A radar-ozonesonde intensive

Results from investigations using wind-profiling radars, ozonesondes and FLEXPART

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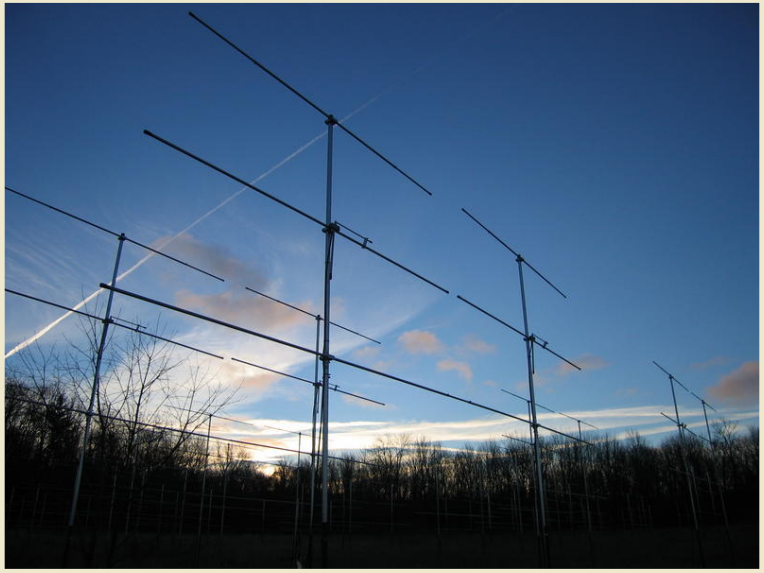
Western

Canada

Our Experiments

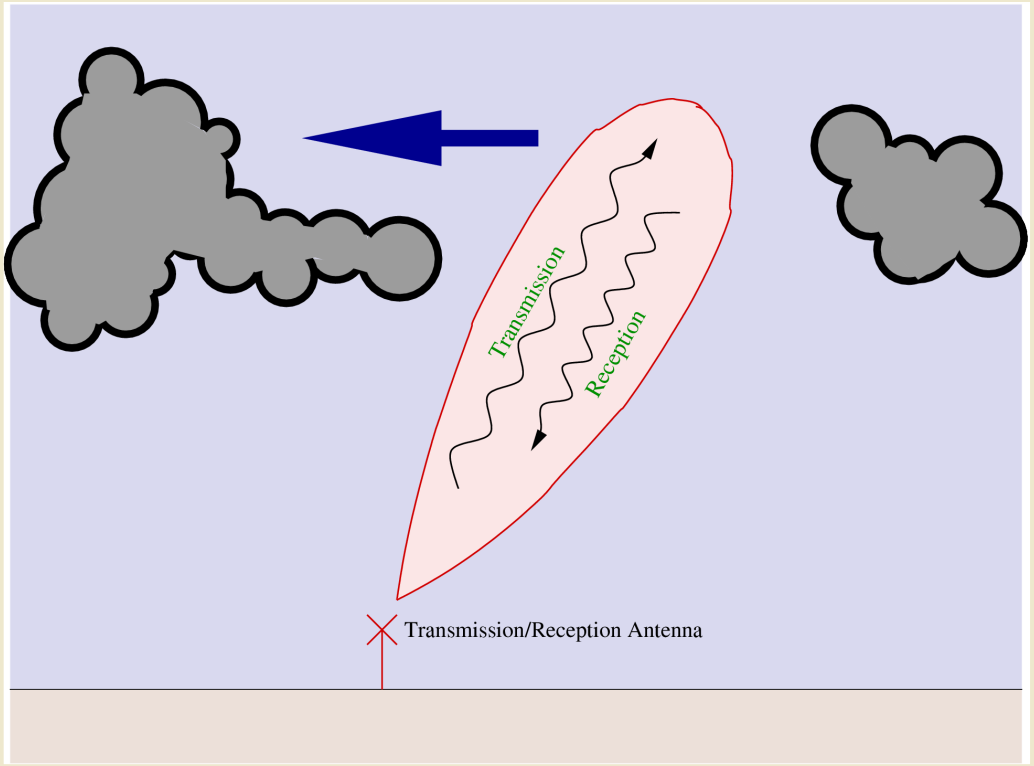
To understand the relationship between stratospheric intrusions and tropopause dynamics.

- High frequency ozone-sonde launches:
  - EnSci 2Z GPS sondes.
  - 2 or more launches per day.
- Wind-profiling radars:
  - McGill radar in Montreal
  - CLOVAR radar in London
  - York U radar in Walsingham



Wind-profiling radars

- VHF radars operating between 40 and 52 MHz.
- Beam half-power half-width of 2.1 degrees.
- Steerable beam allows measurement of:
  - 3-dimensional wind.
  - Turbulence intensity.
  - Tropopause height.



The Radar Tropopause

- Backscattered radar power is approximately proportional to M^2/r^2
  - r is the range from the radar.
  - M is the vertical gradient of the radio refractive index.

$$M = -7.76 \times 10^{-5}\left(\frac{p}{T}\right)\left(\frac{\partial \ln \theta}{\partial z}\right)\left[1 + \frac{15500q}{T}\left(1 - \frac{\frac{\partial \ln q}{\partial z}}{2\frac{\partial \ln \theta}{\partial z}}\right)\right]$$

Potential temperature gradient.

Humidity term.

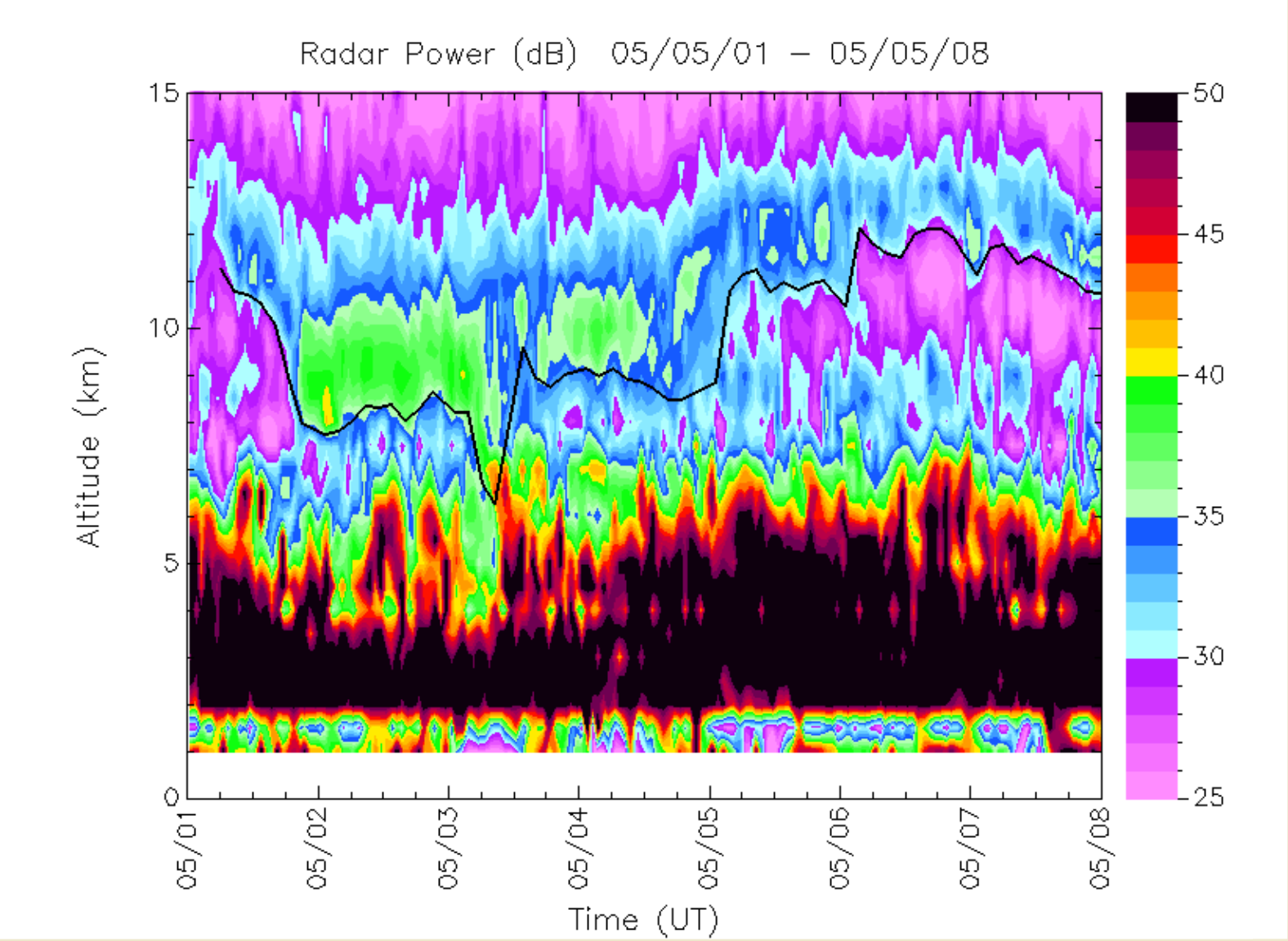
- The potential temperature gradient and the absolute temperature gradient are related by:

$$\frac{1}{\theta}\frac{d\theta}{dz} = \frac{1}{T}\left(\Gamma_d - \Gamma\right)$$

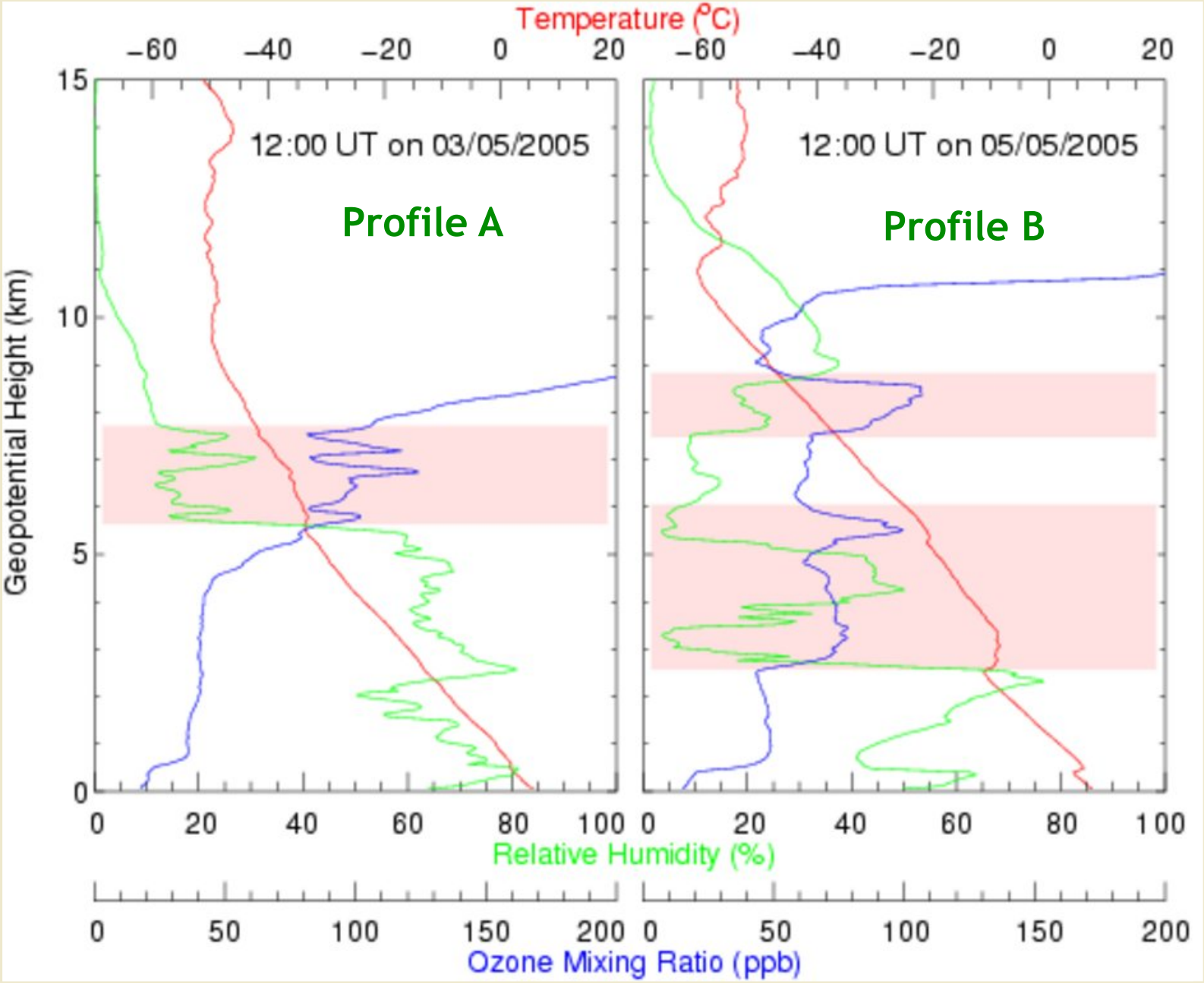
  - tropospheric lapse rate = 6 K/km
  - stratospheric lapse rate < 2 K/km

The abrupt change between the troposphere and stratosphere causes a sudden increase in radar signal strength.

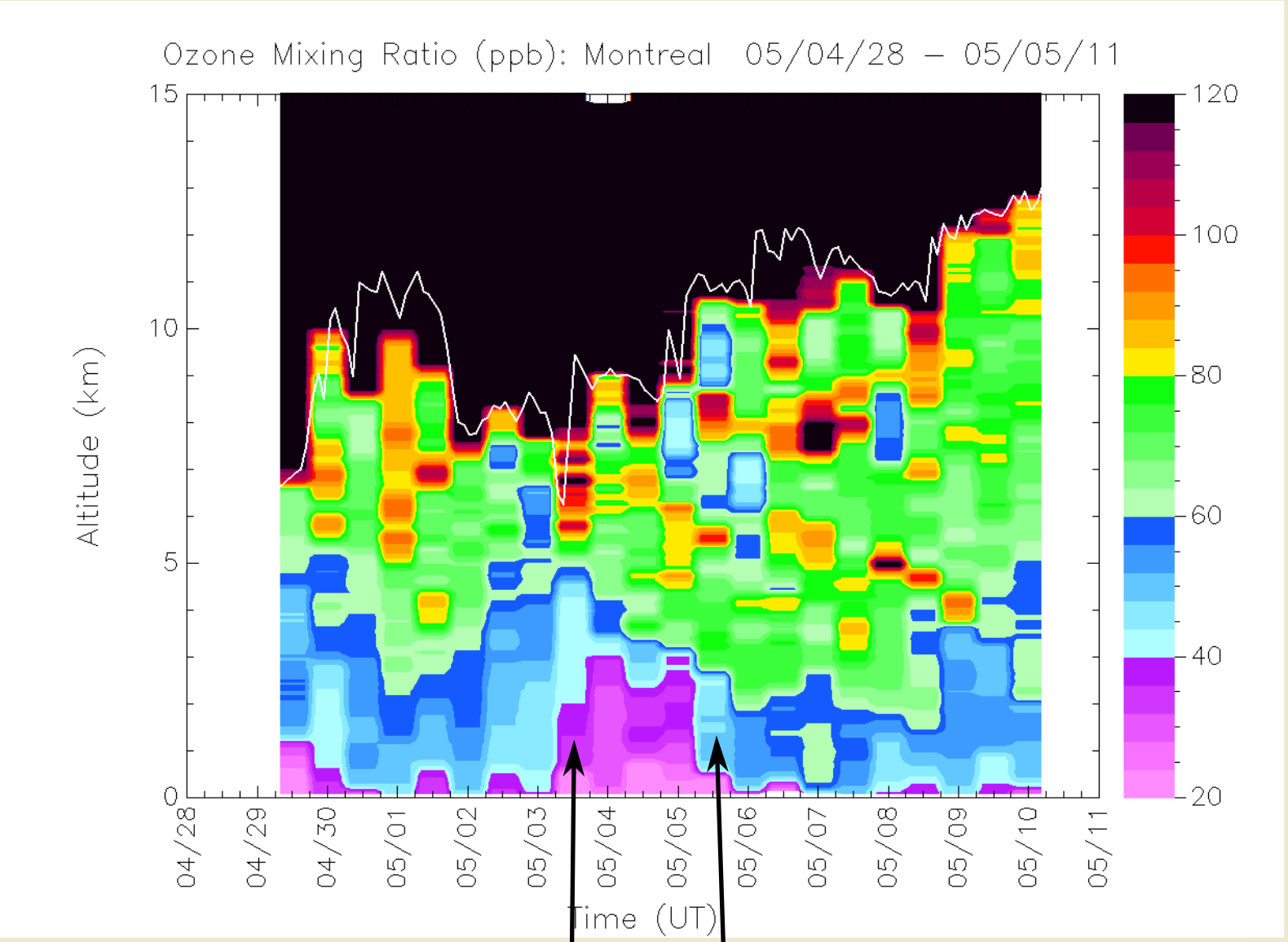
Montreal: Radar total power - May 2005



Montreal: Two sonde profiles

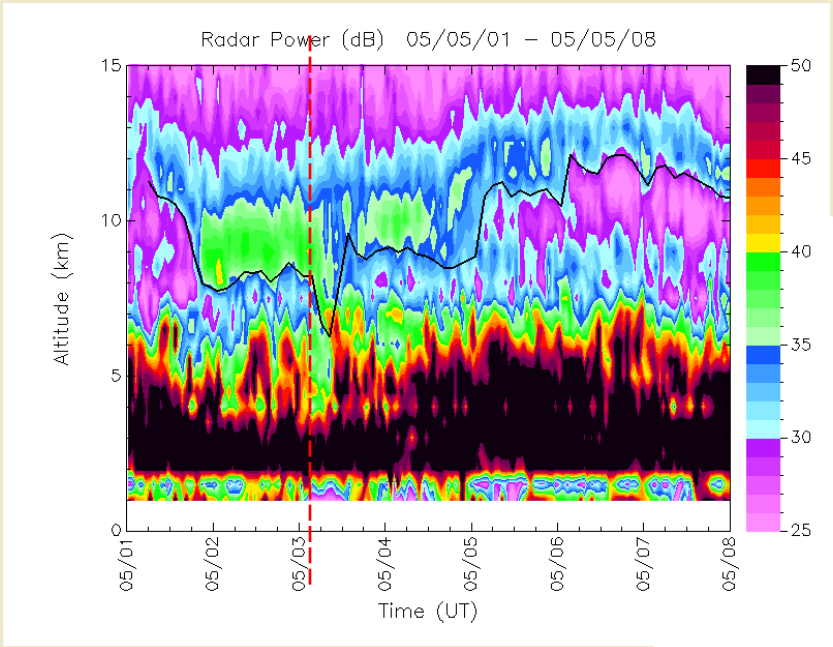


Montreal: Ozone mixing ratio



Modelling the intrusions

- With FLEXPART - Written by Andreas Stohl
  - http://zardoz.nilu.no/~andreas/flextra+flexpart.html
- A Lagrangian particle dispersion model
  - The model domain is filled with (millions of) particles.
  - Particles initially in the stratosphere are given an ozone concentration calculated using potential vorticity.
  - Ozone "parcels" are then advected with the model winds.
- Wind field input from Canadian forecast model: GEM
  - North American regional grid.
  - 0.5 x 0.5 deg, 31 levels, hourly


