
DJF
MAM
JJA
SON
-200 -100 0 100 200
Mean ozone numb. density
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Time, months
423
64
-295
Ozone numb. density
10^10 mol/cm^3
linear scale

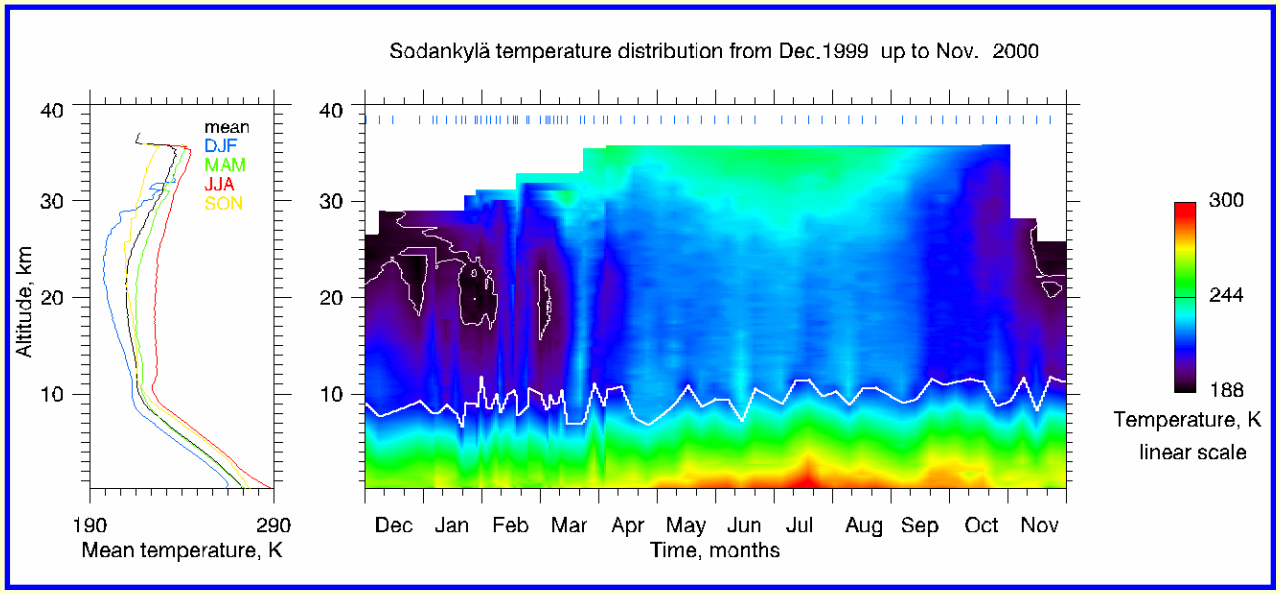
Results

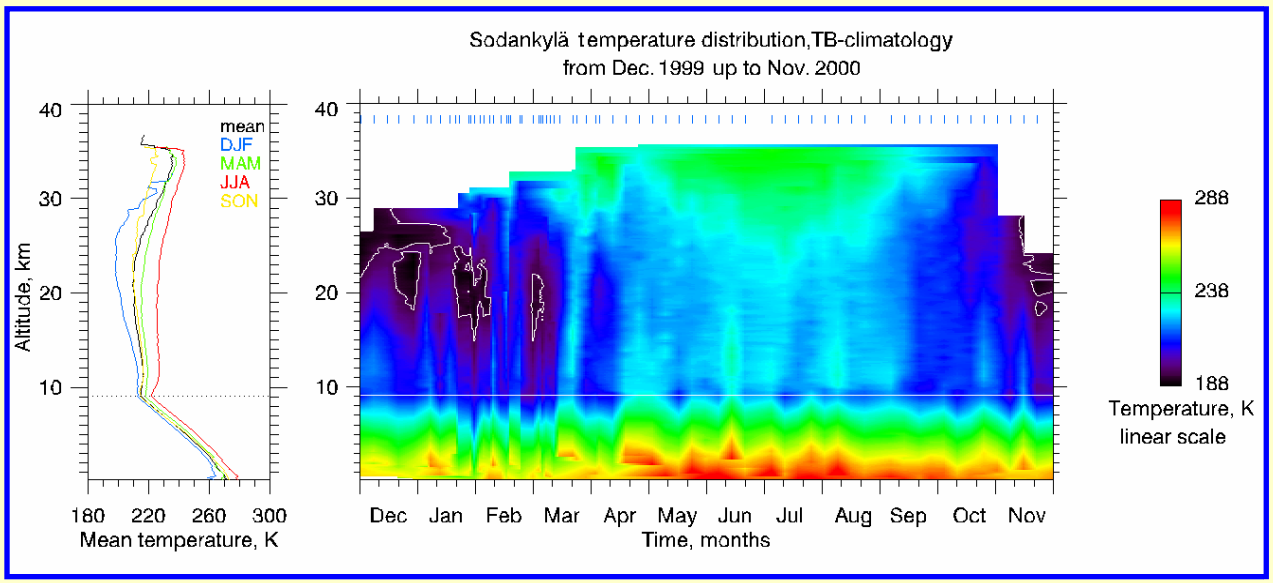

Sodankylä ozone number density distribution from Dec. 1999 up to Nov. 2000
deviation from the annual mean
DJF
MAM
JJA
SON
Altitude, km
40
30
20
10
-200 -100 0 100 200
Mean ozone numb. density
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Time, months
05.07.2000
19.07.2000
Altitude, m
40000
30000
20000
10000
0
0 200 400 600
Ozone number density, 10^10 mol/cm^3
423
64
-295
Ozone numb. density
10^10 mol/cm^3
linear scale

Results

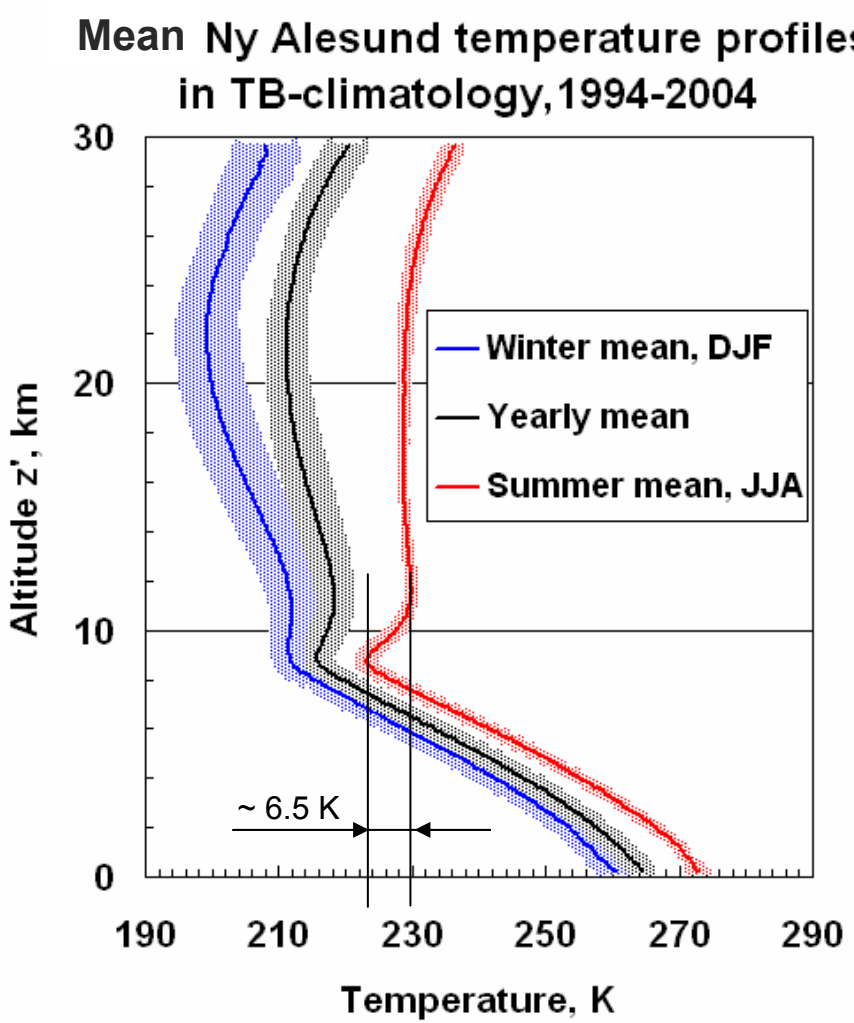

Ny Alesund mean ozone number density profiles, 1994-2004
Altitude, km
30
20
10
0
0
200
400
600
Ozone number density, 10^10 mol/cm^3
Winter mean, DJF
Summer mean, JJA
Spring mean, MAM
Autumn mean, SON
Sodankylä mean ozone number density profiles, 1994-2004
30
20
10
0
0
200
400
600
Ozone number density, 10^10 mol/cm^3
Winter mean, DJF
Spring mean, MAM
Summer mean, JJA
Autumn mean, SON

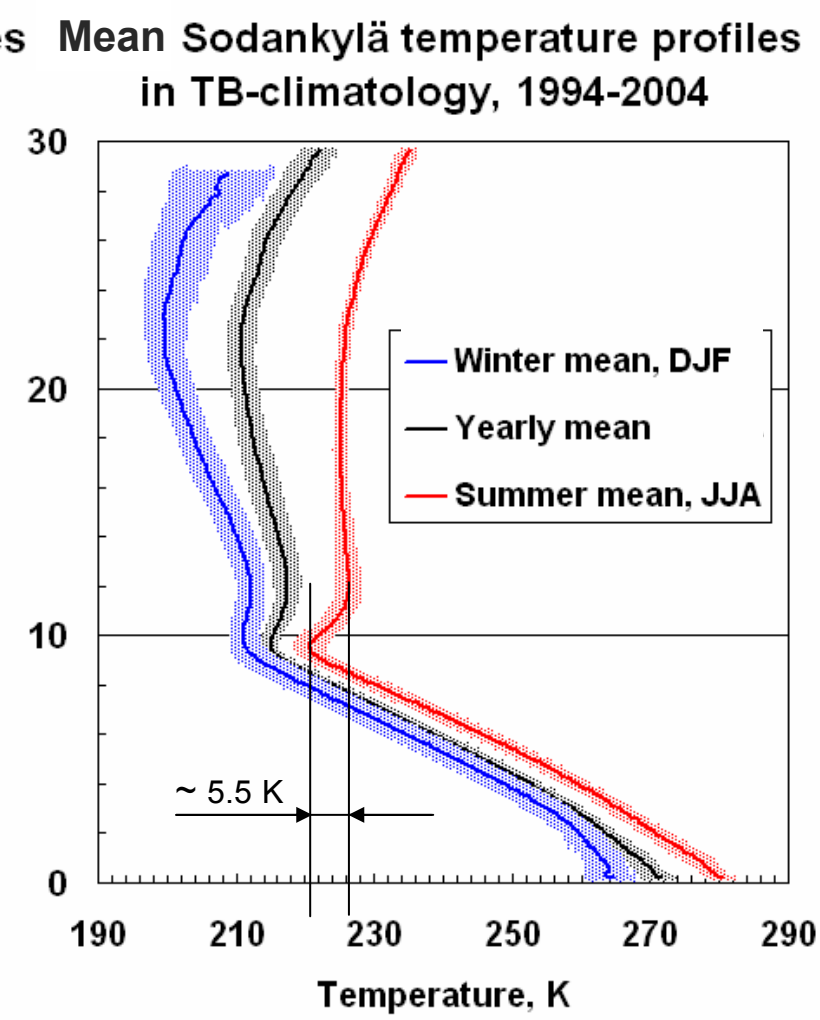
Results


Sodankylä temperature distribution from Dec.1999 up to Nov. 2000
mean
DJF
MAM
JJA
SON
Altitude, km
40
30
20
10
190
290
Mean temperature, K
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Time, months
300
244
188
Temperature, K
linear scale

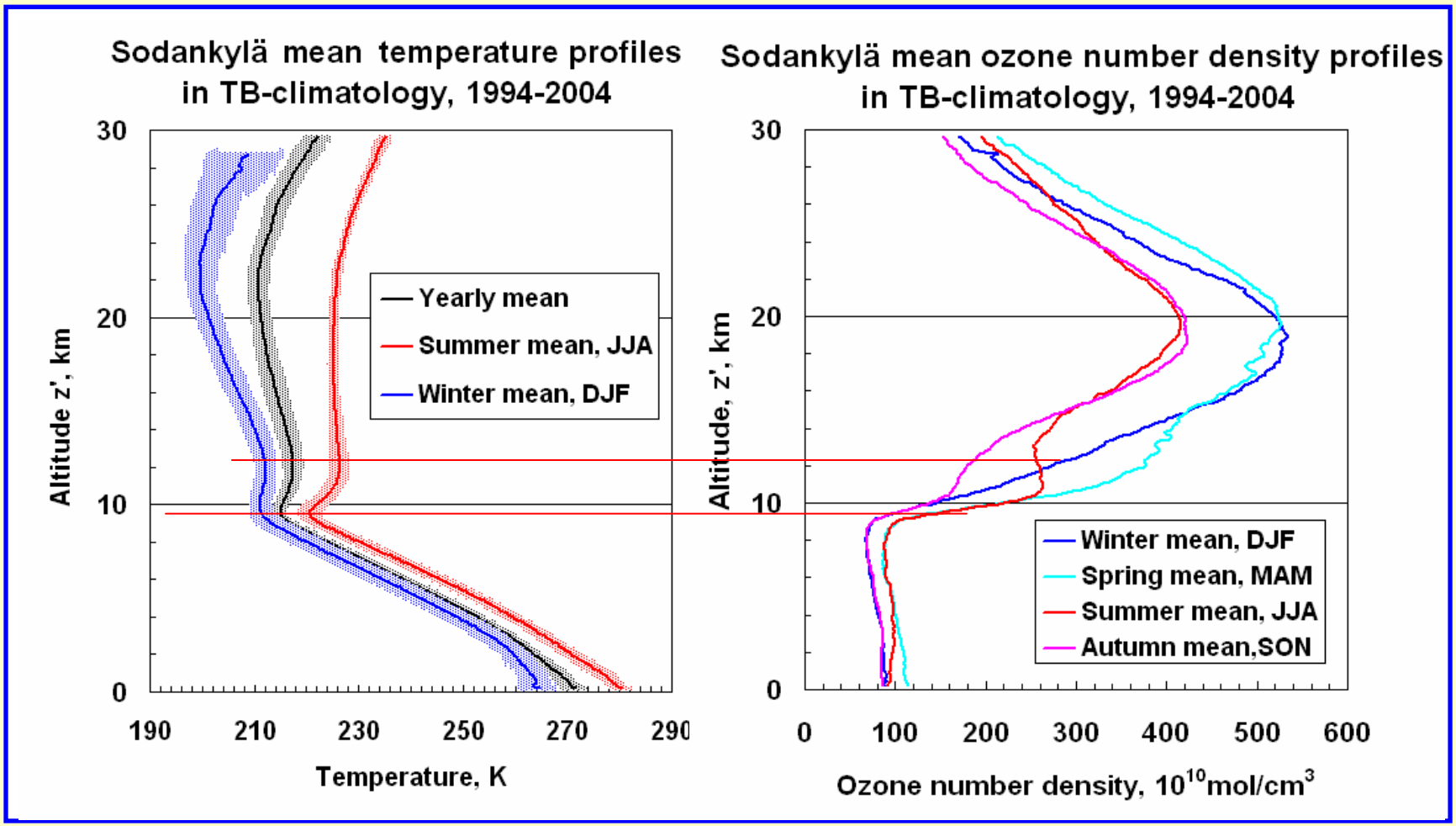

Sodankylä temperature distribution,TB-climatology
from Dec. 1999 up to Nov. 2000
mean
DJF
MAM
JJA
SON
Altitude, km
40
30
20
10
180 220 260 300
Mean temperature, K
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Time, months
288
238
188
Temperature, K
linear scale