Radar Power (dB) 05/05/01 – 05/05/08
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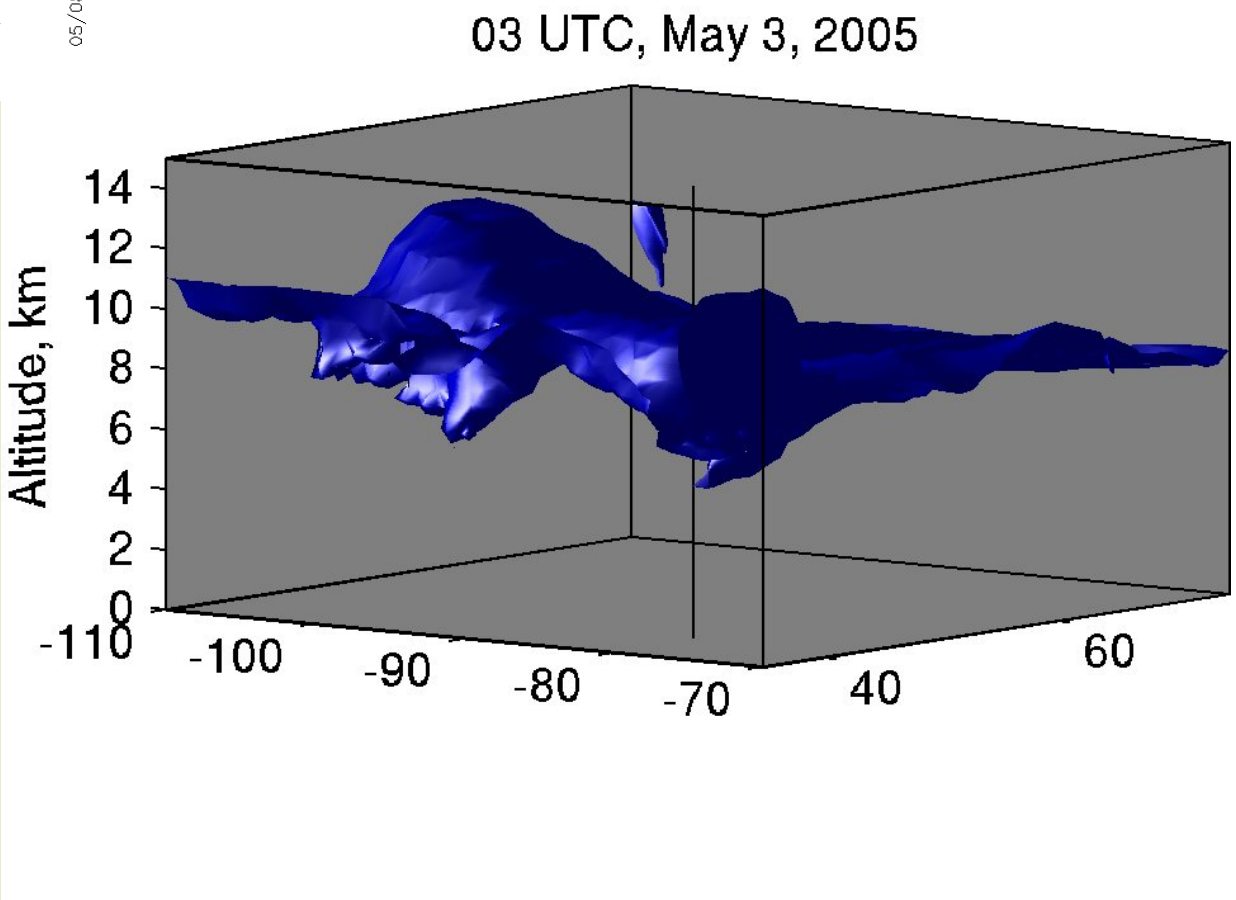
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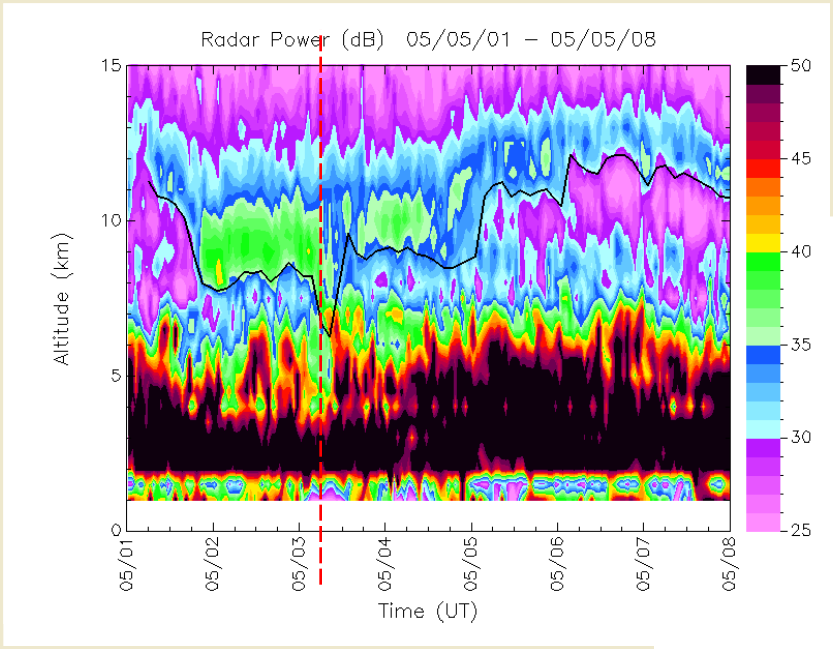
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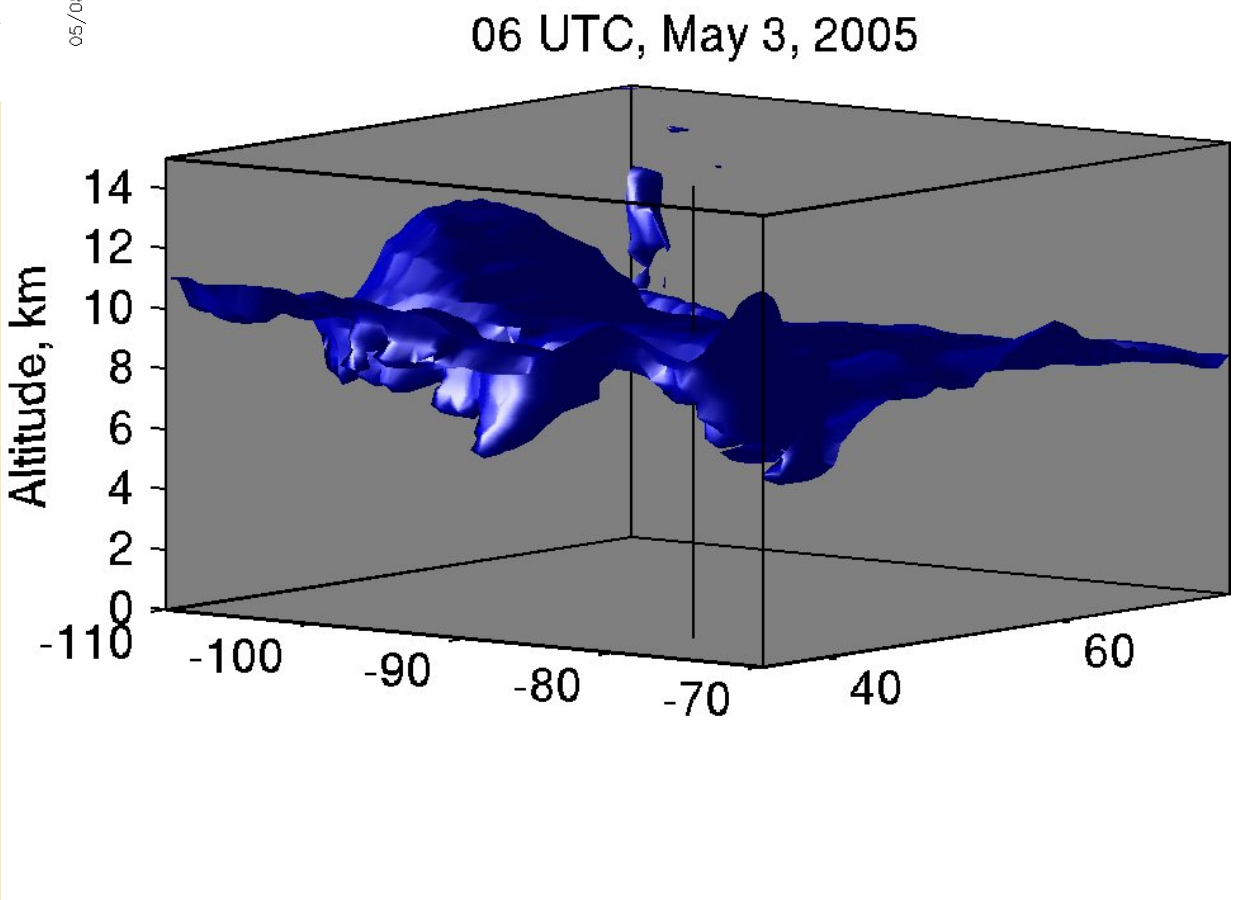
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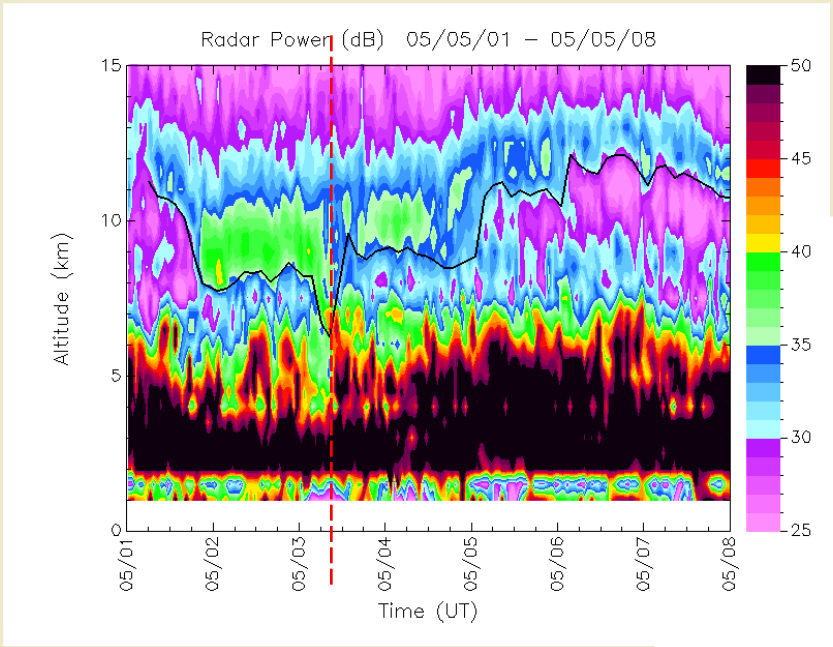
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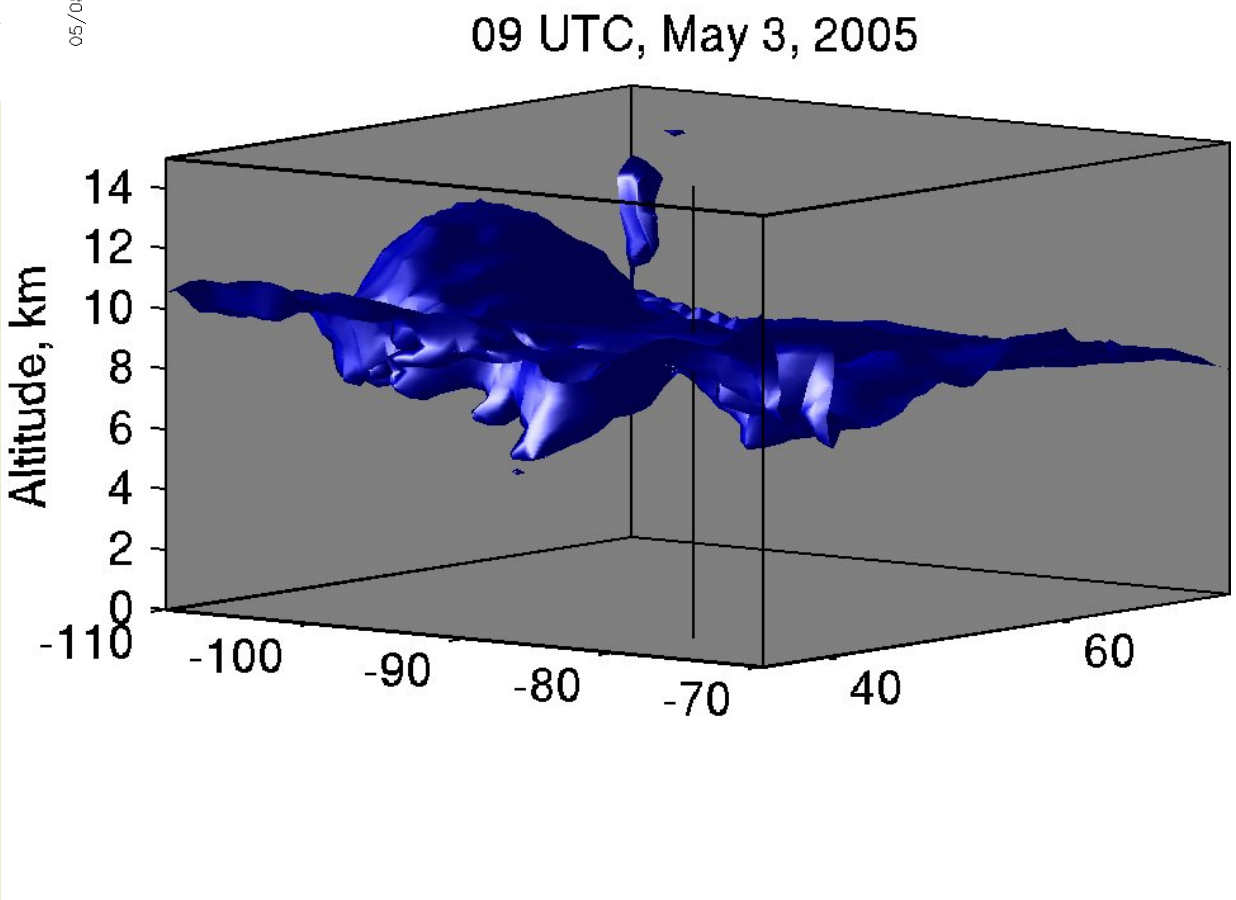
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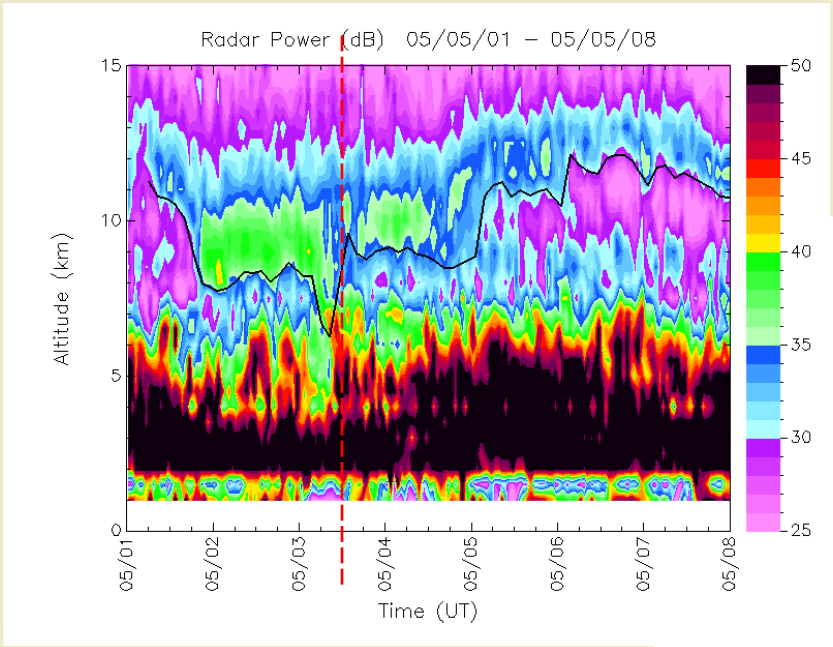
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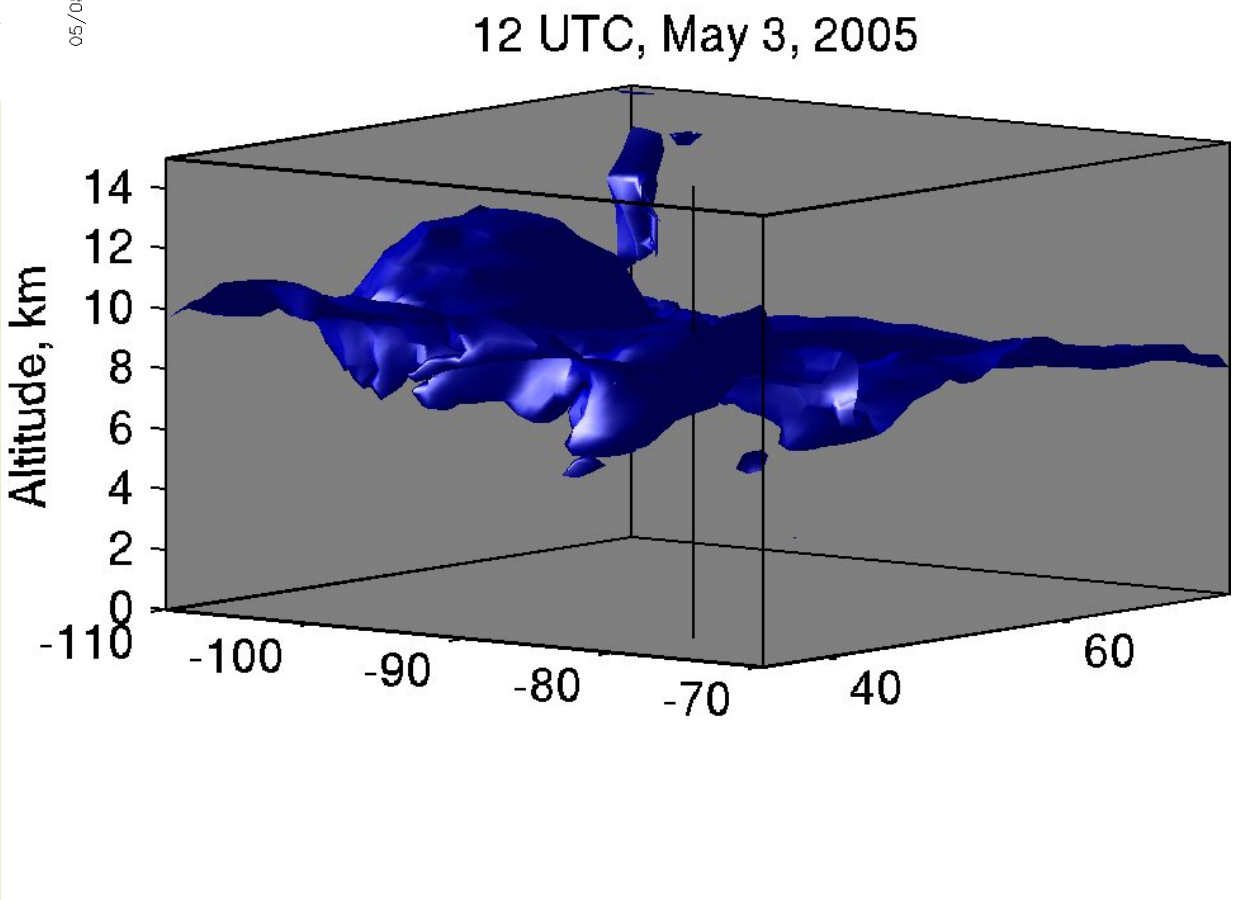
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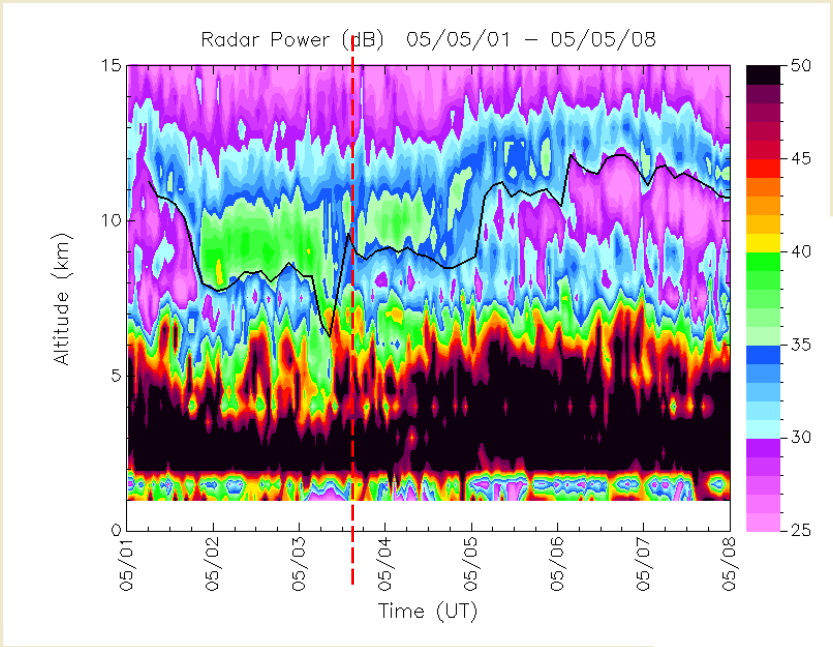