Results

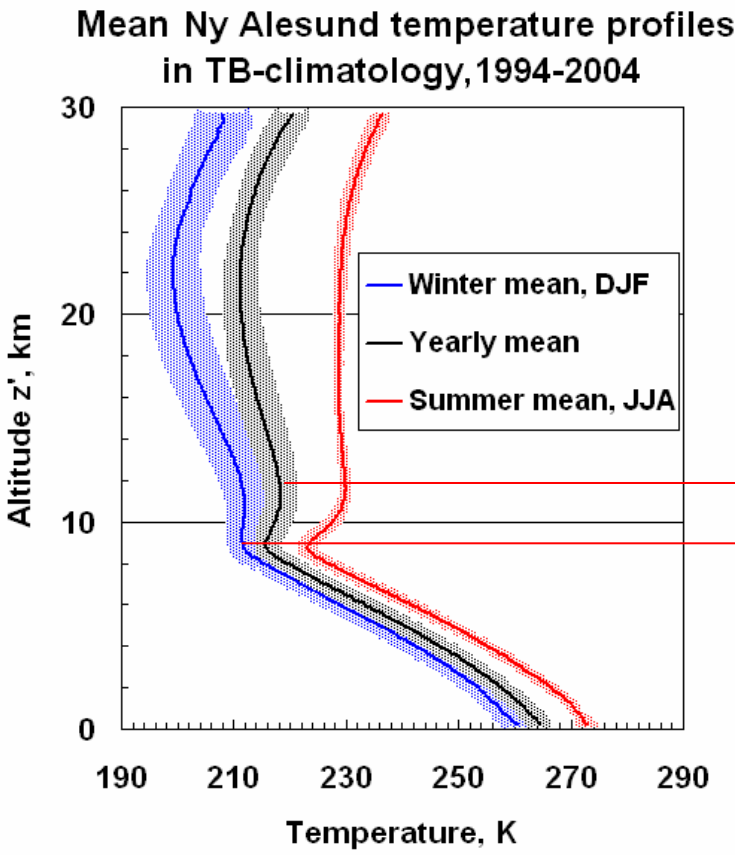

Mean Ny Alesund temperature profiles in TB-climatology,1994-2004
Altitude z', km
30
20
10
0
190
210
230
250
270
290
Temperature, K
Winter mean, DJF
Yearly mean
Summer mean, JJA
~ 6.5 K

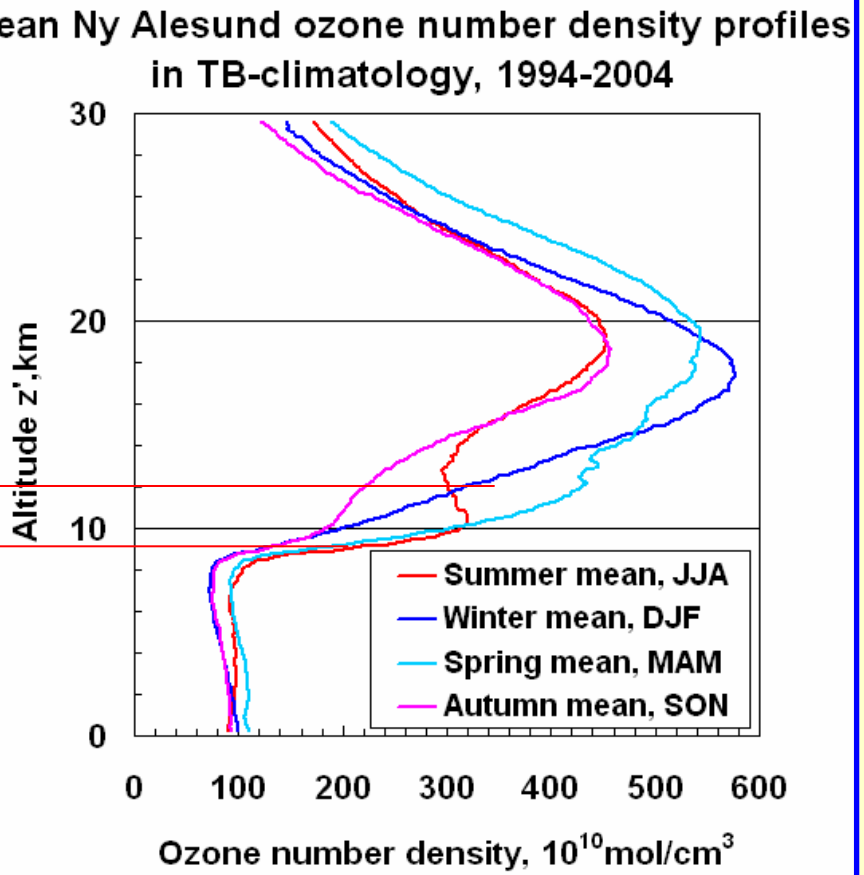

Mean Sodankylä temperature profiles in TB-climatology, 1994-2004
30
20
10
0
190
210
230
250
270
290
Temperature, K
Winter mean, DJF
Yearly mean
Summer mean, JJA
~ 5.5 K

Results

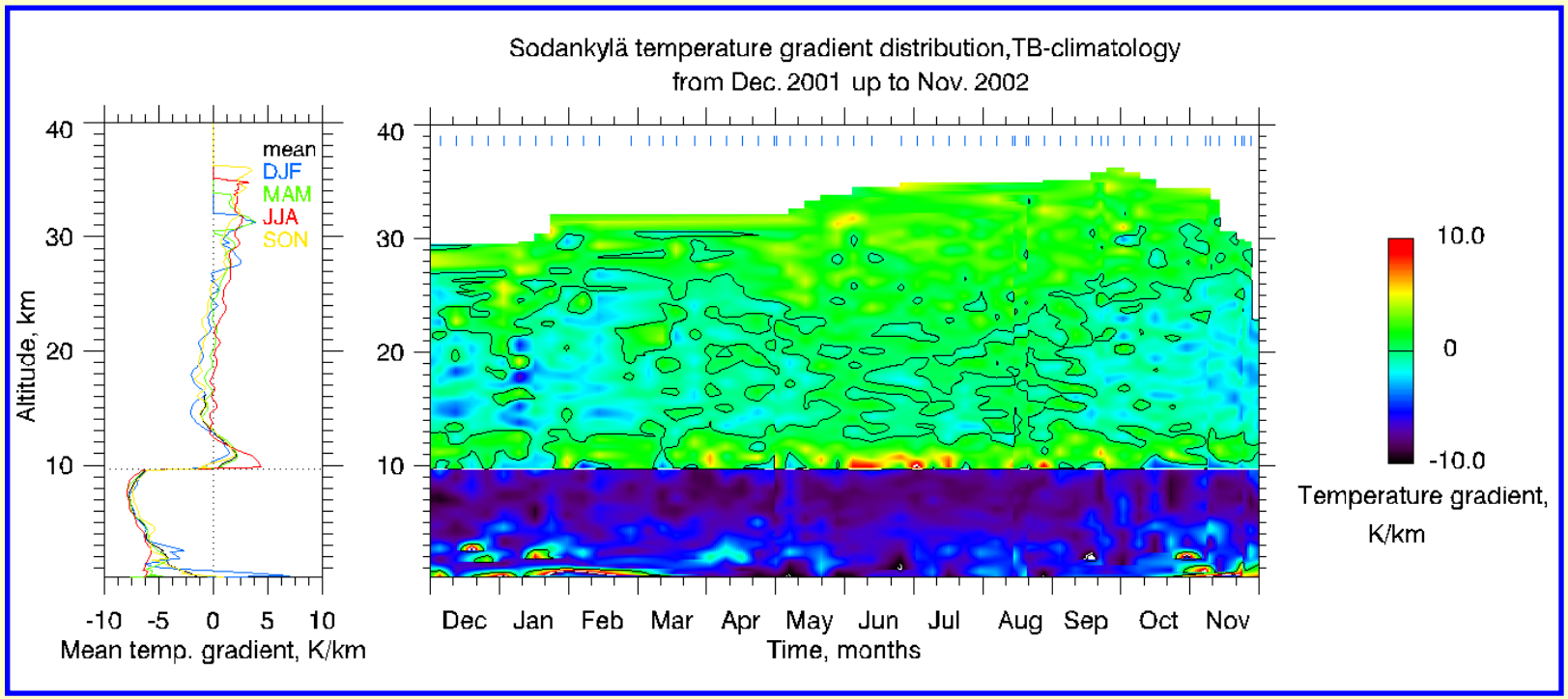

Sodankylä mean temperature profiles in TB-climatology, 1994-2004
Altitude z', km
30
20
10
0
190
210
230
250
270
290
Temperature, K
Yearly mean
Summer mean, JJA
Winter mean, DJF
Sodankylä mean ozone number density profiles in TB-climatology, 1994-2004
Altitude, z', km
30
20
10
0
0
100
200
300
400
500
600
Ozone number density, 10^{10}mol/cm^3
Winter mean, DJF
Spring mean, MAM
Summer mean, JJA
Autumn mean,SON