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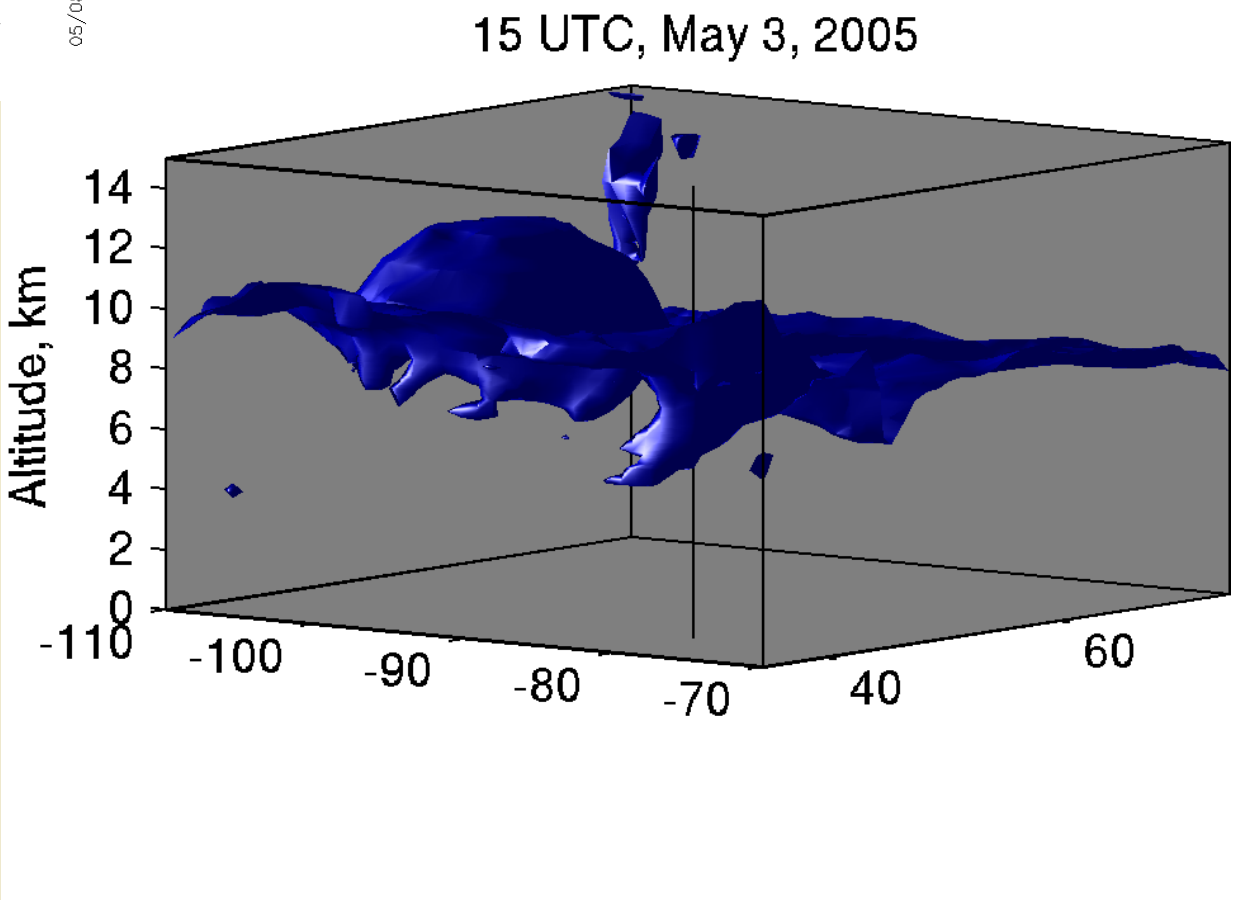
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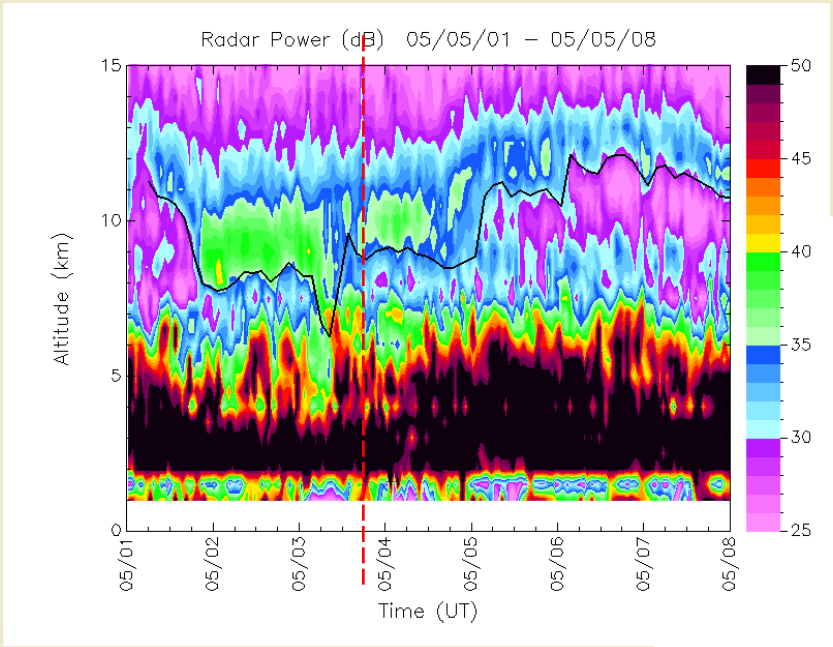
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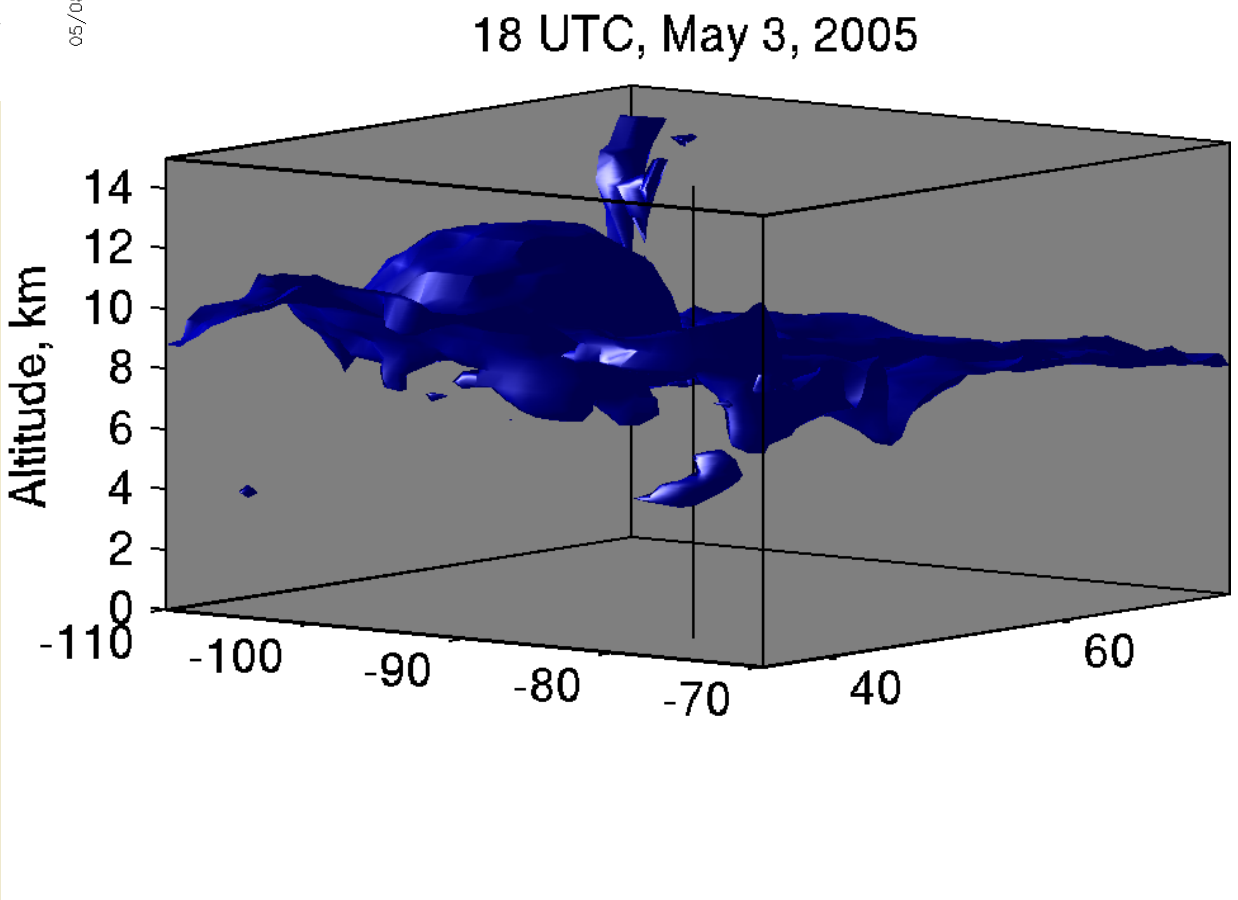
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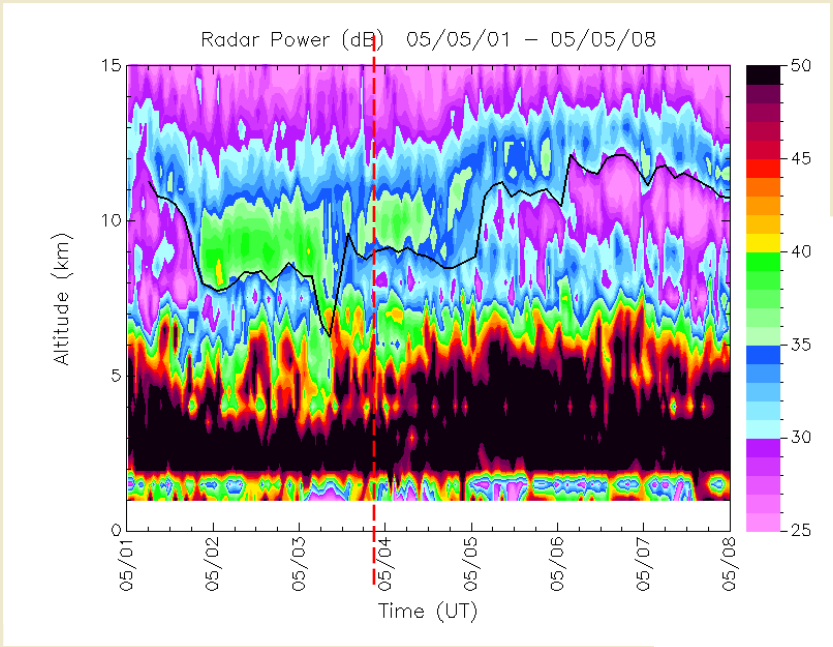
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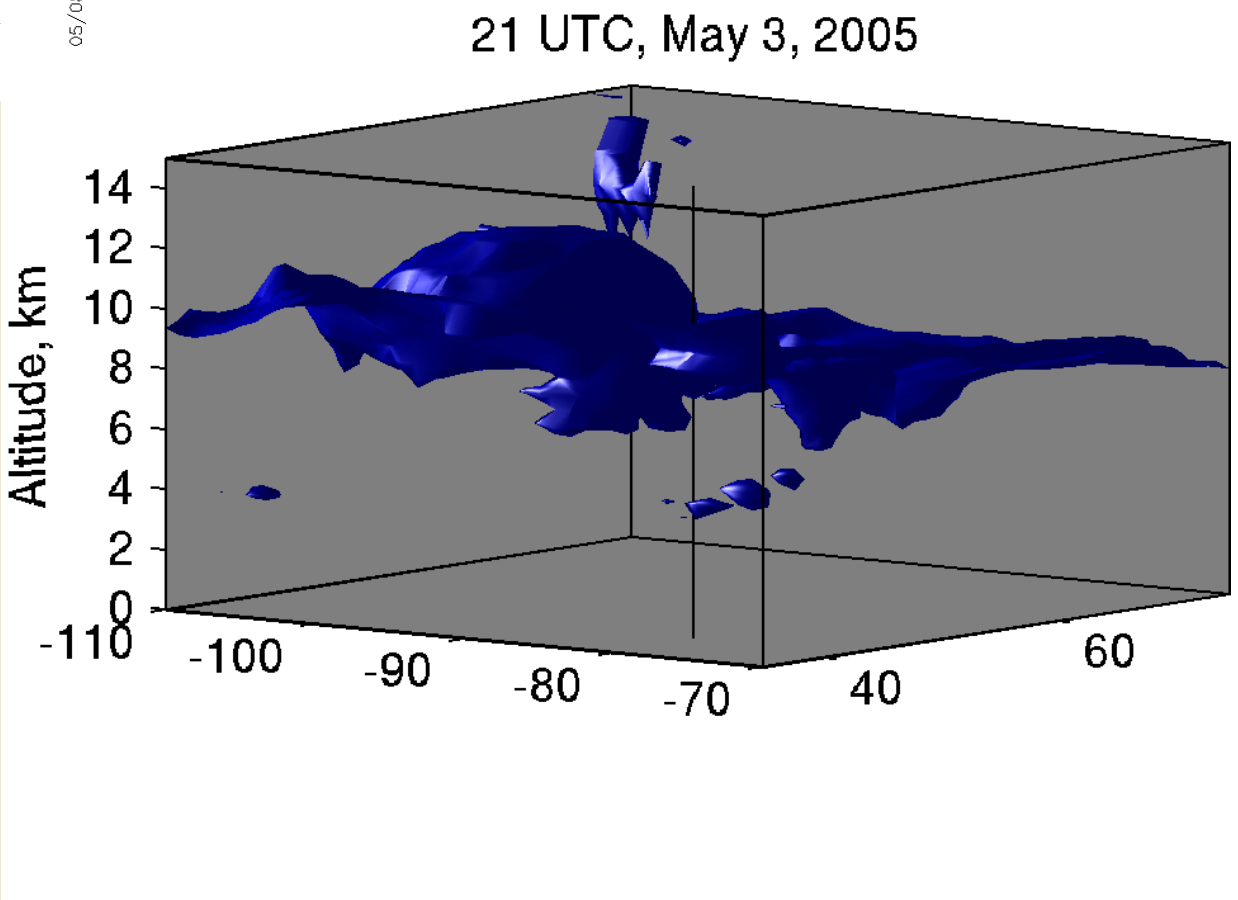
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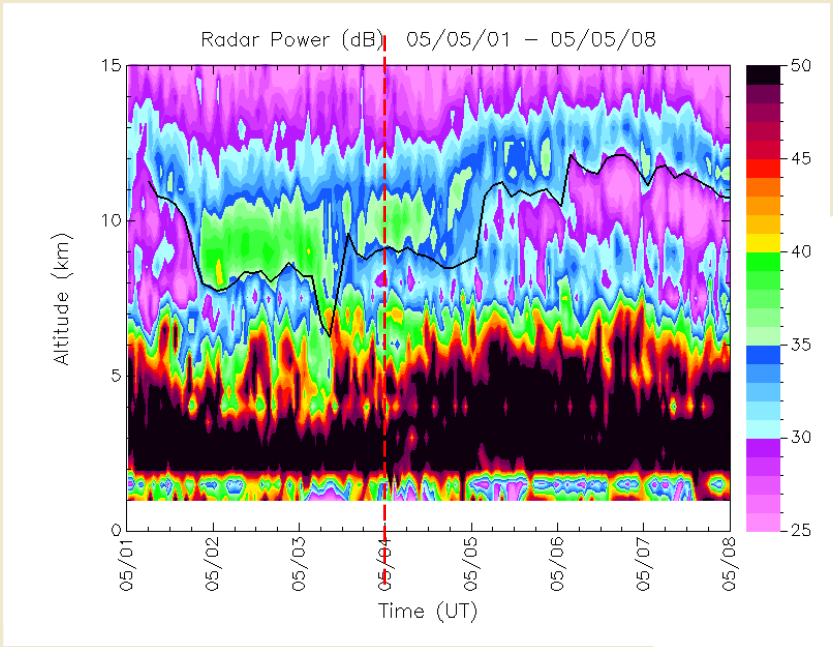
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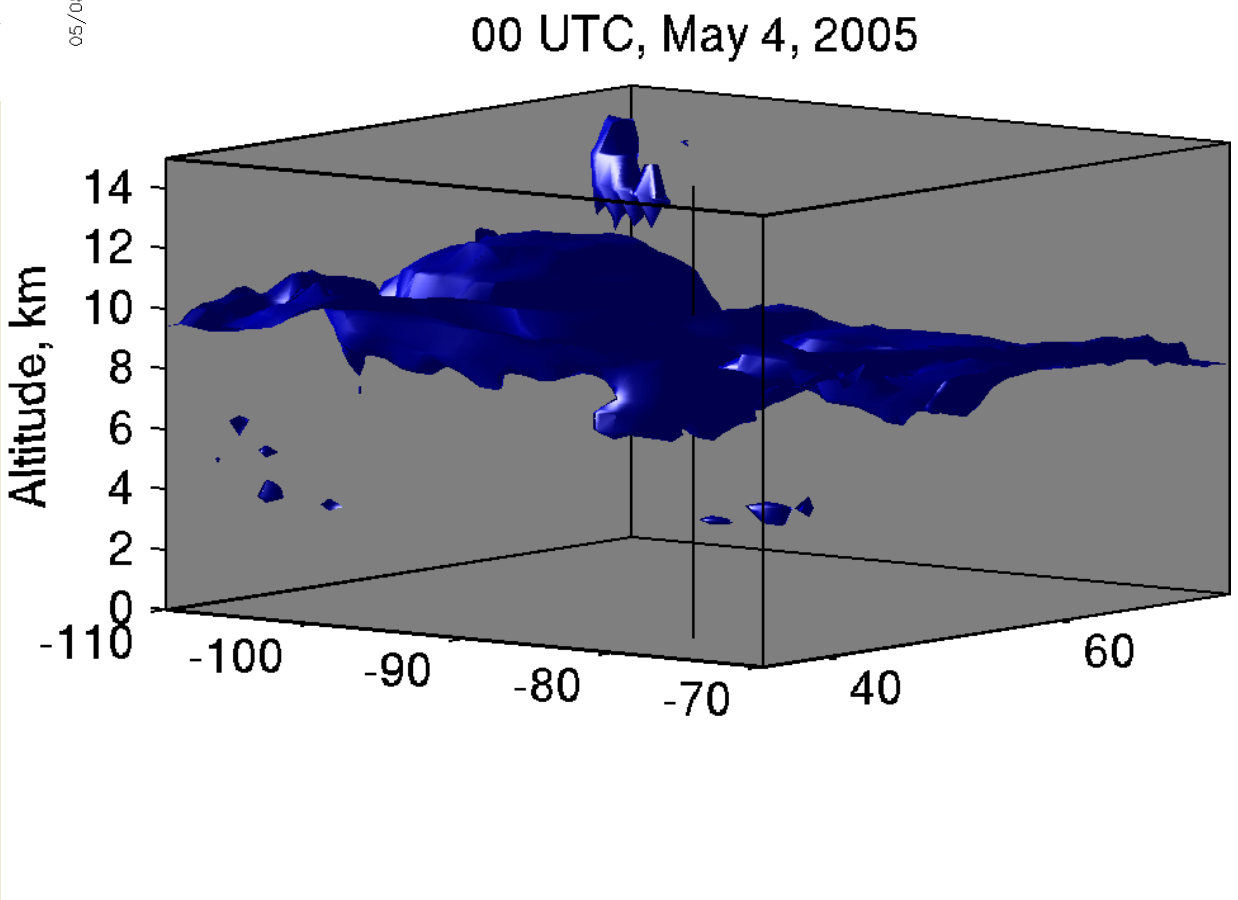
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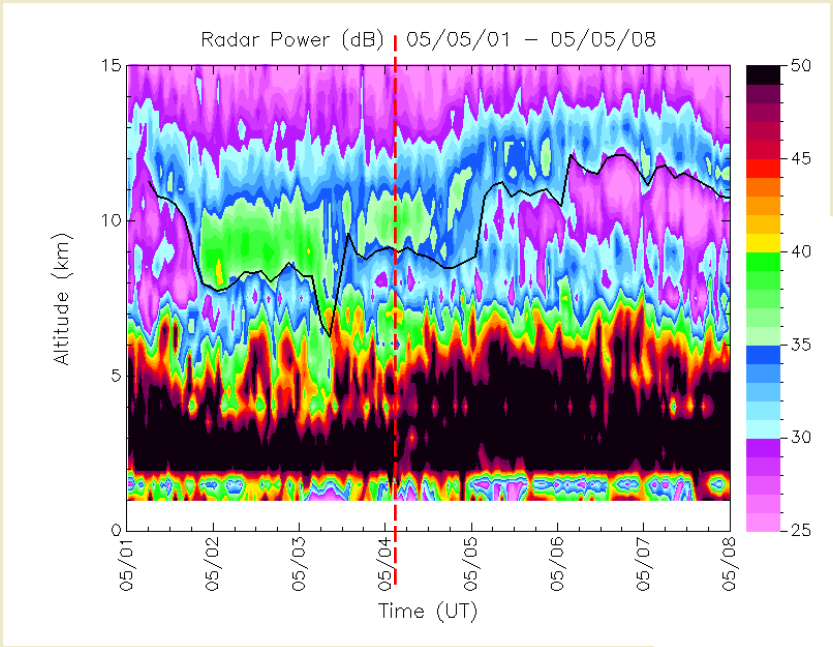
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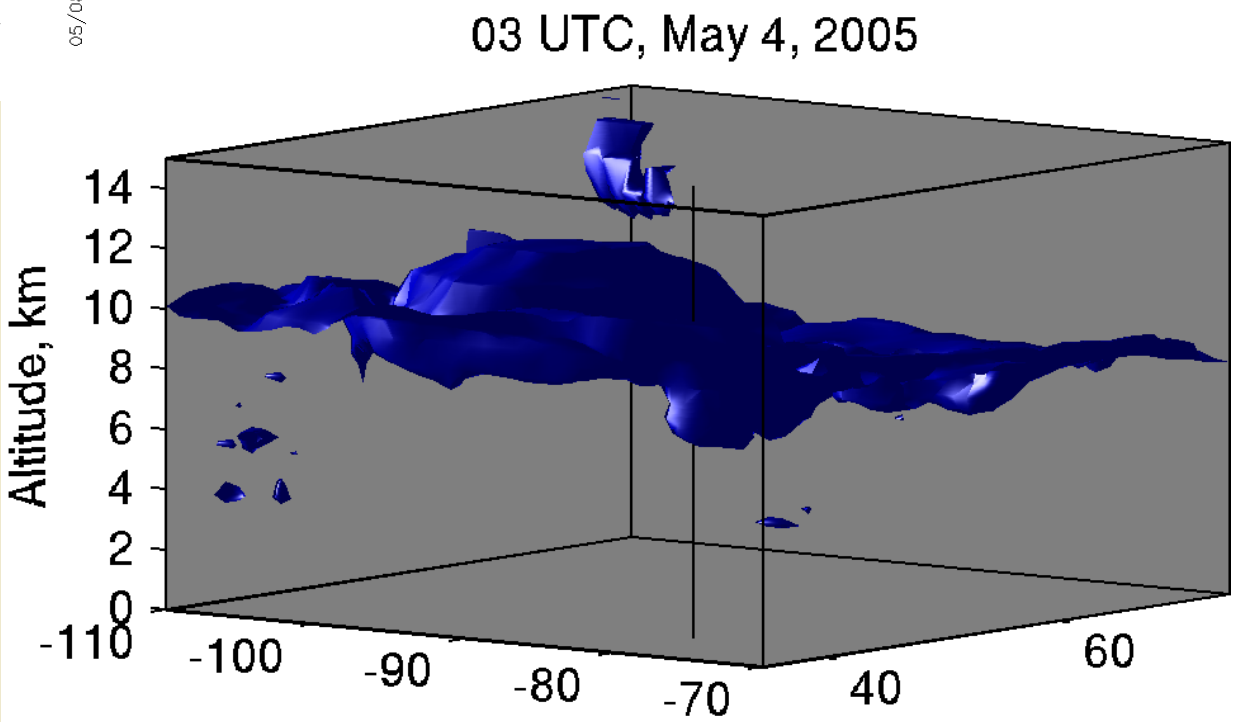