Results

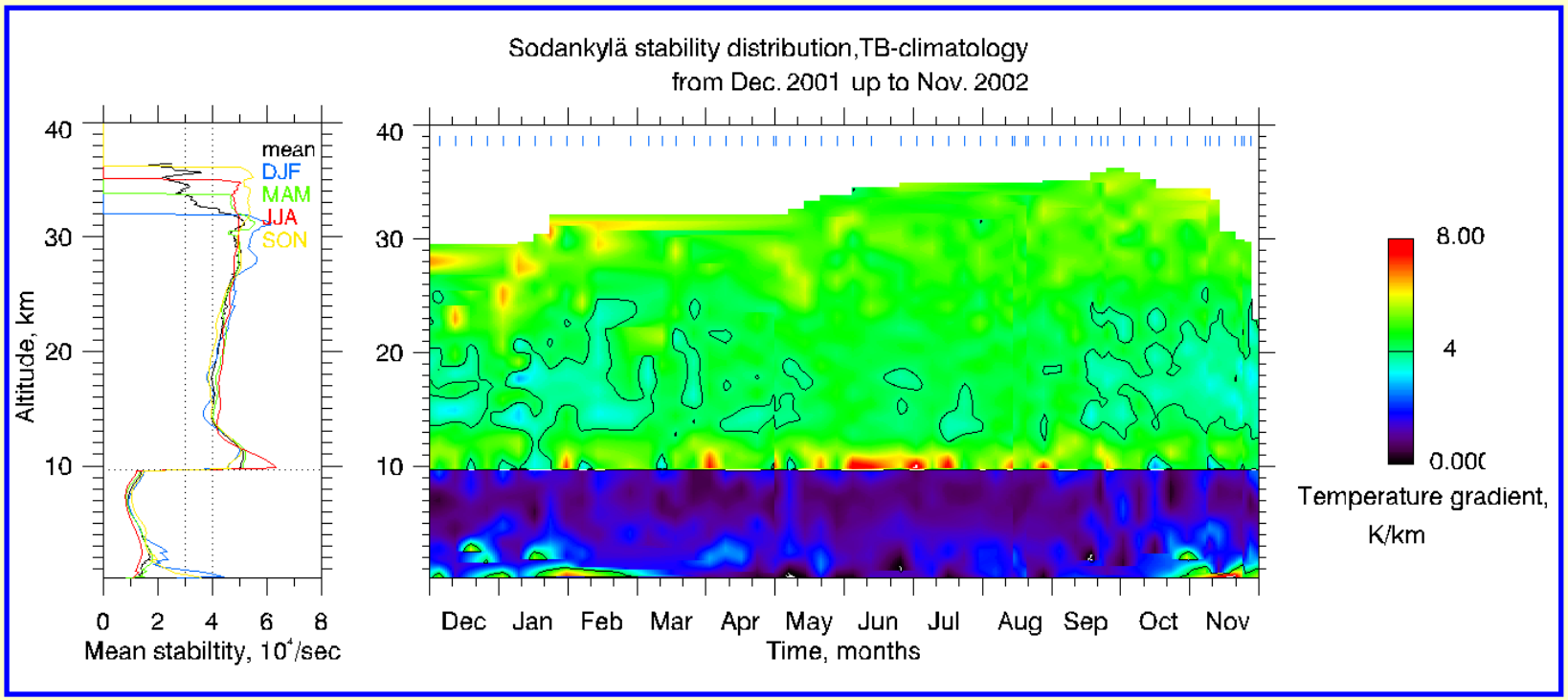

Mean Ny Alesund temperature profiles
in TB-climatology,1994-2004
Altitude z', km
30
20
10
0
190
210
230
250
270
290
Temperature, K
Winter mean, DJF
Yearly mean
Summer mean, JJA


Mean Ny Alesund ozone number density profiles
in TB-climatology, 1994-2004
Altitude z',km
30
20
10
0
0
100
200
300
400
500
600
Ozone number density, 10^10 mol/cm^3
Summer mean, JJA
Winter mean, DJF
Spring mean, MAM
Autumn mean, SON

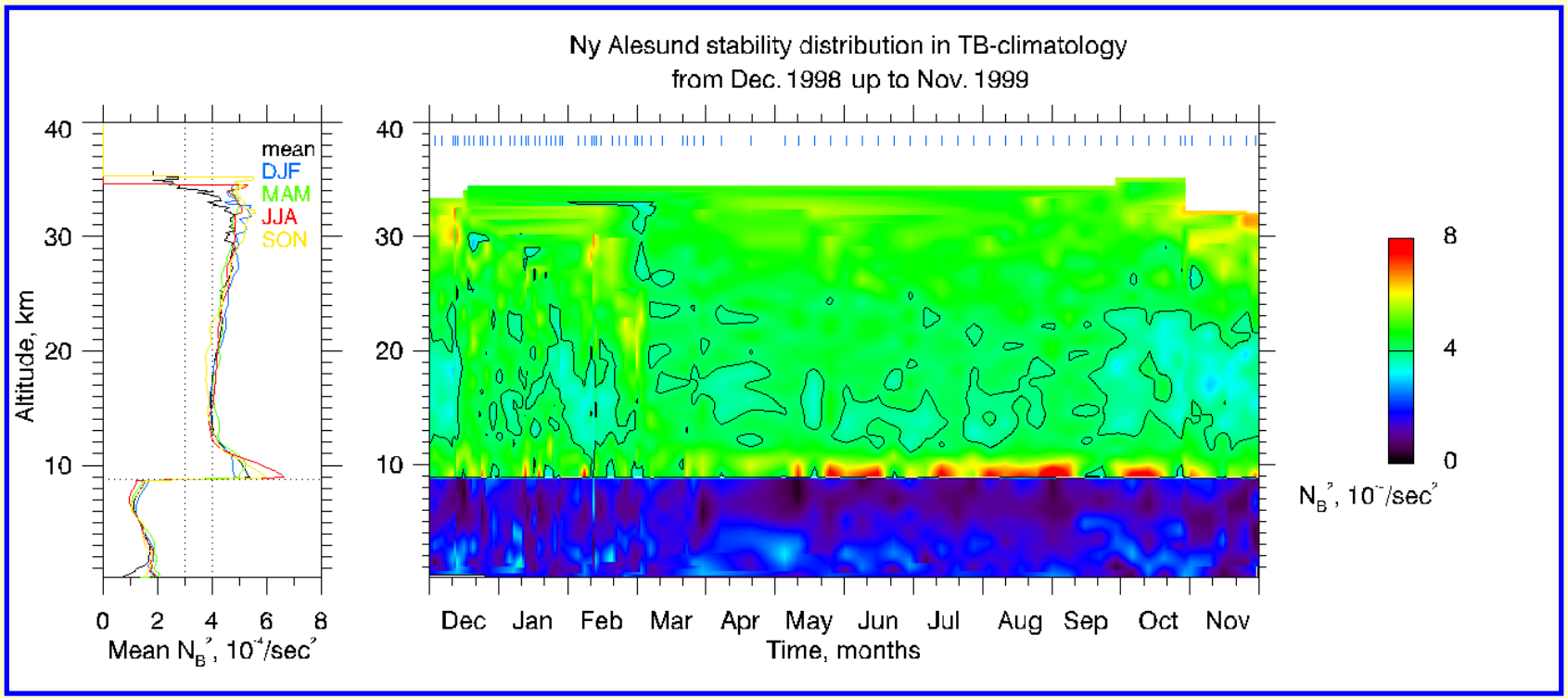
Results


Sodankylä temperature gradient distribution,TB-climatology
from Dec. 2001 up to Nov. 2002
Altitude, km
40
30
20
10
mean
DJF
MAM
JJA
SON
-10 -5 0 5 10
Mean temp. gradient, K/km
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Time, months
10.0
0
-10.0
Temperature gradient, K/km

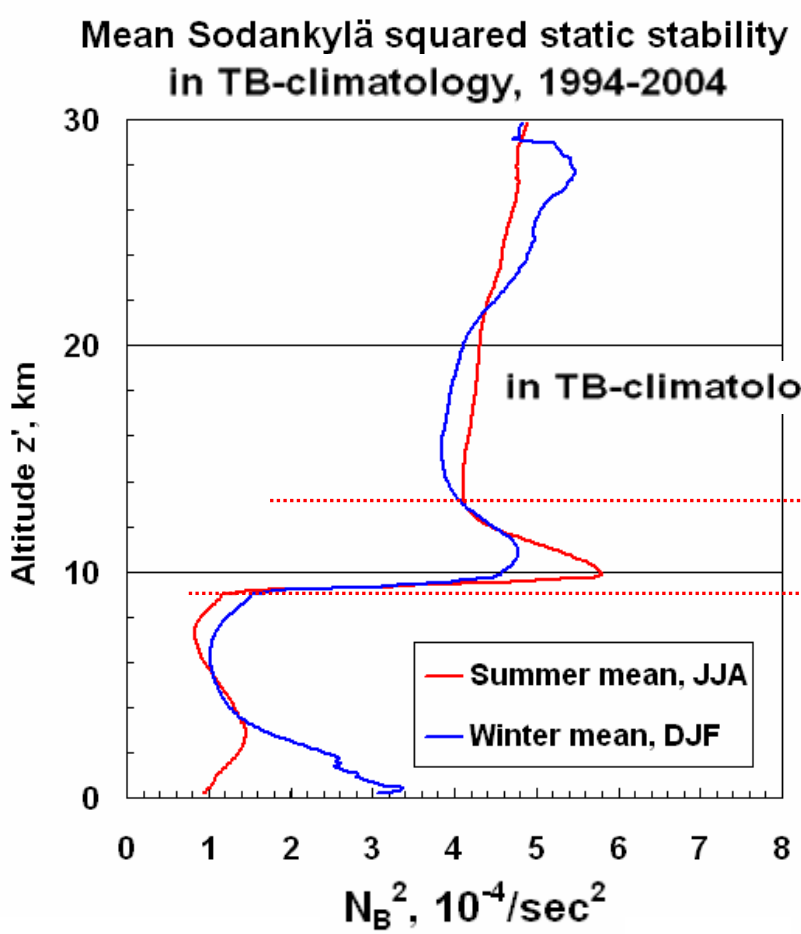
Results

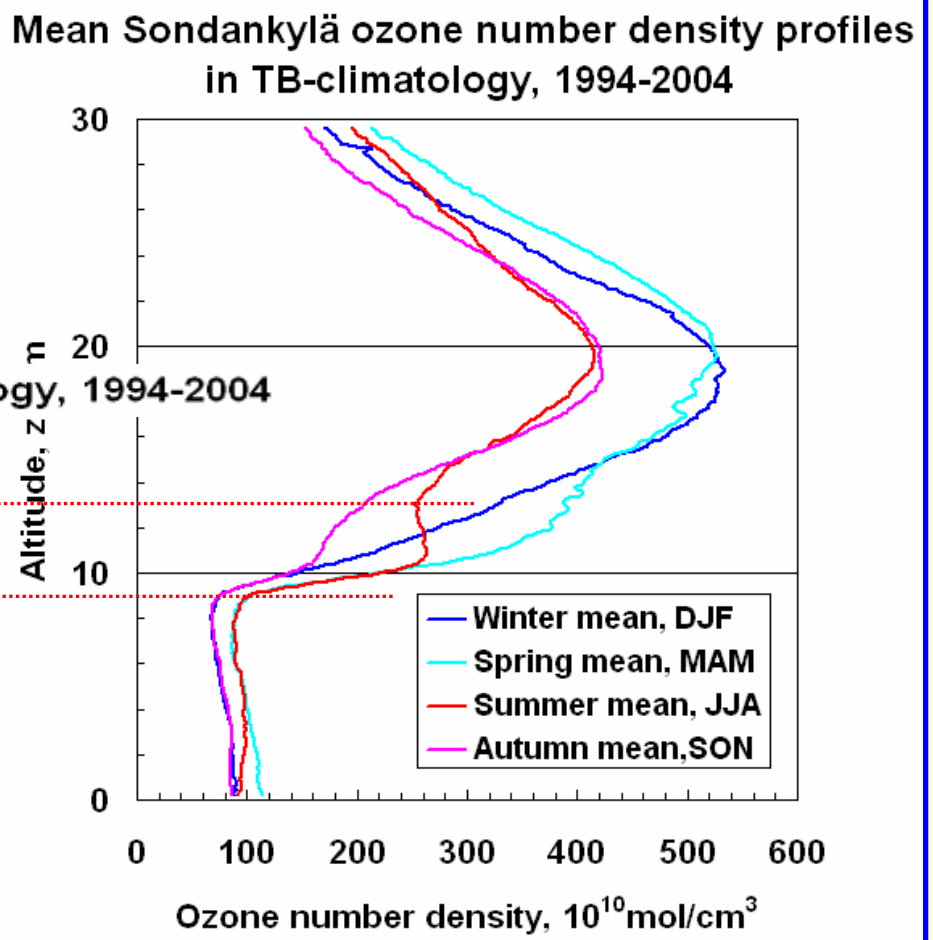

Sodankylä stability distribution,TB-climatology
from Dec. 2001 up to Nov. 2002
Altitude, km
40
30
20
10
mean
DJF
MAM
JJA
SON
0
2
4
6
8
Mean stabiltity, 10⁴/sec
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Time, months
8.00
4
0.000
Temperature gradient,
K/km