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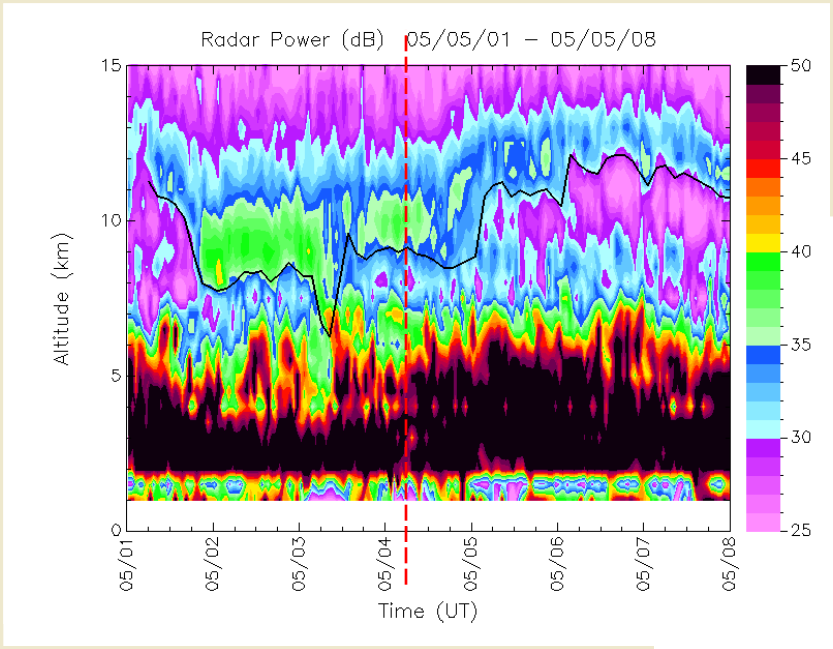
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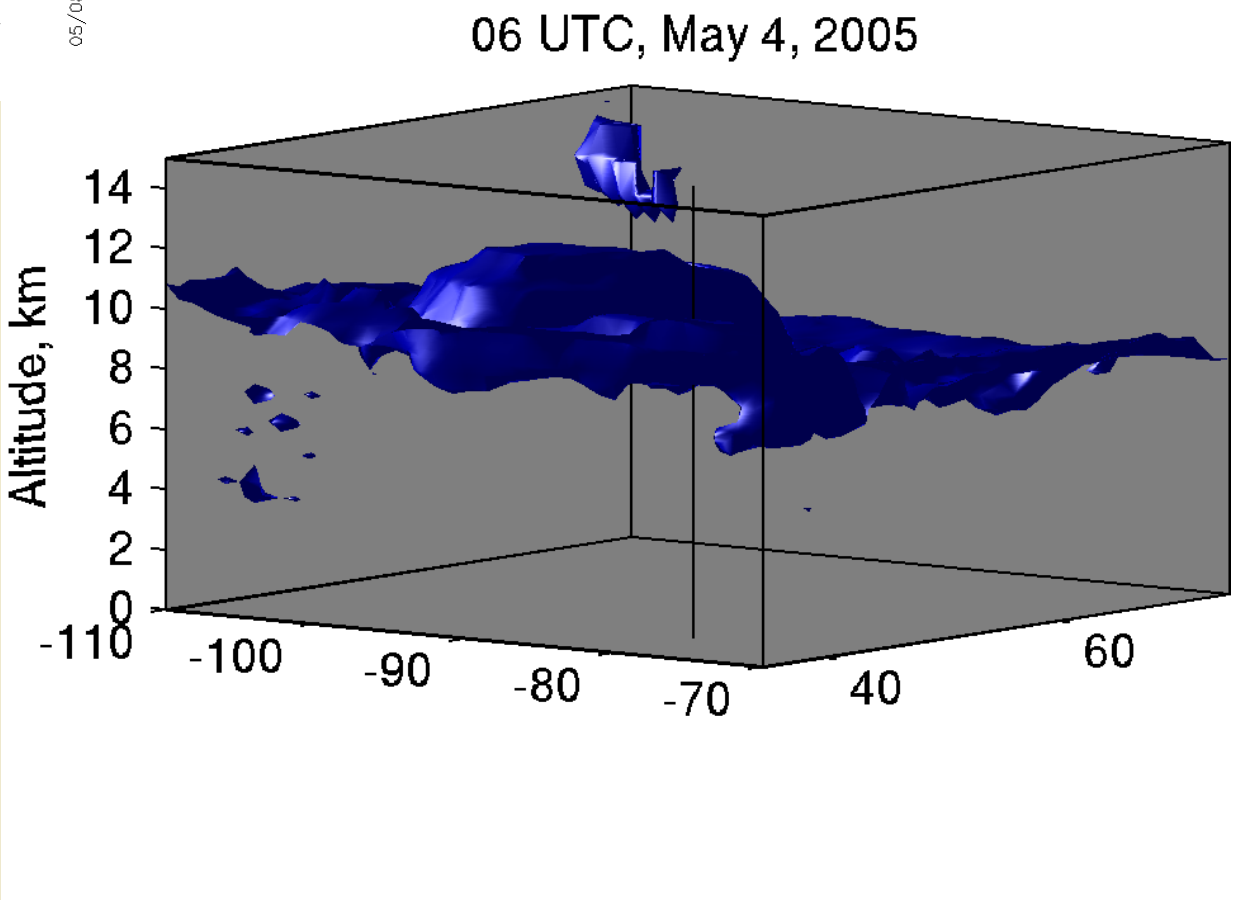
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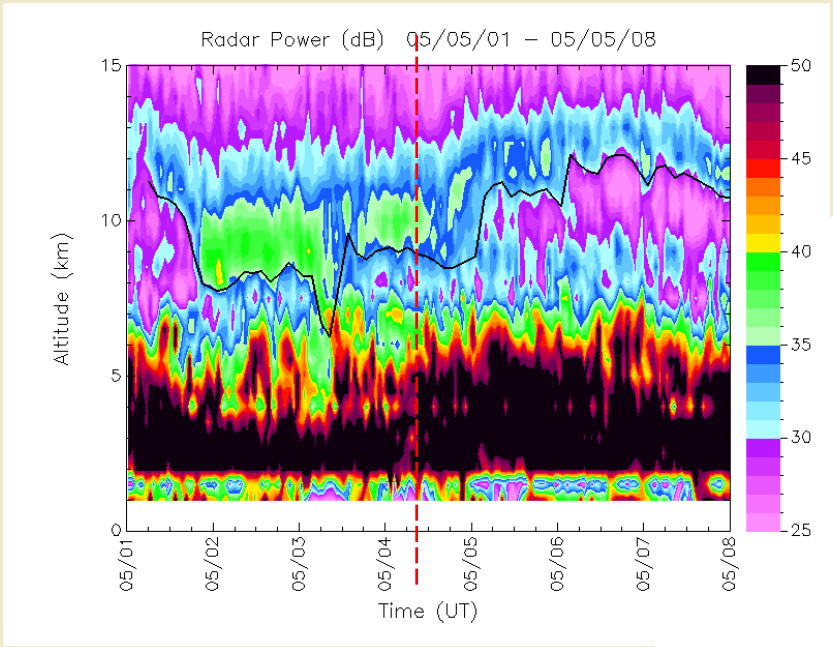
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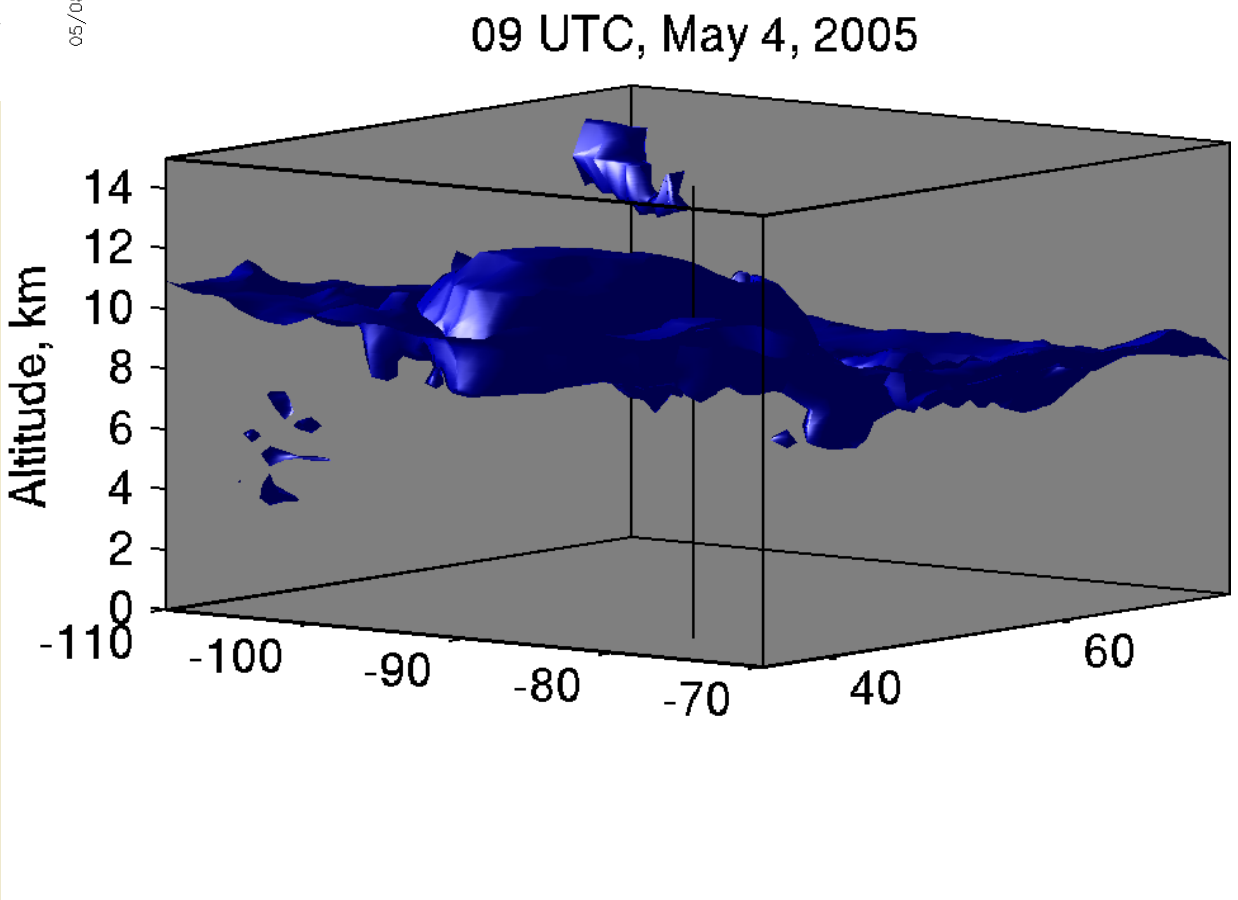
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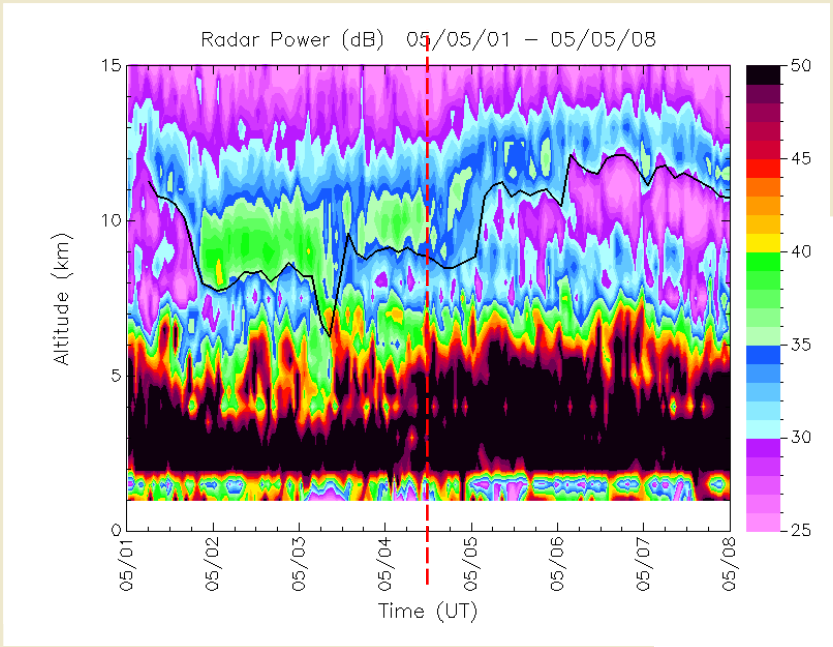
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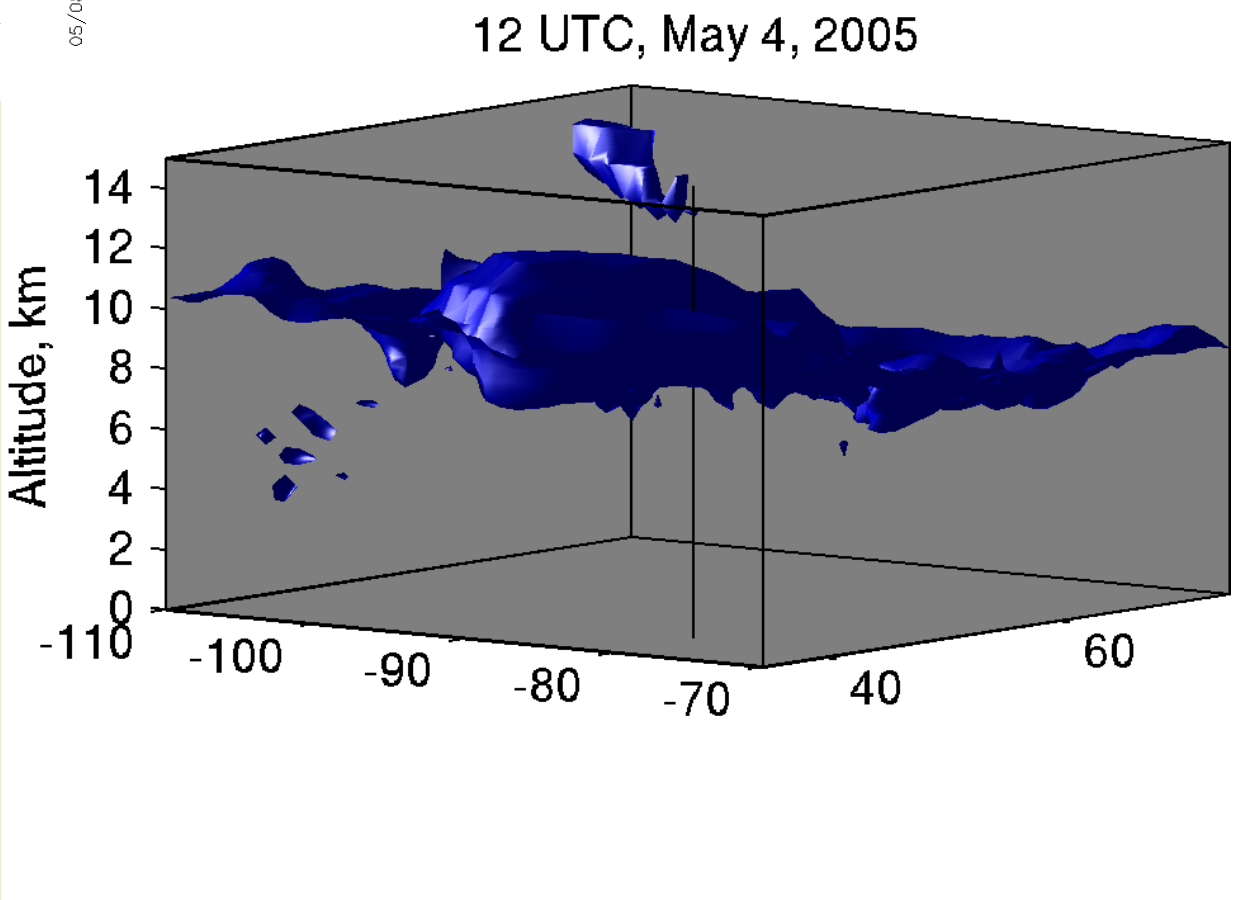
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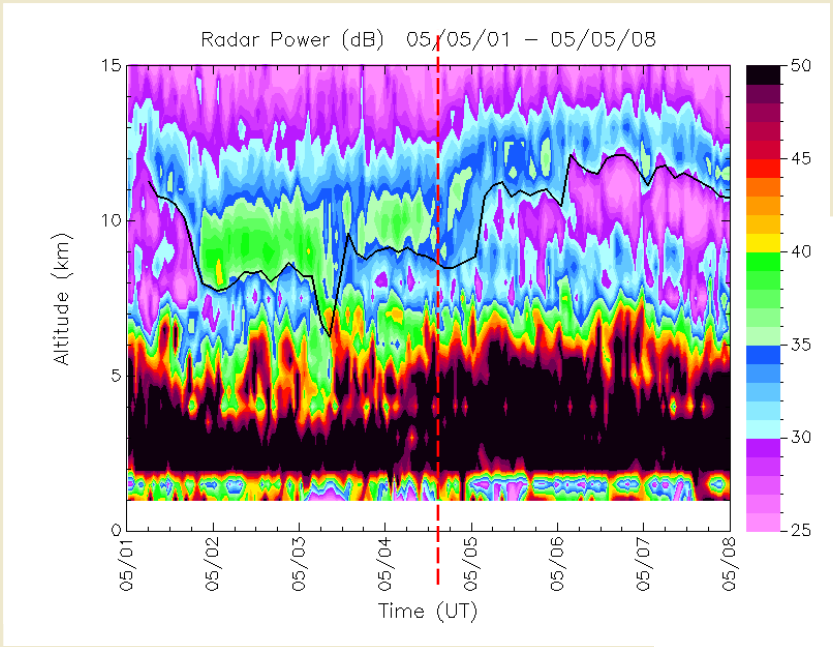
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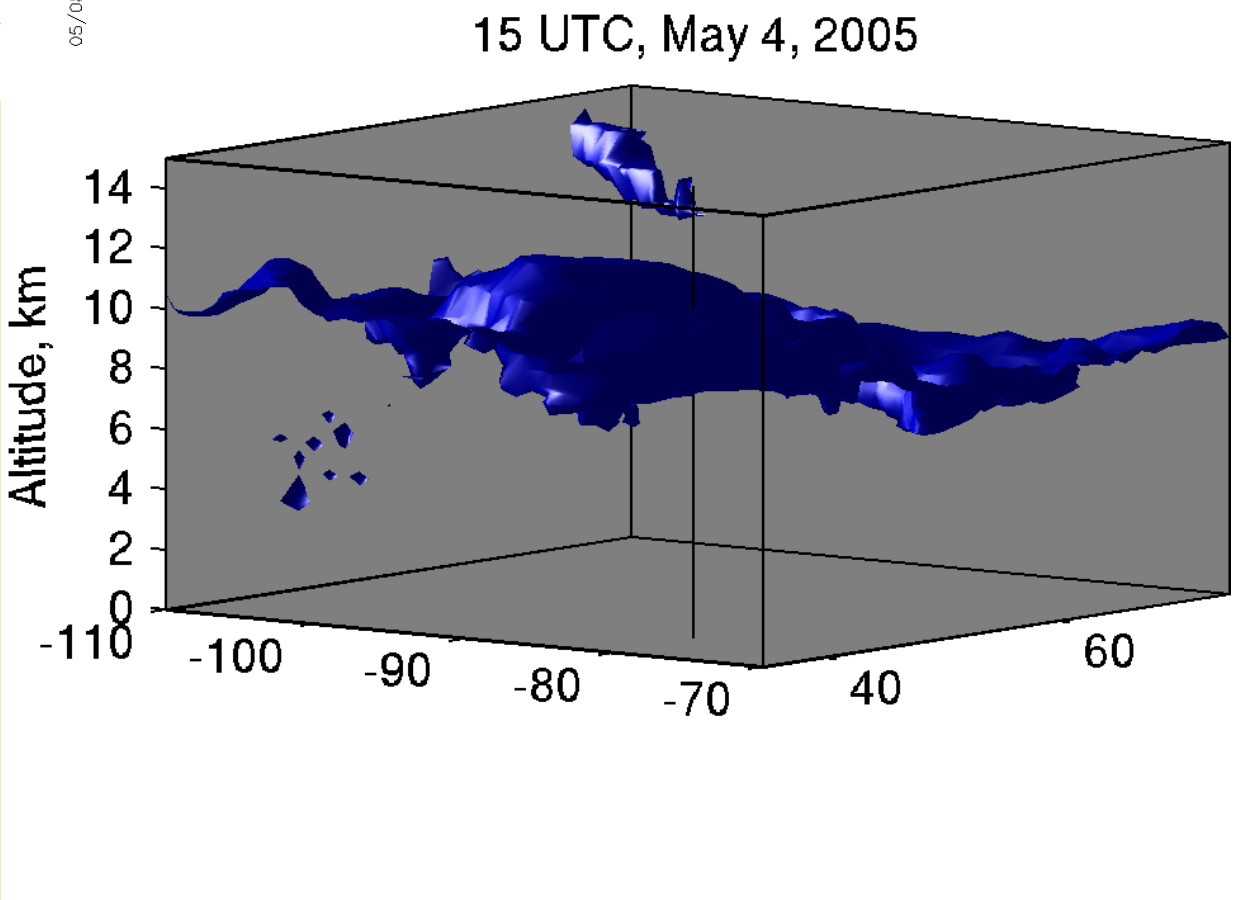
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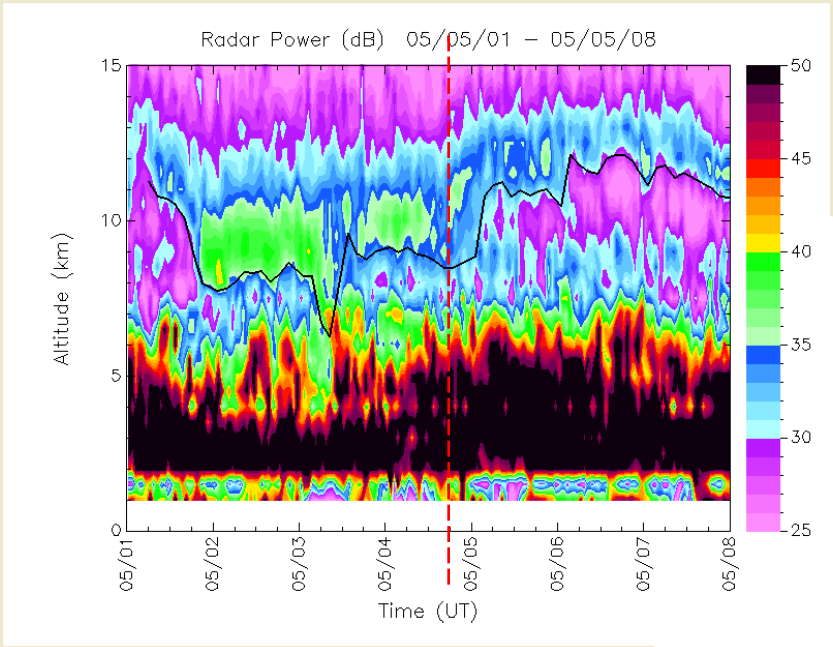