Results

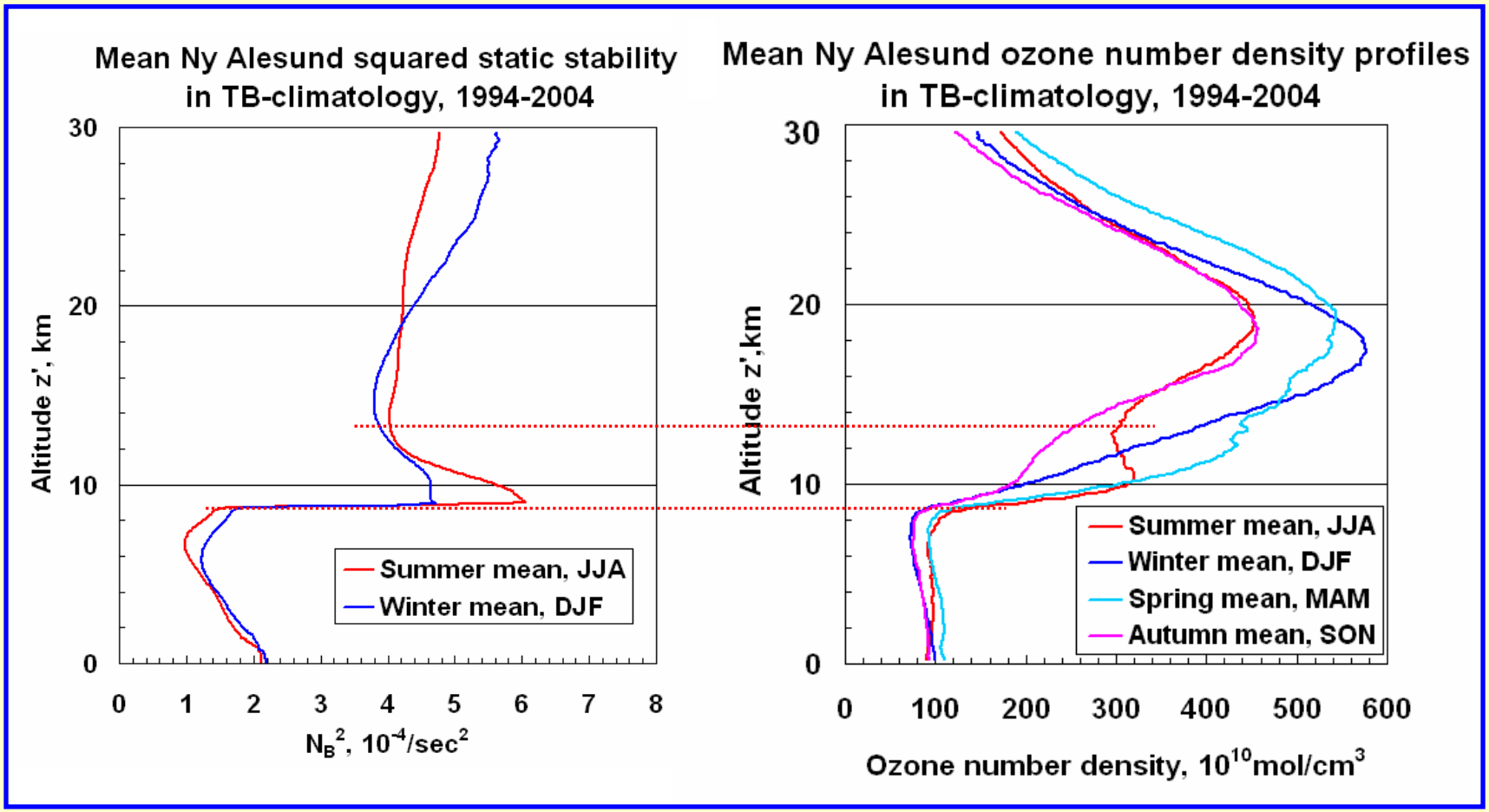

Ny Alesund stability distribution in TB-climatology
from Dec. 1998 up to Nov. 1999
Altitude, km
40
30
20
10
mean
DJF
MAM
JJA
SON
0 2 4 6 8
Mean N_B^2, 10^{-4}/sec^2
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Time, months
8
4
0
N_B^2, 10^{-4}/sec^2

Results

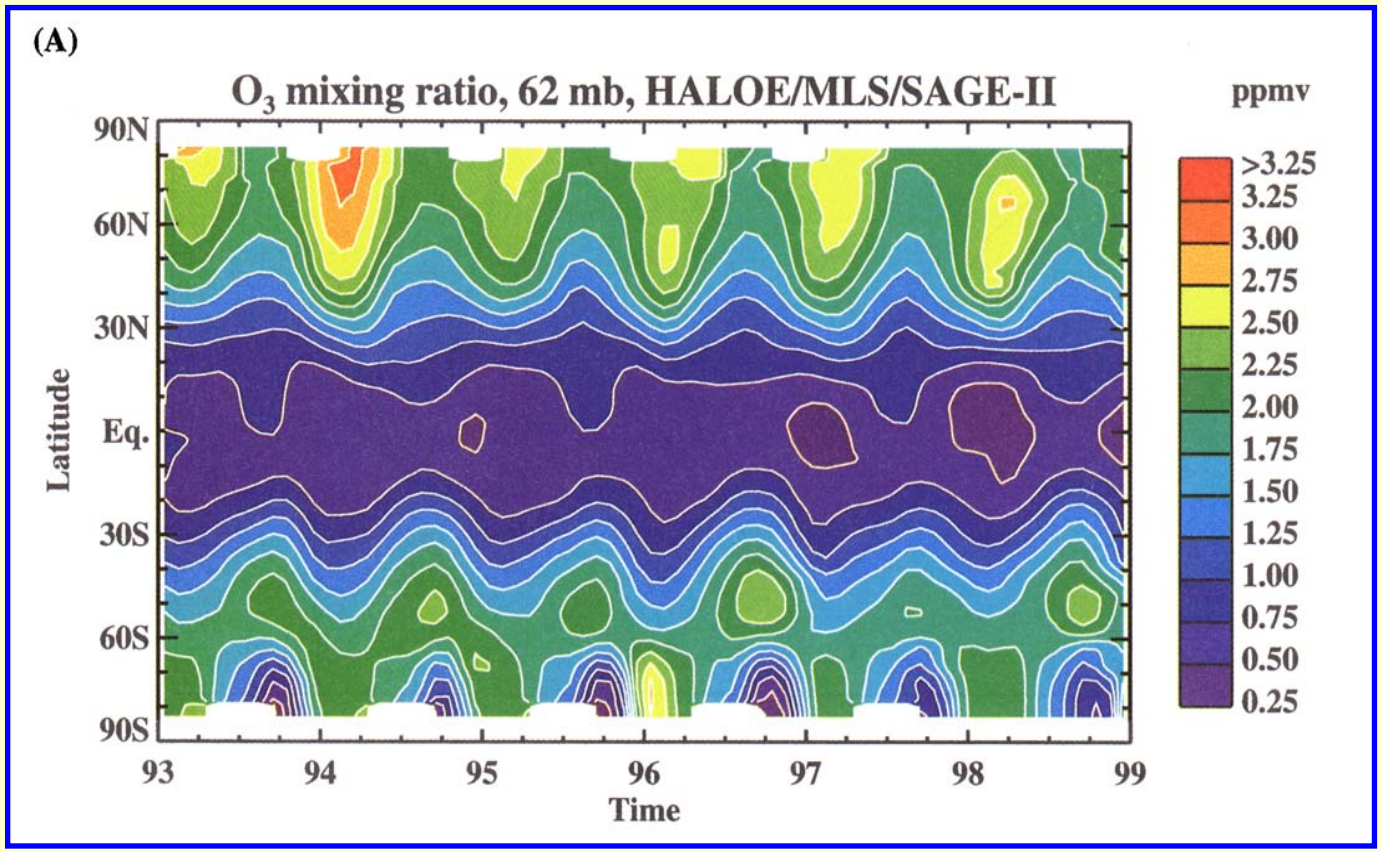

Mean Sodankylä squared static stability
in TB-climatology, 1994-2004
Altitude z', km
30
20
10
0
0
1
2
3
4
5
6
7
8
N_B^2, 10^{-4}/sec^2
Summer mean, JJA
Winter mean, DJF


Mean Sondankylä ozone number density profiles
in TB-climatology, 1994-2004
in TB-climatology, 1994-2004
Altitude, z
30
20
10
0
0
100
200
300
400
500
600
Ozone number density, 10^{10}mol/cm^3
Winter mean, DJF
Spring mean, MAM
Summer mean, JJA
Autumn mean,SON

Results


Mean Ny Alesund squared static stability in TB-climatology, 1994-2004
Altitude z', km
30
20
10
0
0 1 2 3 4 5 6 7 8
N_B^2, 10^{-4}/sec^2
Summer mean, JJA
Winter mean, DJF
Mean Ny Alesund ozone number density profiles in TB-climatology, 1994-2004
Altitude z',km
30
20
10
0
0 100 200 300 400 500 600
Ozone number density, 10^{10}mol/cm^3
Summer mean, JJA
Winter mean, DJF
Spring mean, MAM
Autumn mean, SON

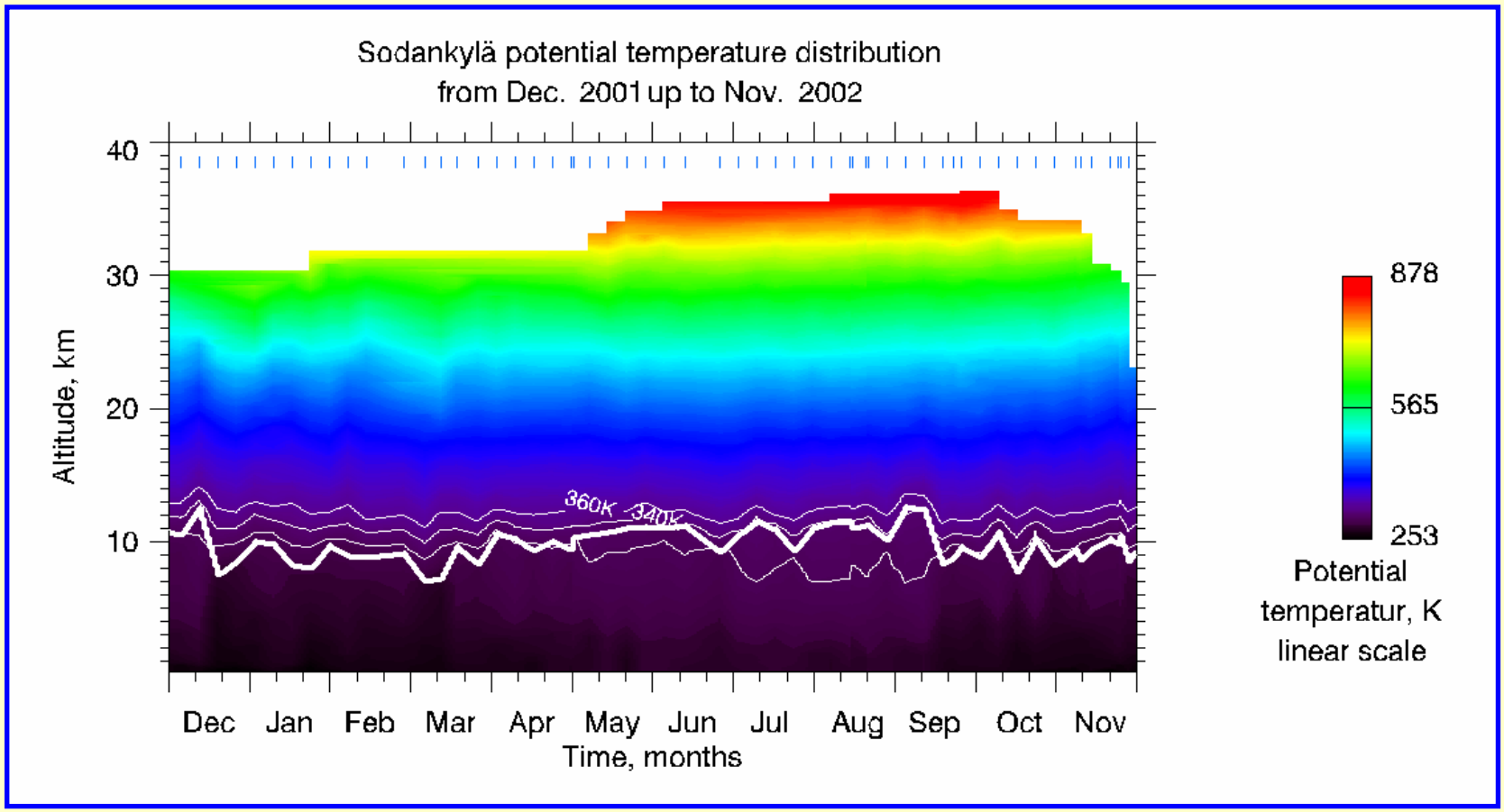
Discussion



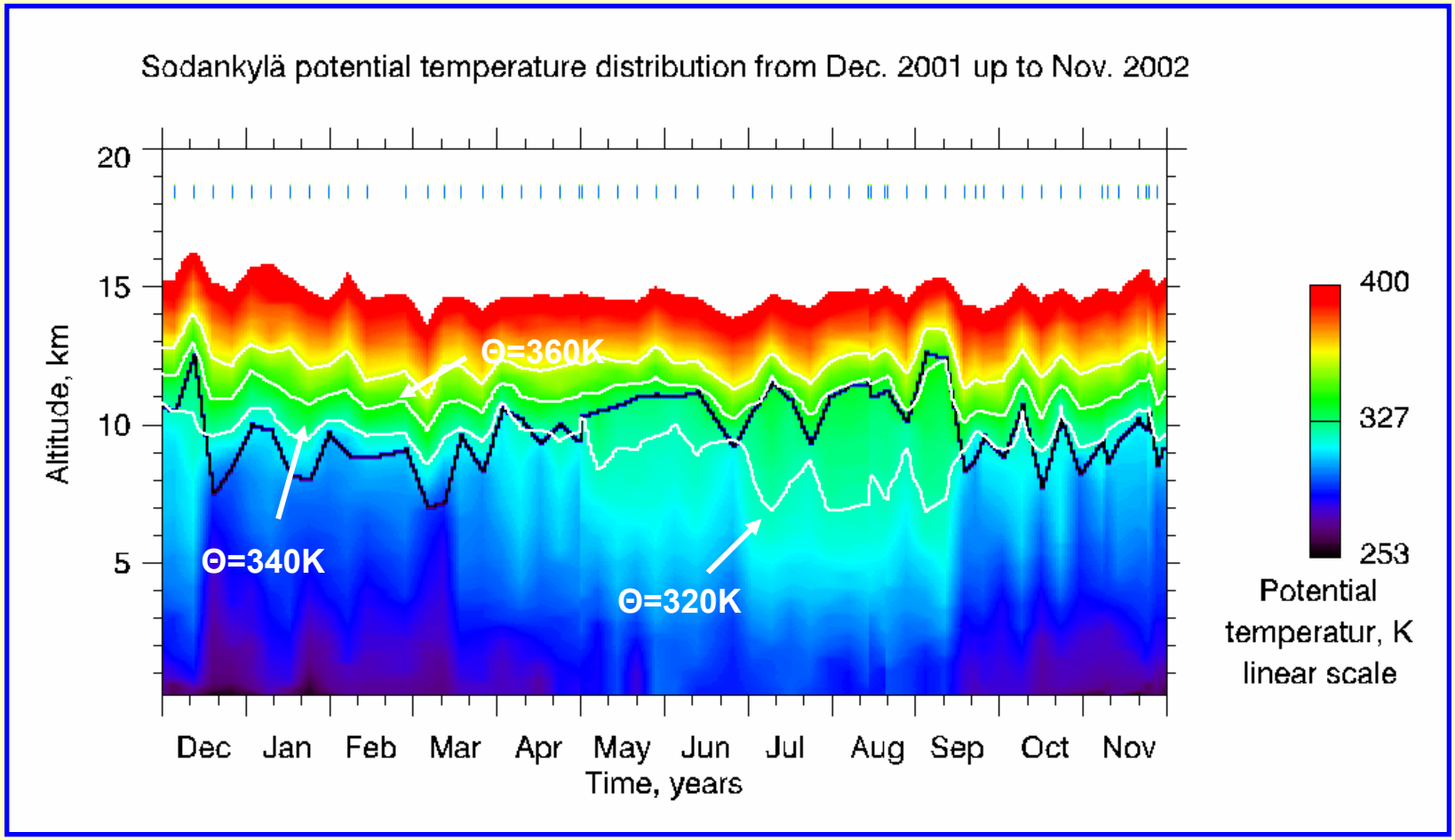
„Poleward transport will effectivly decrease high-latitude ozone in the lower stratosphere and increase high-latitude ozone in the middle stratosphere.“