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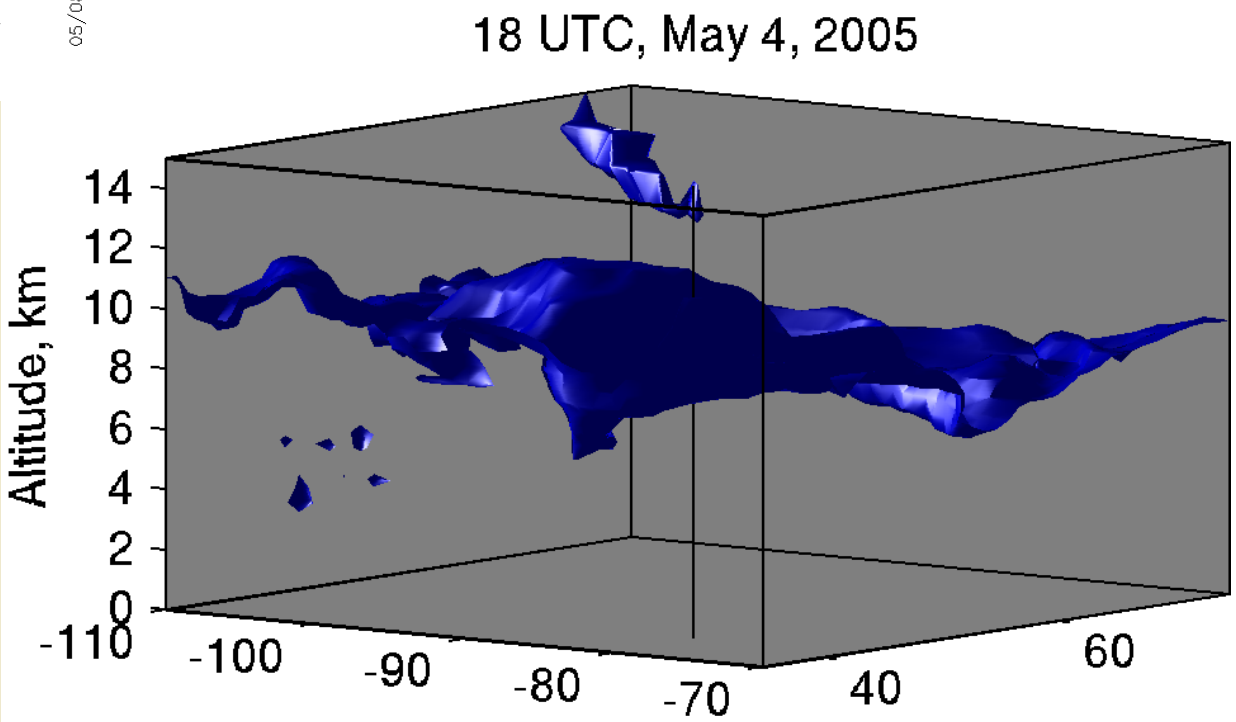
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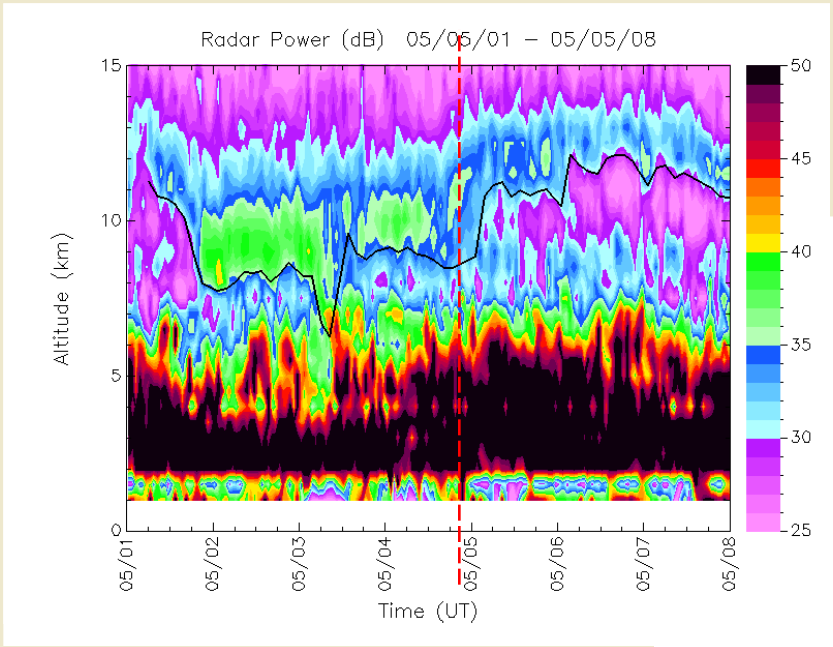
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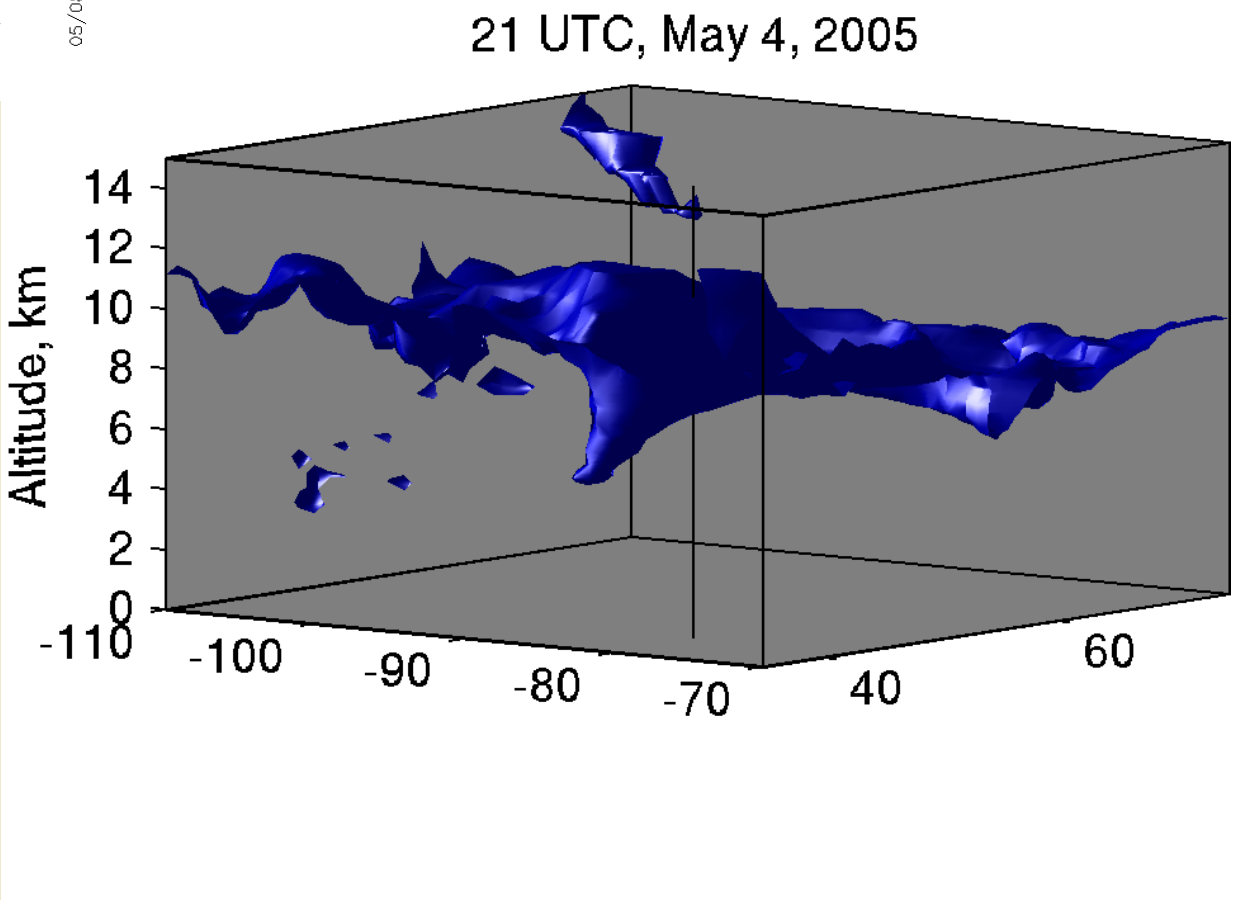
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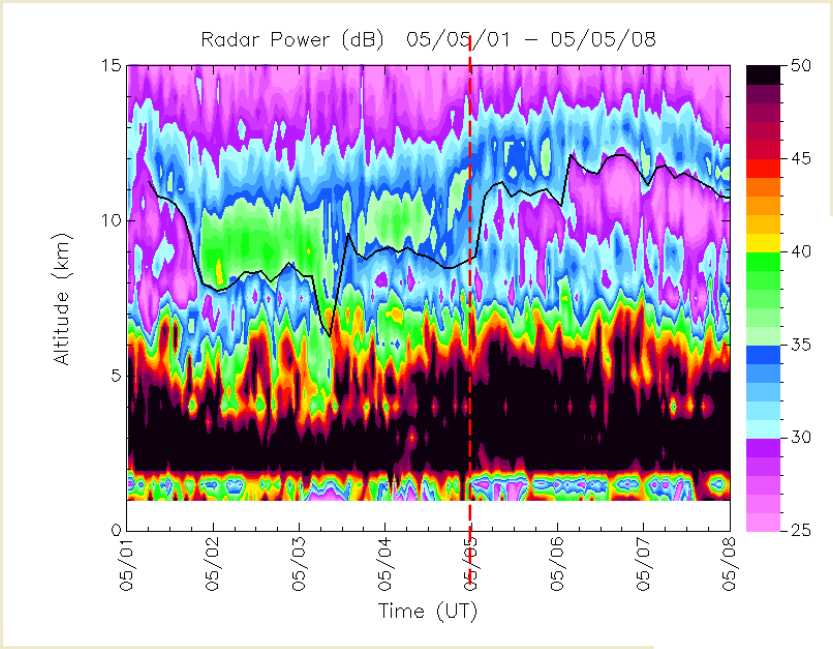
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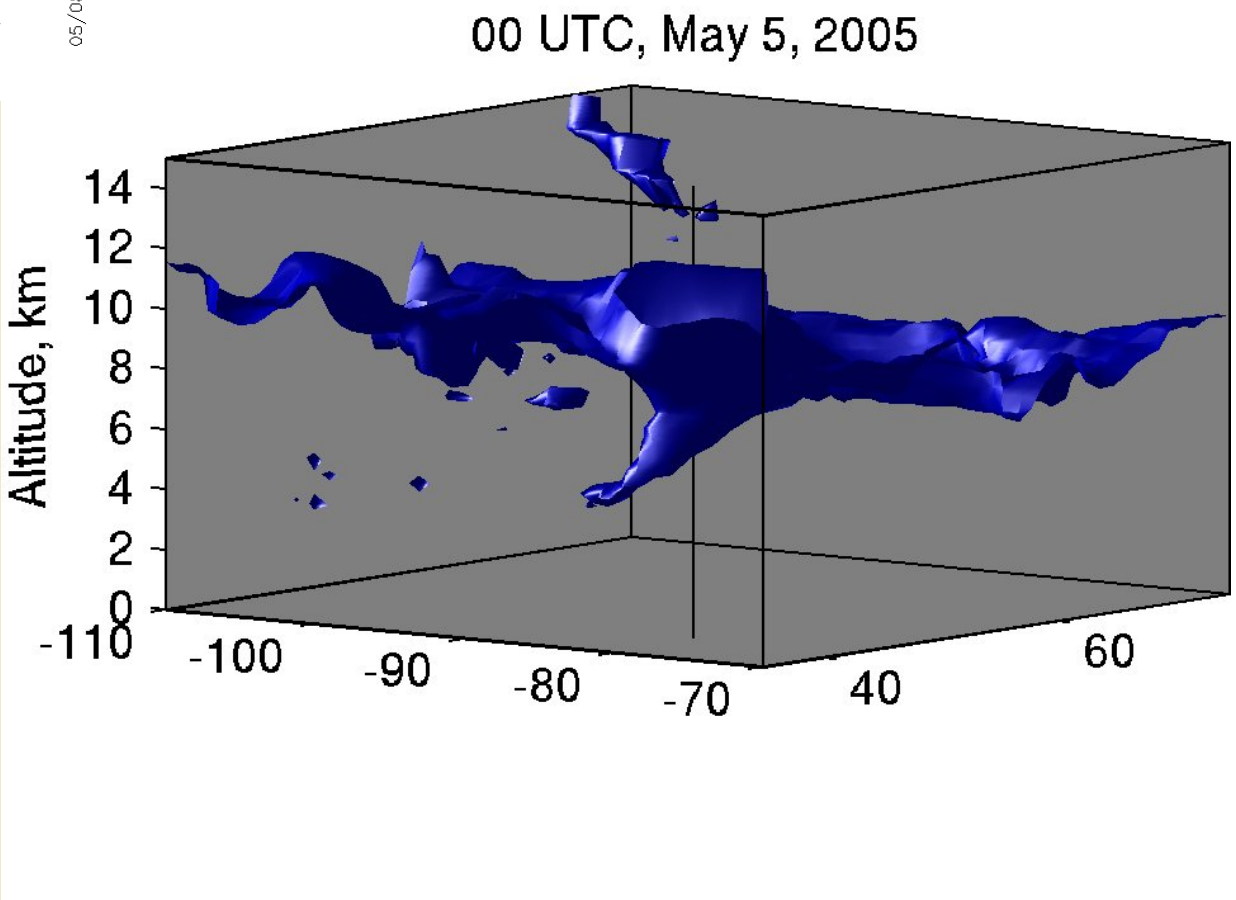
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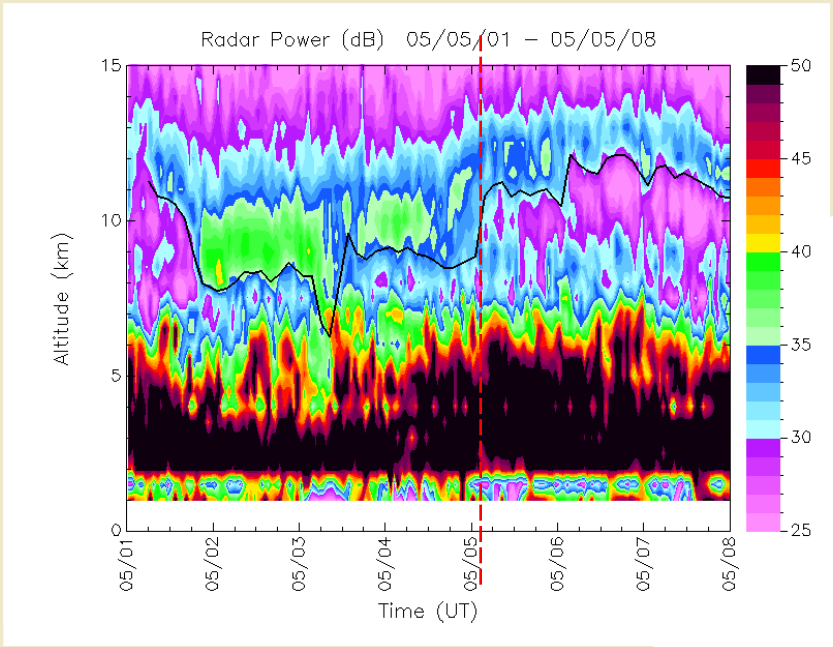
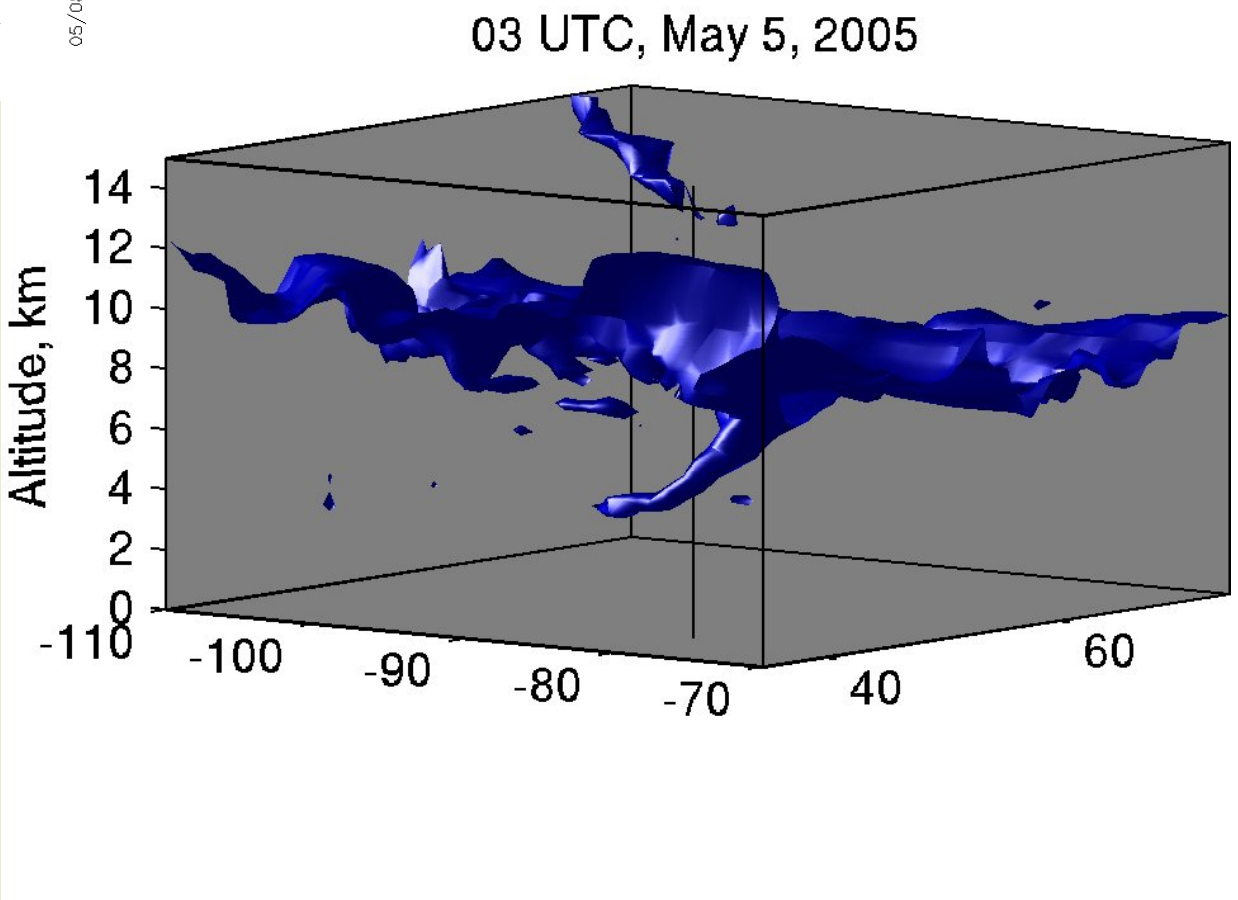
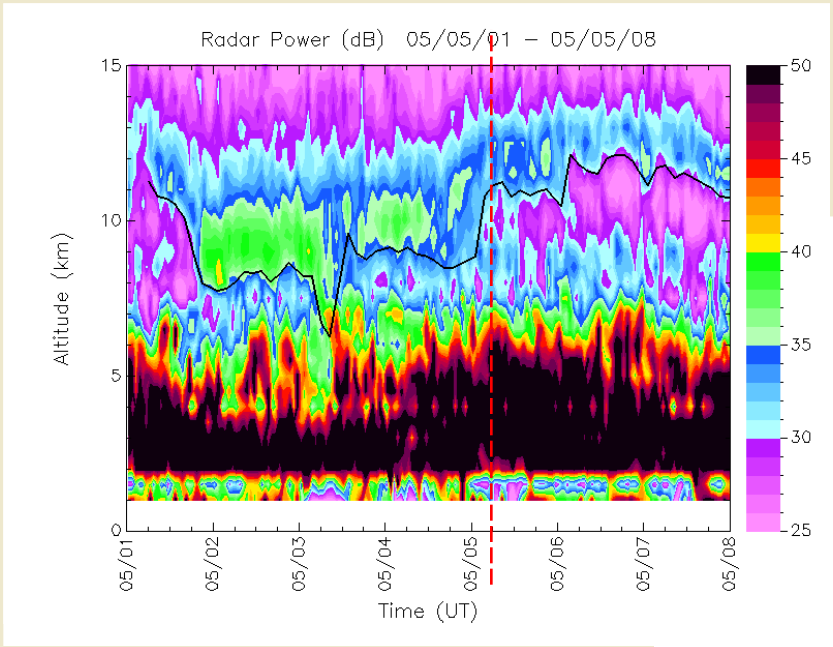
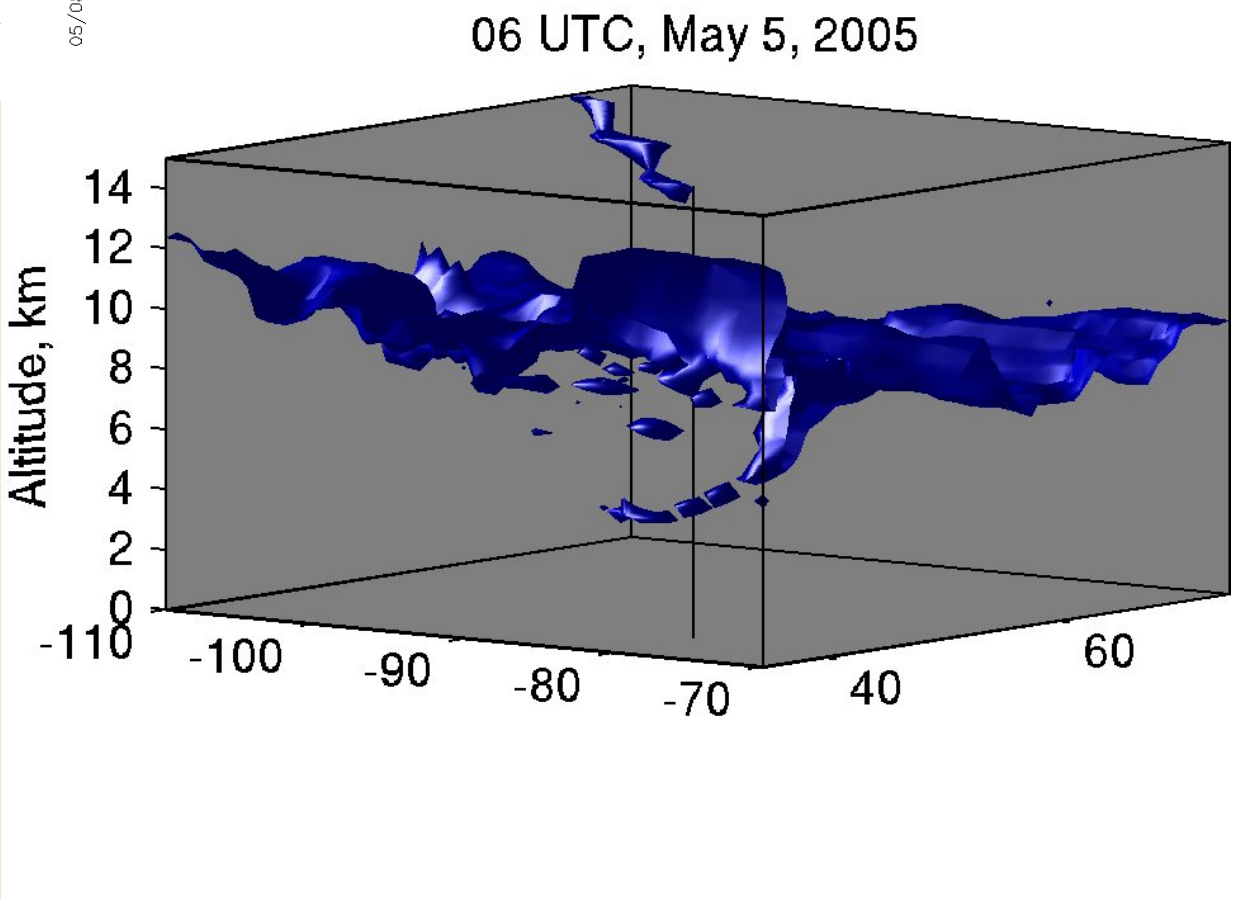
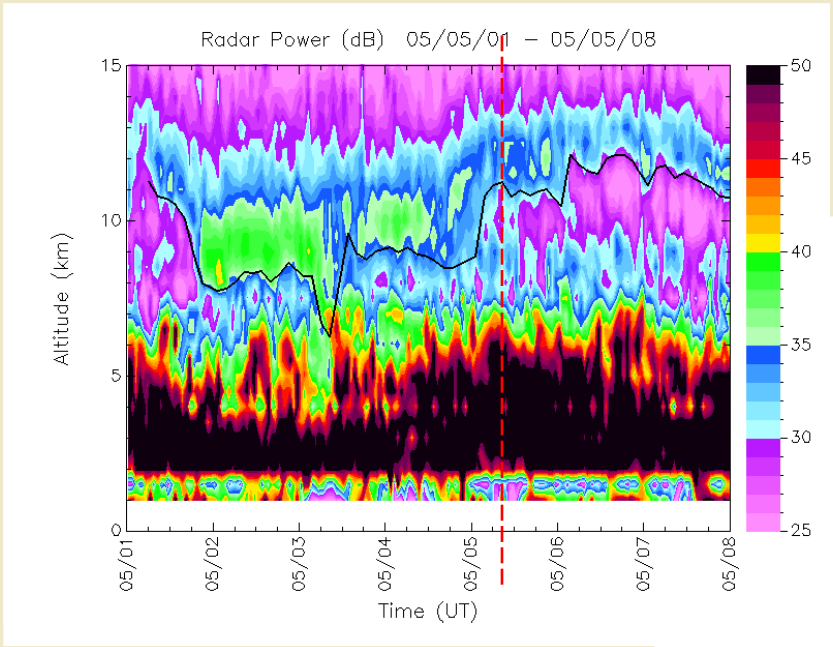
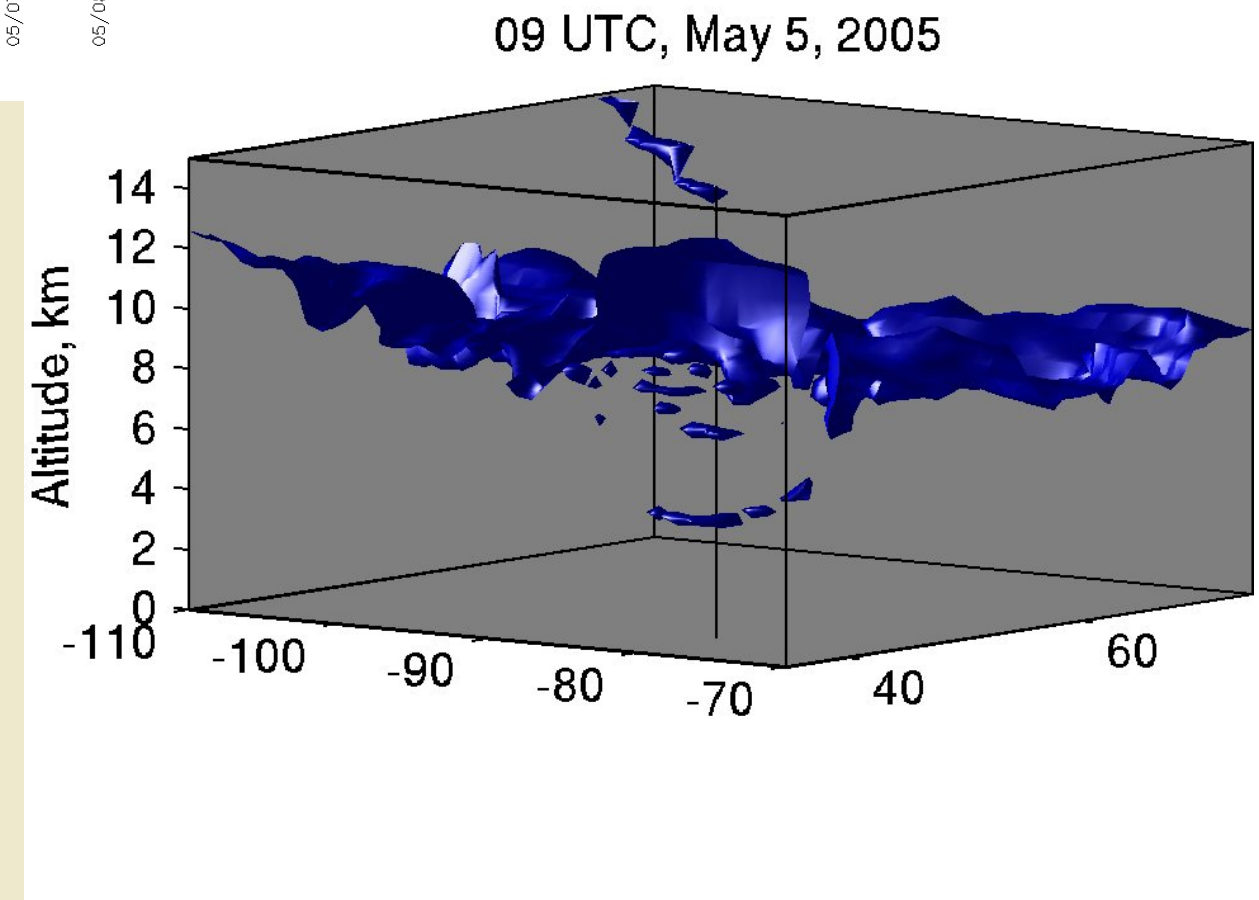