Rosenlof,K.H., JGR, 40,D21, 26,511-26,523, 1999

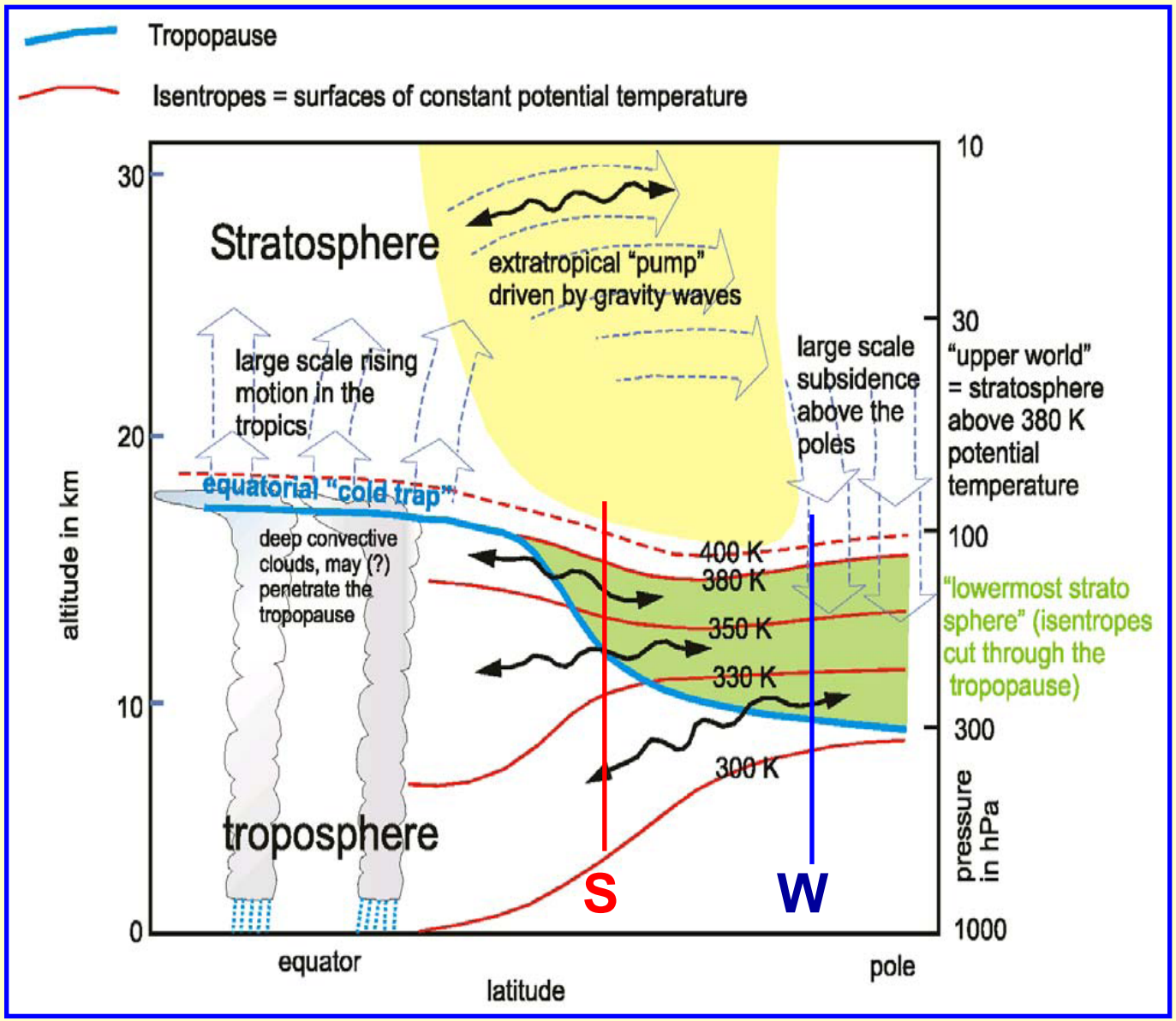
Discussion


Sodankylä potential temperature distribution
from Dec. 2001 up to Nov. 2002
Altitude, km
40
30
20
10
360K
340K
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Time, months
878
565
253
Potential
temperatur, K
linear scale

Discussion


Sodankylä potential temperature distribution from Dec. 2001 up to Nov. 2002
Altitude, km
20
15
10
5
Θ=360K
Θ=340K
Θ=320K
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Time, years
400
327
253
Potential temperatur, K
linear scale

Discussion


Tropopause
Isentropes = surfaces of constant potential temperature
Stratosphere
extratropical "pump" driven by gravity waves
large scale rising motion in the tropics
large scale subsidence above the poles
equatorial "cold trap"
deep convective clouds, may (?) penetrate the tropopause
troposphere
400 K
380 K
350 K
330 K
300 K
S
W
altitude in km
30
20
10
0
10
30
100
300
1000
pressure in hPa
"upper world" = stratosphere above 380 K potential temperature
"lowermost strato sphere" (isentropes cut through the tropopause)
equator
pole
latitude

Conclusions

- A second ozone maximum is found, located just above the tropopause at high latitude during late spring and summer every year with different amplitude
- It is shown, that the second ozone maximum is related to the troposphere inversion layer
- It is demonstrated, that the troposphere inversion layer at high latitudes is very stable, restricted vertical transport.
- Ozone in the inversion layer is dynamically controlled by horizontal advection. Ozone is stronger chemically controlled and destroyed catalytically above the troposphere inversion layer. As a result of both processes the second ozone maximum is built up.

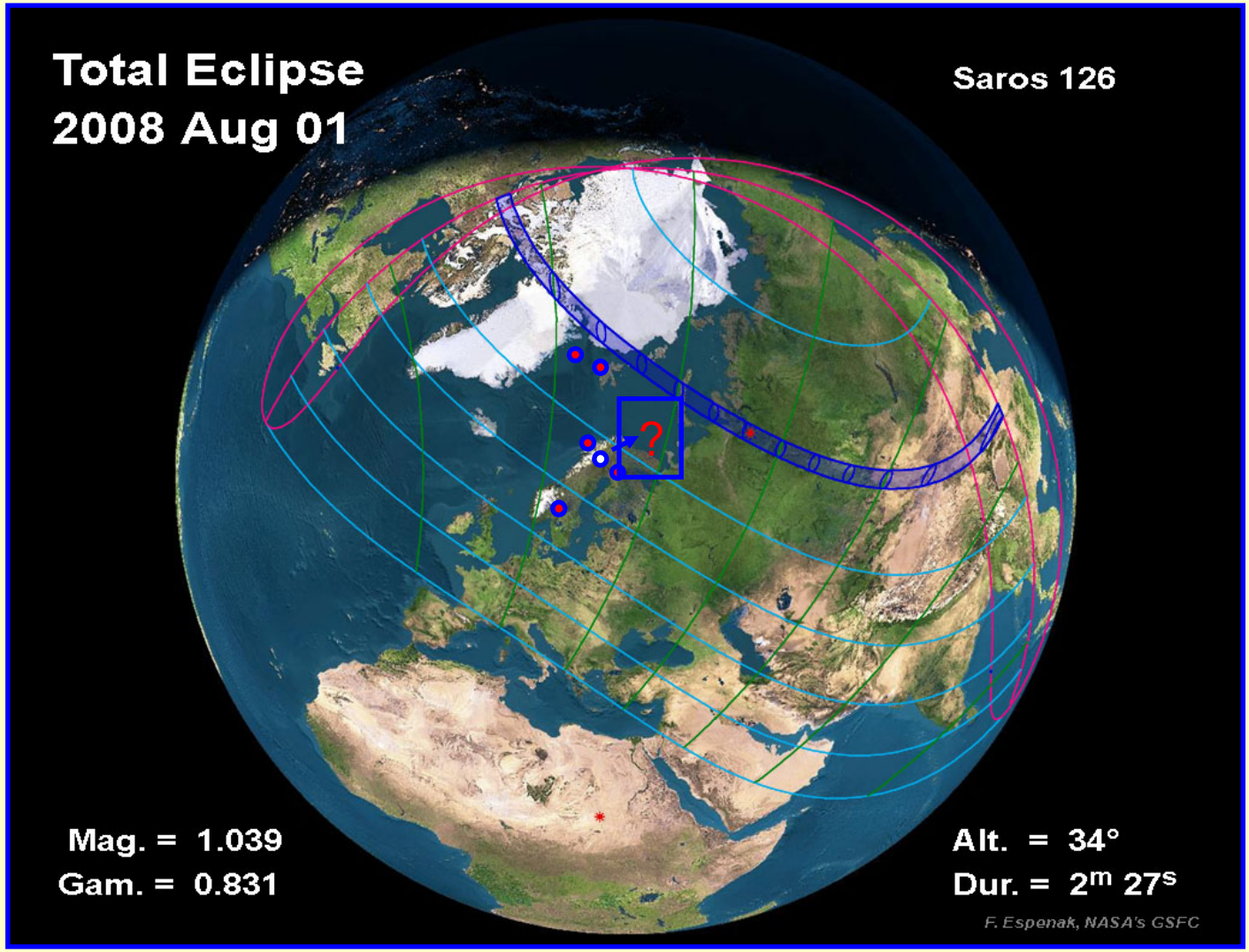
Solar eclipse 2008 - Joint project

Loacation	Measurement typeT	Altitude region, km	Responsible scientist	Institut
ALOMAR, 69°N, 16°E	RMR lidar	40 - 100	G. Baumgarten	IAP Kühlungsborn, Germany
	Radar	80 - 110	N.Engler	IAP Kühlungsborn, Germany
	Ozone lidar Brewer	30 - 50	M.Gausa	ALOMAR, Norway
Ny Ålesund 79°N, 12°E	Ozone sonde 1 up to 3	0 - 35	P. von der Gathen	AWI Potsdam, Germany
	Optical filter measurements Total ozone content		B. Petkov	ISAC-CNR Bologna, Italy
Sodankylä 67°N, 27°E	2 ozone sondes	0 - 35	R. Kivi	ARC, Finnish Meteorological Institute, Sodankylä, Finland
Oslo 60°N, 10°E	Brewer GUV		K. Stebel	NILU, Kjeller, Norway
Research ship “Oceania“ near Svalbard	Total ozone, Microtops		T. Zielinski	Polish Academie of sciences, Poland

ESRANGE ? 68°N, 21°E

Radar, Lidar, S. Kirkwood, K.H. Fricke

Solar eclipse 2008 - Joint project



rolwer52@yahoo.co.uk

Thank you very much for your attention