Radar Power (dB) 05/05/01 – 05/05/08
Altitude (km)
15
10
5
0
50
45
40
35
30
25
05/01
05/02
05/03
05/04
05/05
05/06
05/07
05/08
Time (UT)

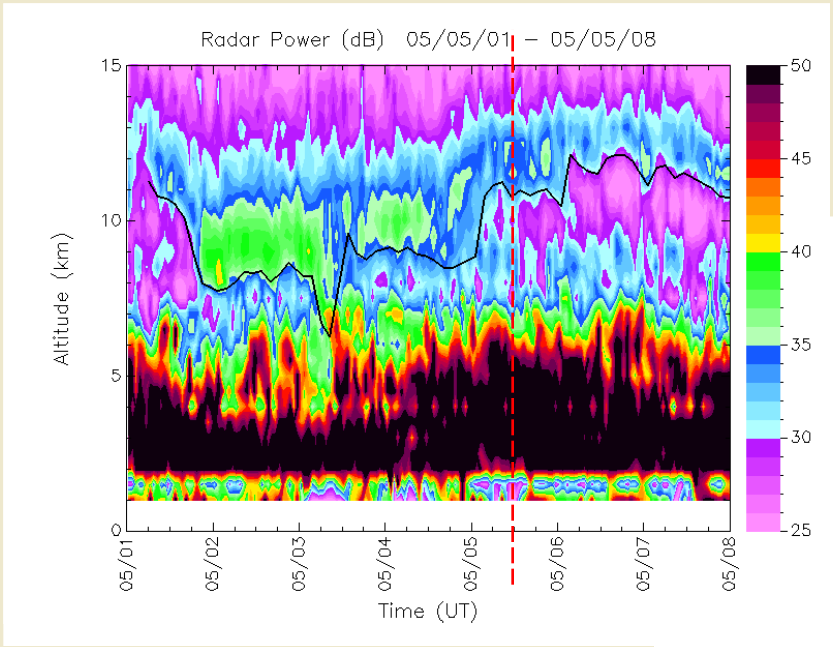

03 UTC, May 5, 2005
Altitude, km
14
12
10
8
6
4
2
0
-110
-100
-90
-80
-70
40
60

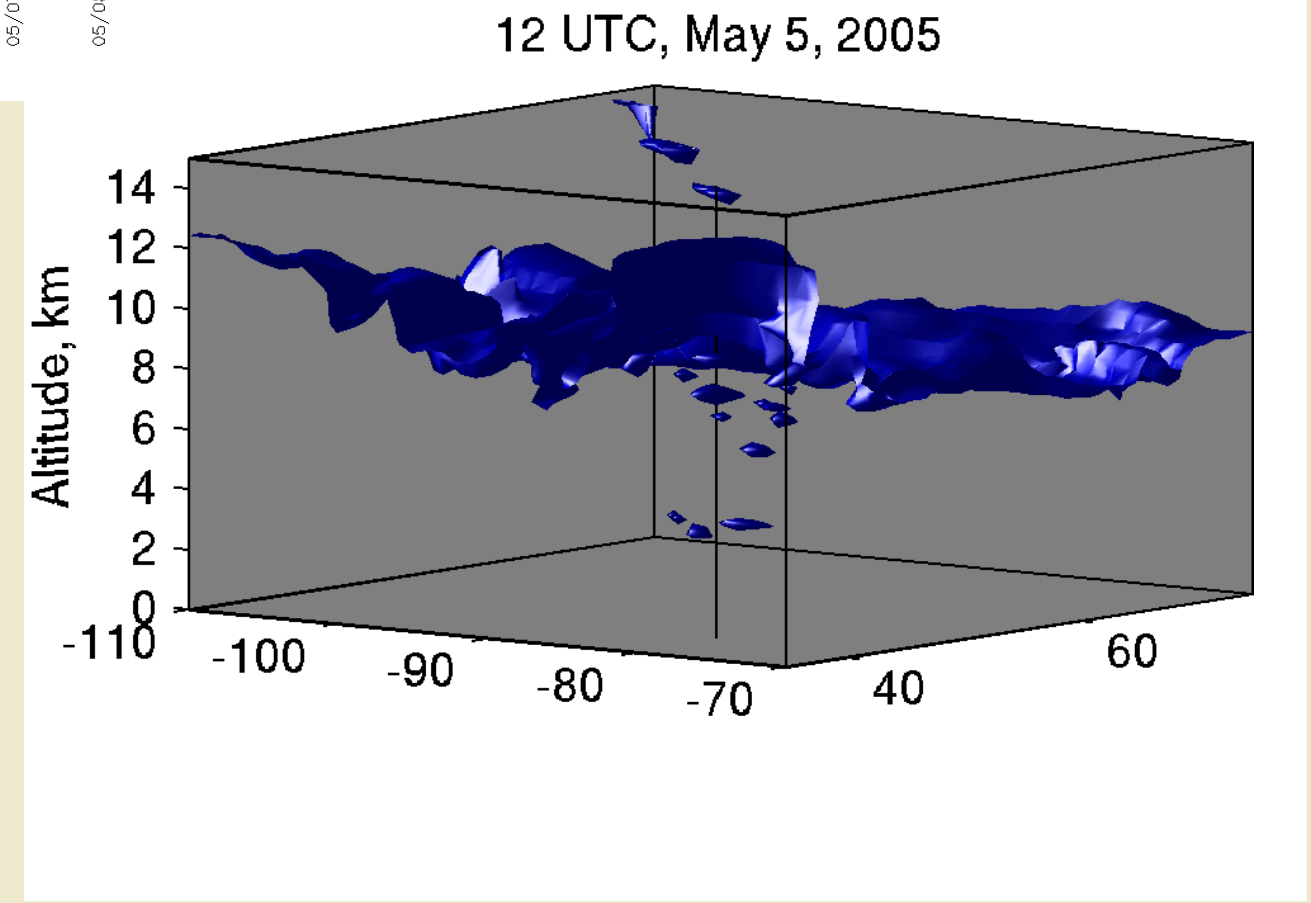

Radar Power (dB) 05/05/01 – 05/05/08
Altitude (km)
15
10
5
0
50
45
40
35
30
25
05/01
05/02
05/03
05/04
05/05
05/06
05/07
05/08
Time (UT)

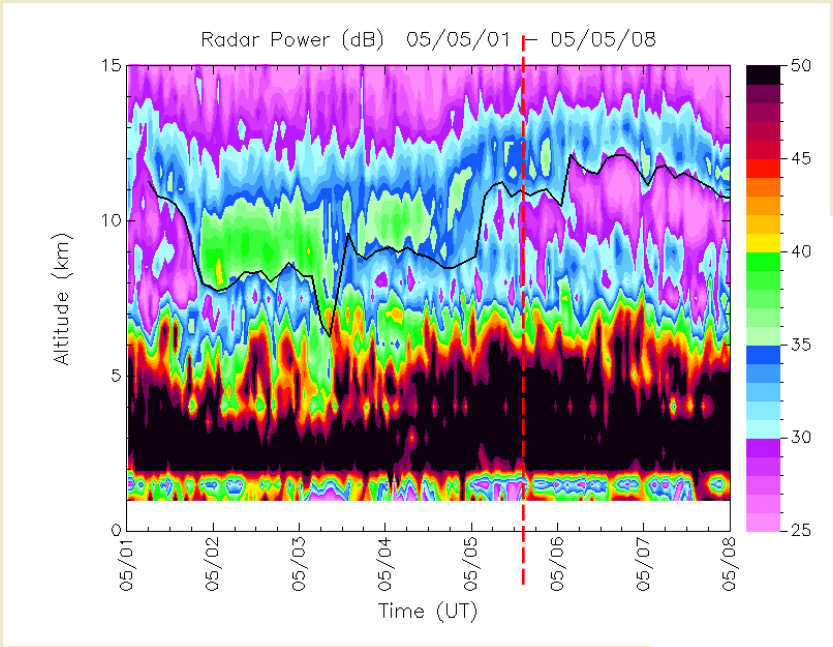

06 UTC, May 5, 2005
Altitude, km
14
12
10
8
6
4
2
0
-110
-100
-90
-80
-70
40
60

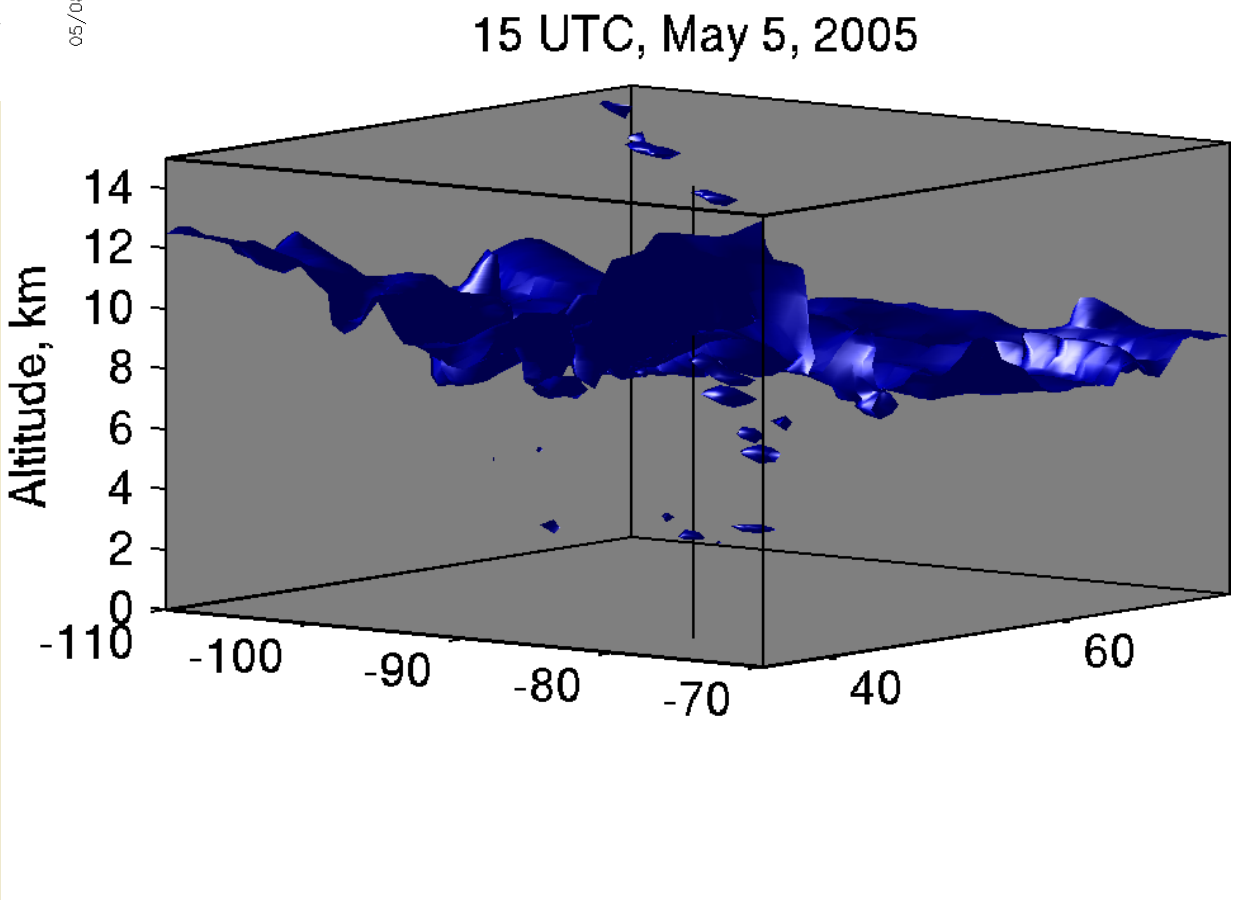

Radar Power (dB) 05/05/01 – 05/05/08
Altitude (km)
15
10
5
0
50
45
40
35
30
25
05/01
05/02
05/03
05/04
05/05
05/06
05/07
05/08
Time (UT)


09 UTC, May 5, 2005
Altitude, km
14
12
10
8
6
4
2
0
-110
-100
-90
-80
-70
40
60

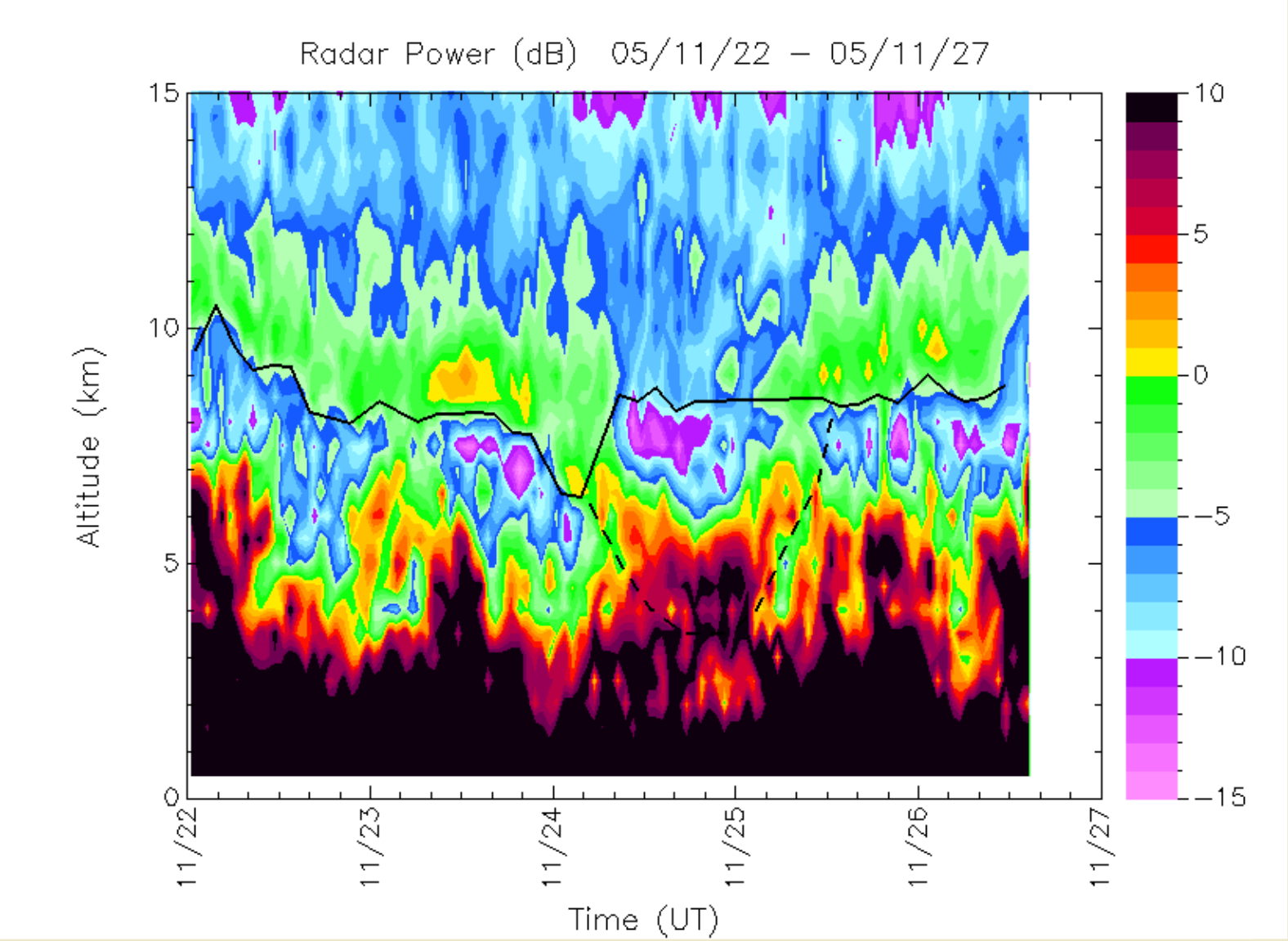

Radar Power (dB) 05/05/01 – 05/05/08
Altitude (km)
15
10
5
0
50
45
40
35
30
25
05/01
05/02
05/03
05/04
05/05
05/06
05/07
05/08
Time (UT)


12 UTC, May 5, 2005
Altitude, km
14
12
10
8
6
4
2
0
-110
-100
-90
-80
-70
40
60

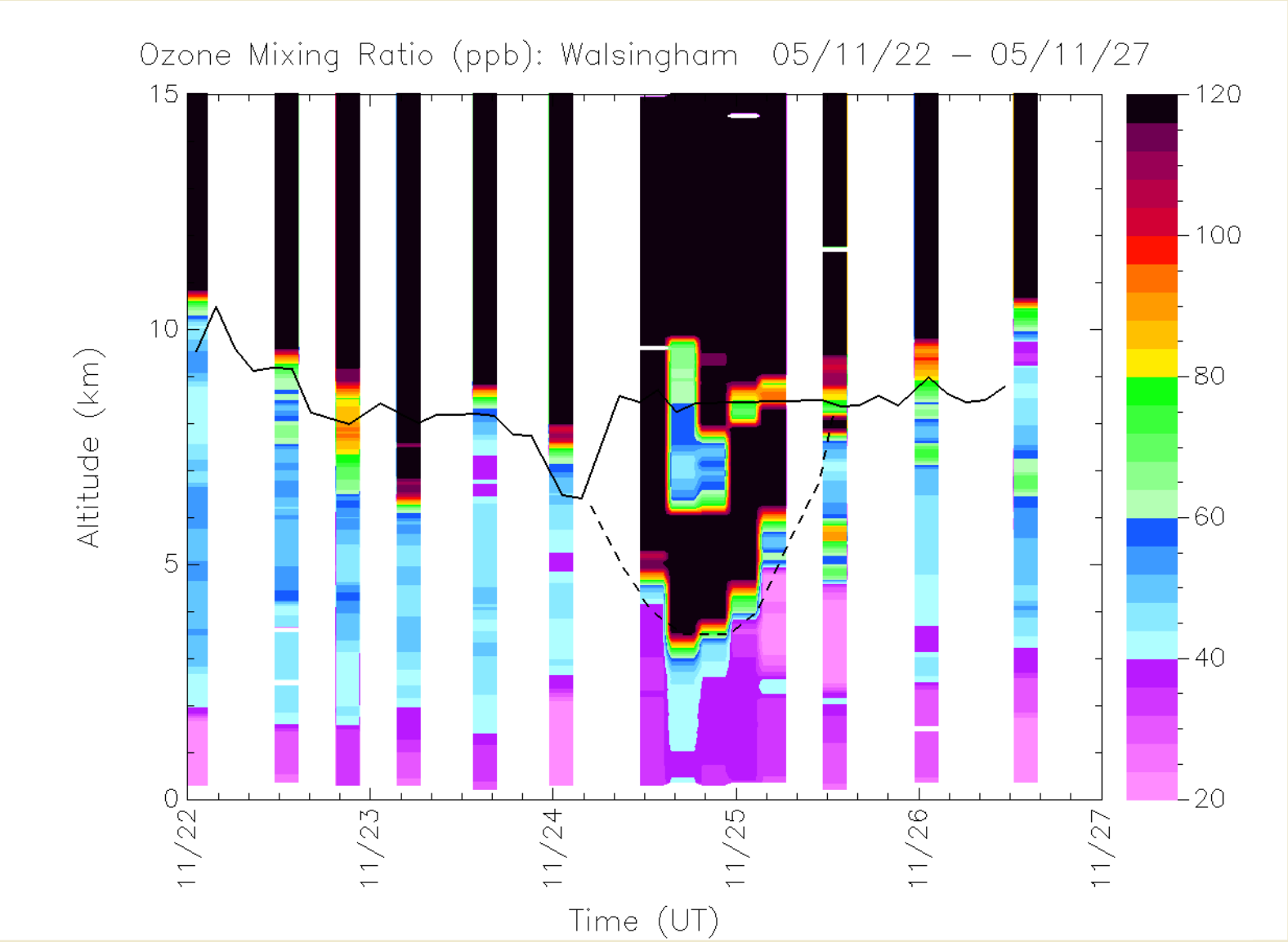

Radar Power (dB) 05/05/01 – 05/05/08
Altitude (km)
15
10
5
0
50
45
40
35
30
25
05/01
05/02
05/03
05/04
05/05
05/06
05/07
05/08
Time (UT)

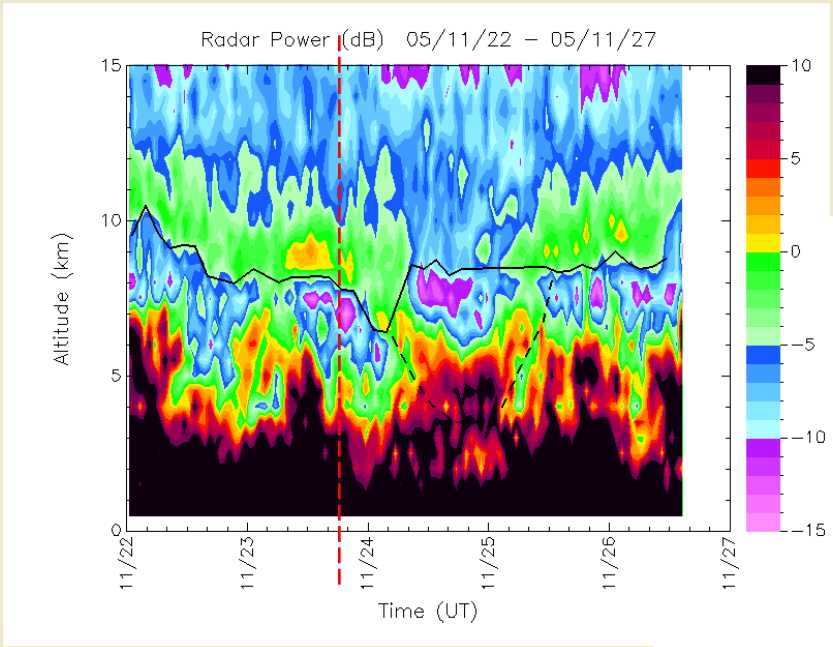

15 UTC, May 5, 2005
Altitude, km
14
12
10
8
6
4
2
0
-110
-100
-90
-80
-70
40
60

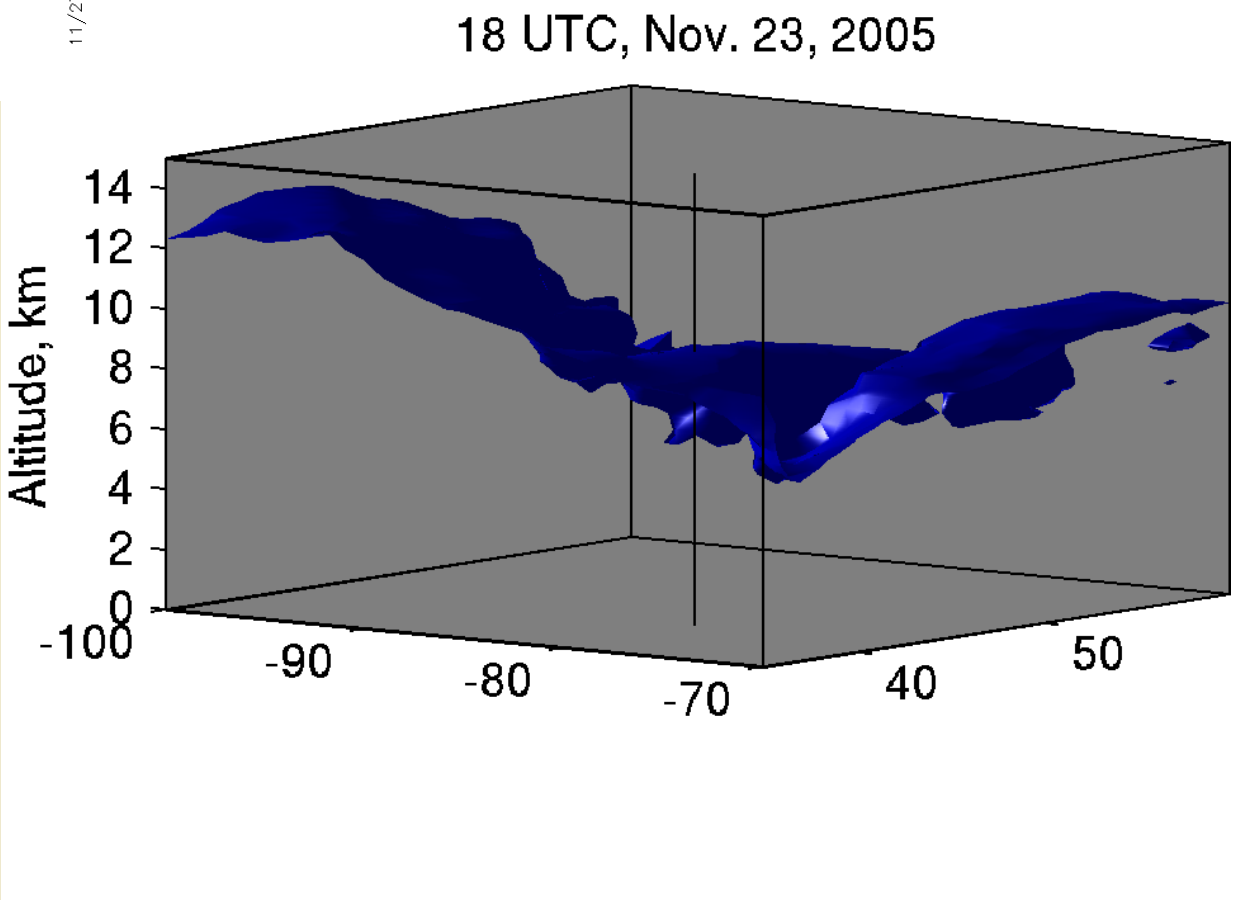
Walsingham: Radar total power

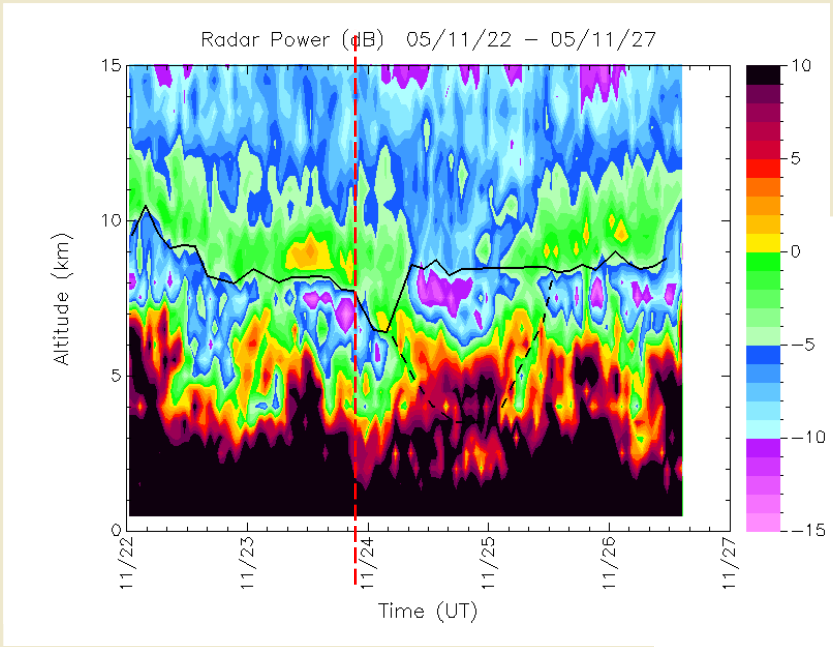


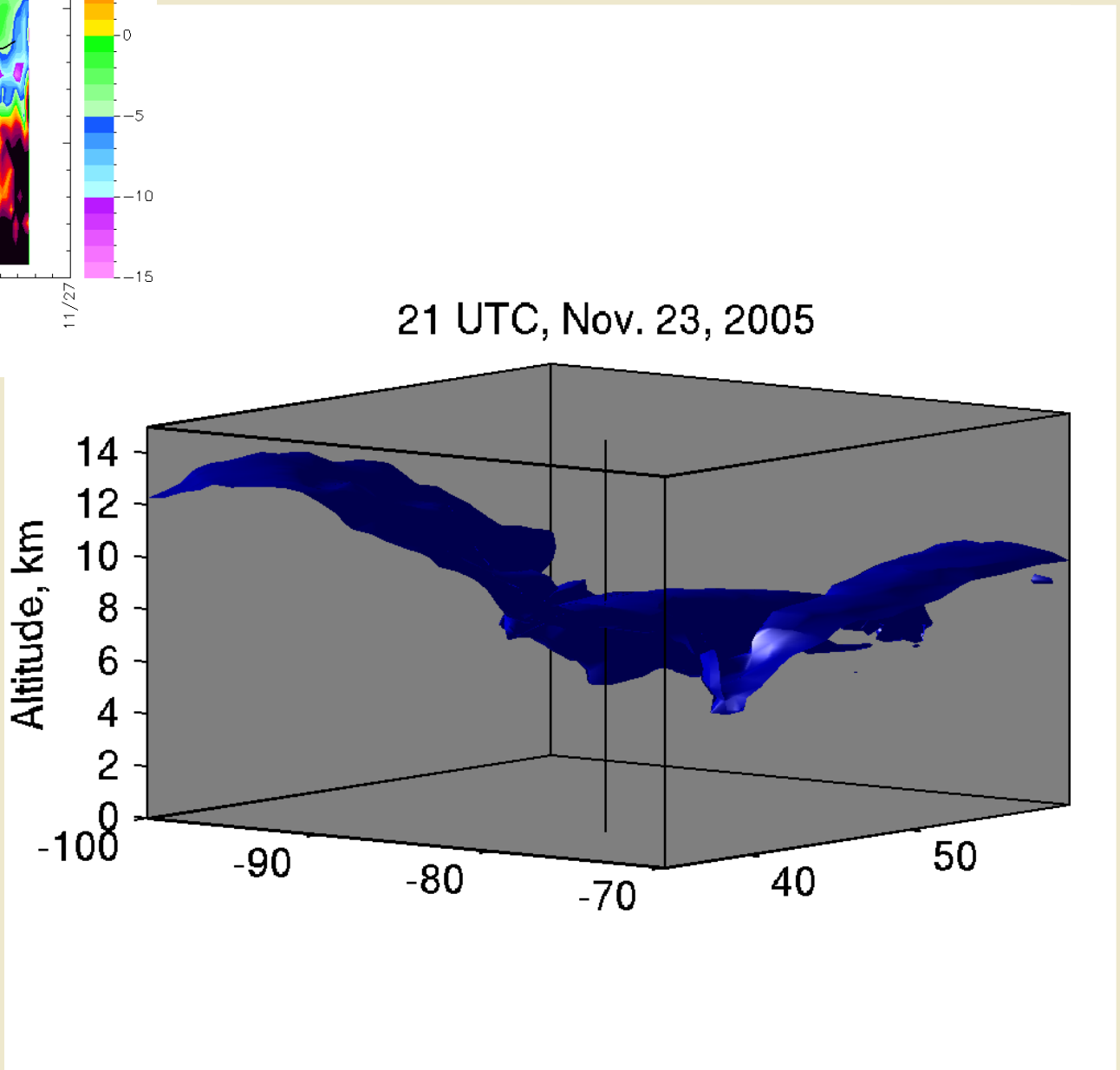
Walsingham: Ozone mixing ratio

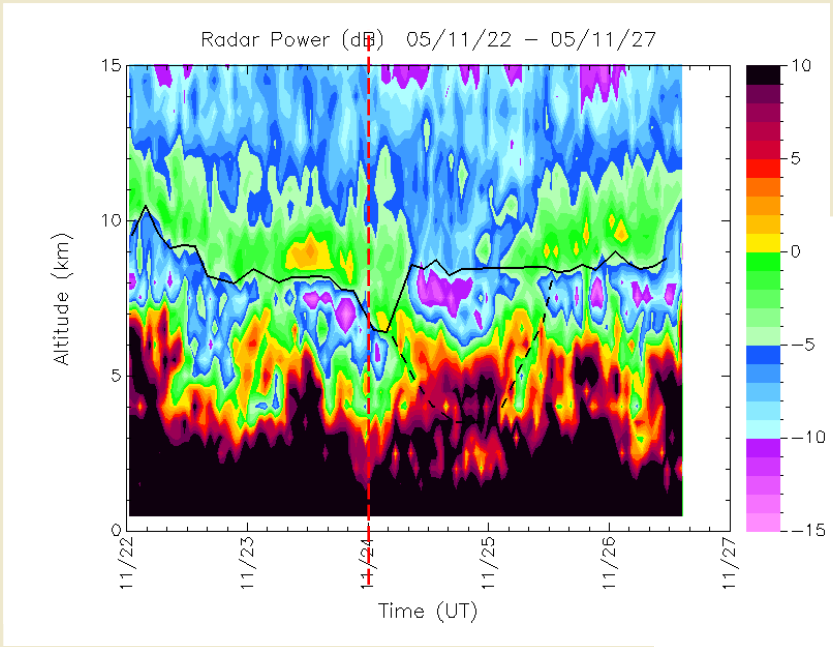


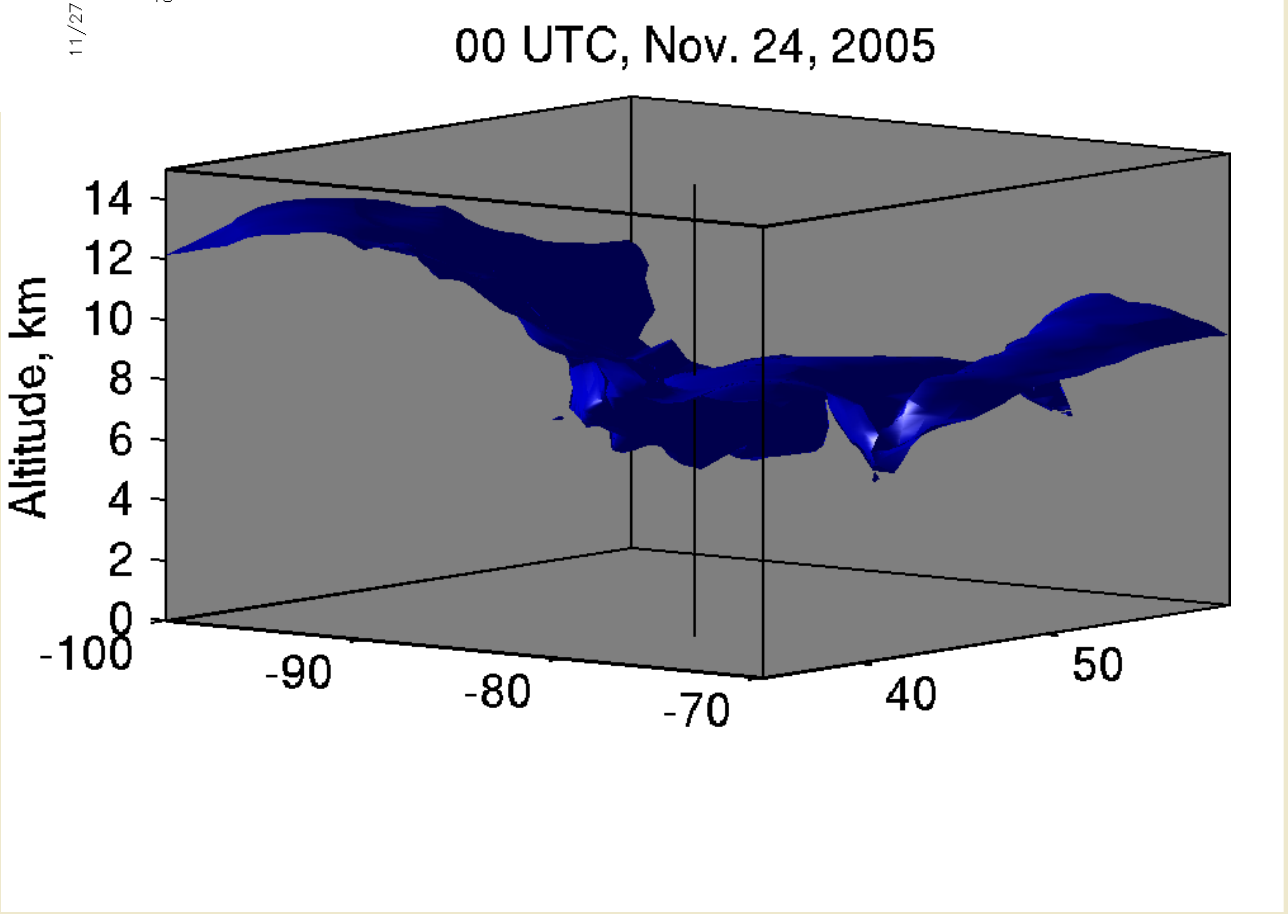

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
15
10
5
0
10
5
0
−5
−10
−15
11/22
11/23
11/24
11/25
11/26
11/27
Time (UT)

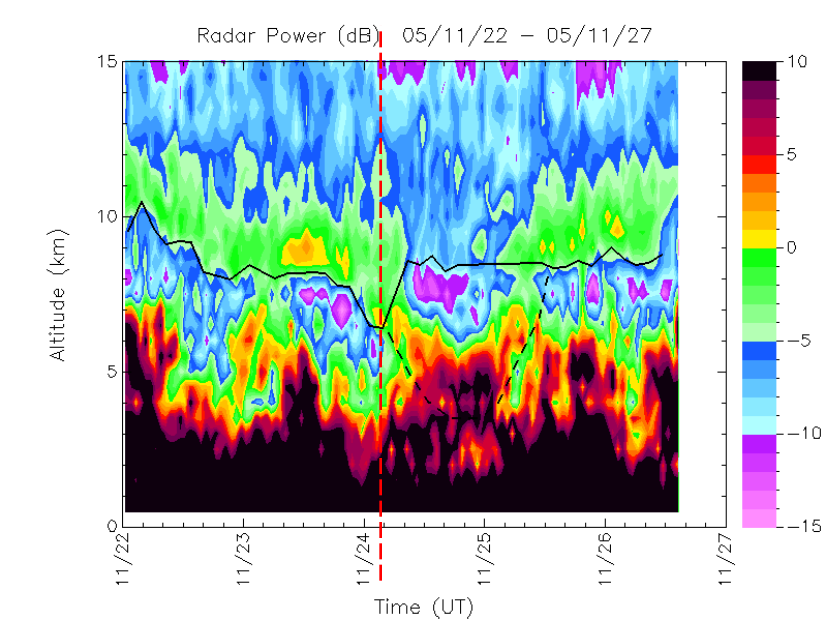

18 UTC, Nov. 23, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

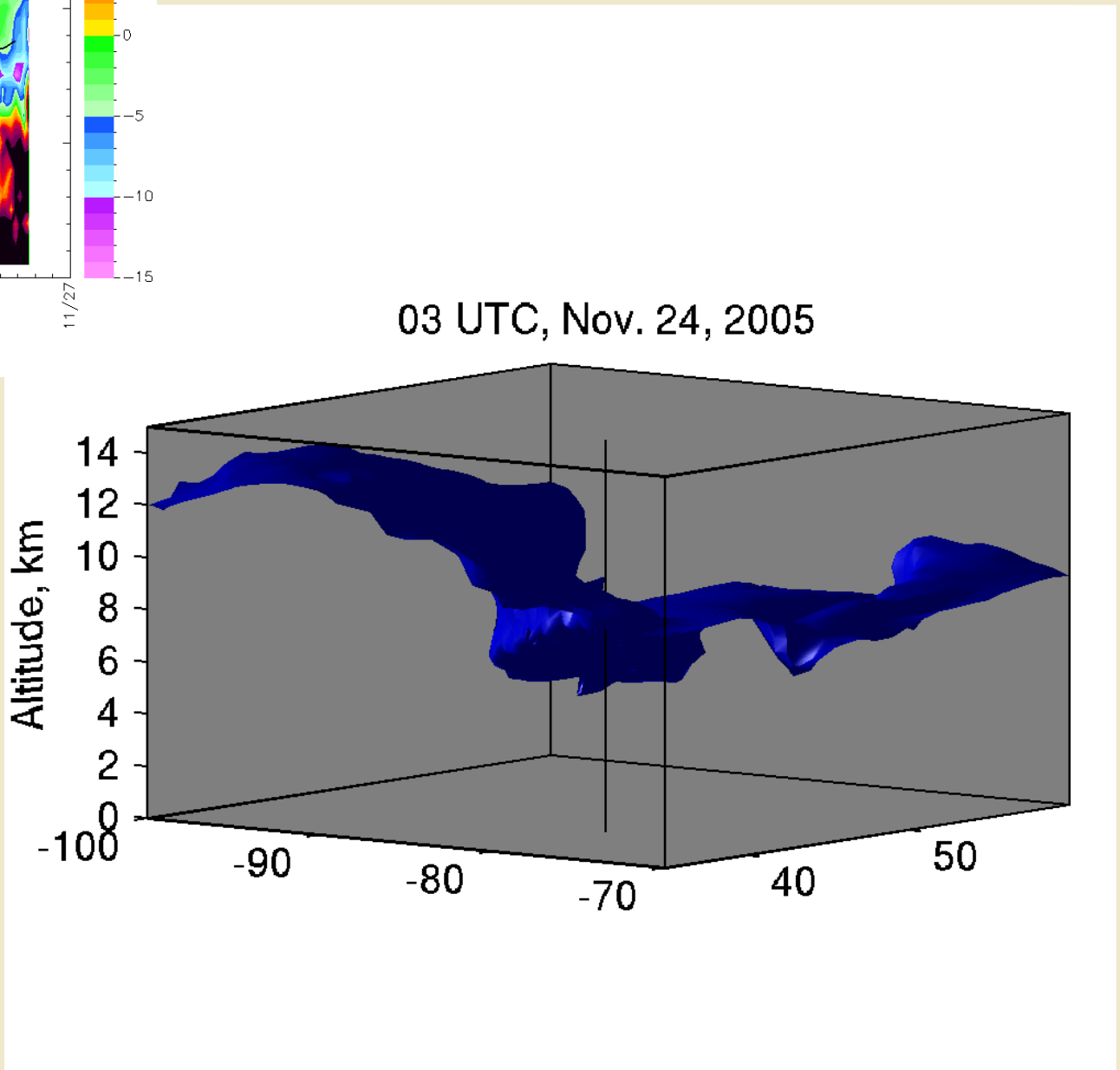

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
15
10
5
0
10
5
0
−5
−10
−15
11/22
11/23
11/24
11/25
11/26
11/27
Time (UT)

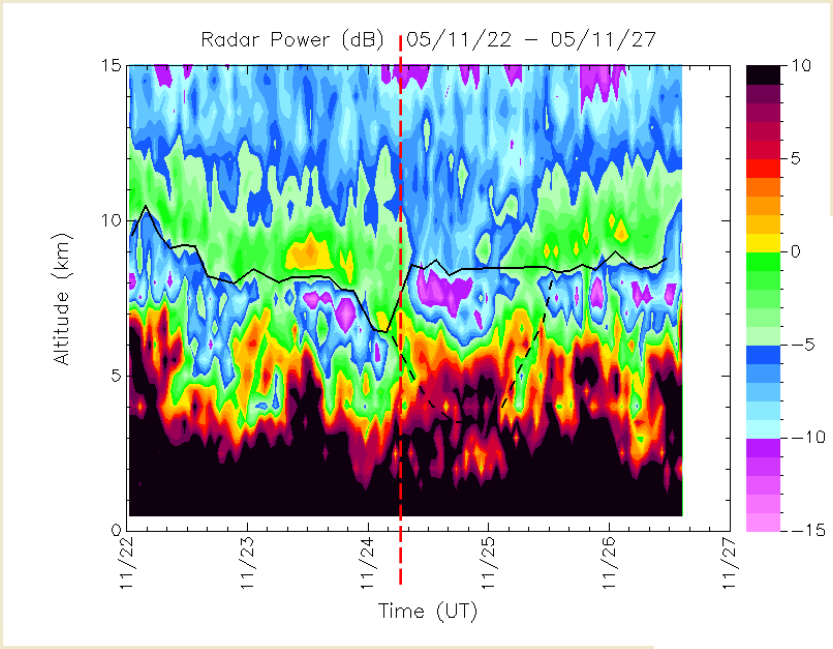

21 UTC, Nov. 23, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

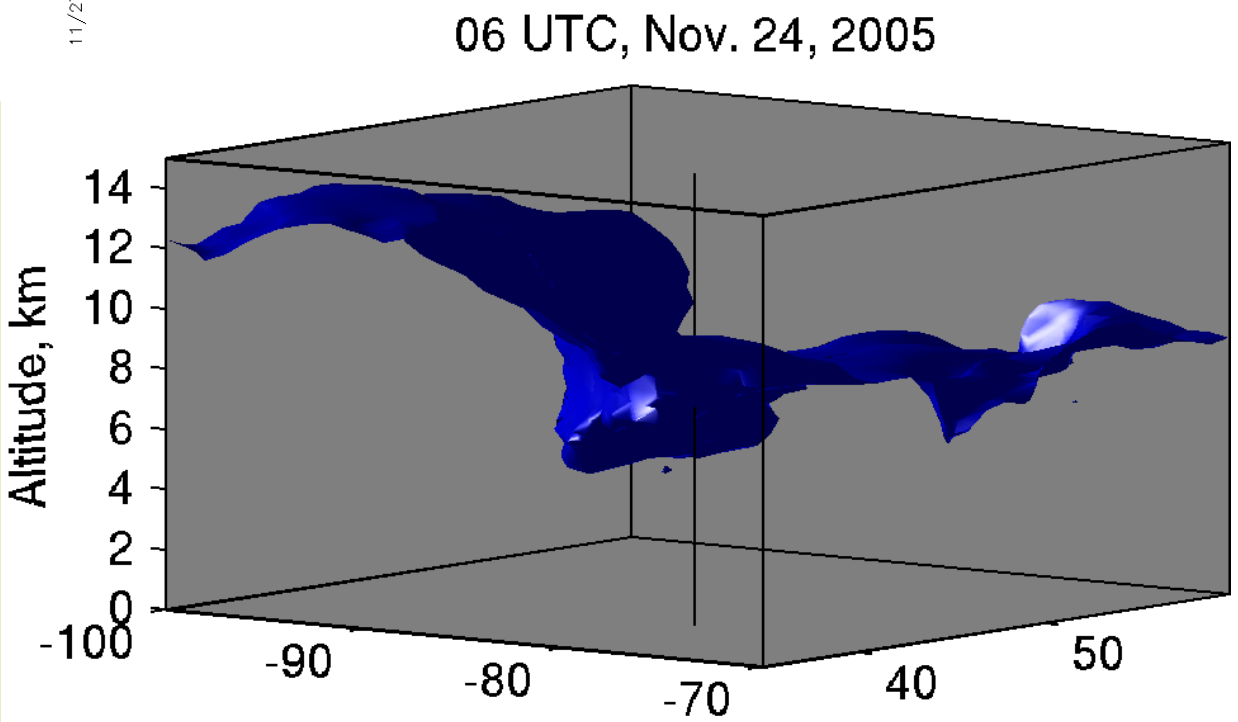

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
15
10
5
0
10
5
0
−5
−10
−15
11/22
11/23
11/24
11/25
11/26
11/27
Time (UT)

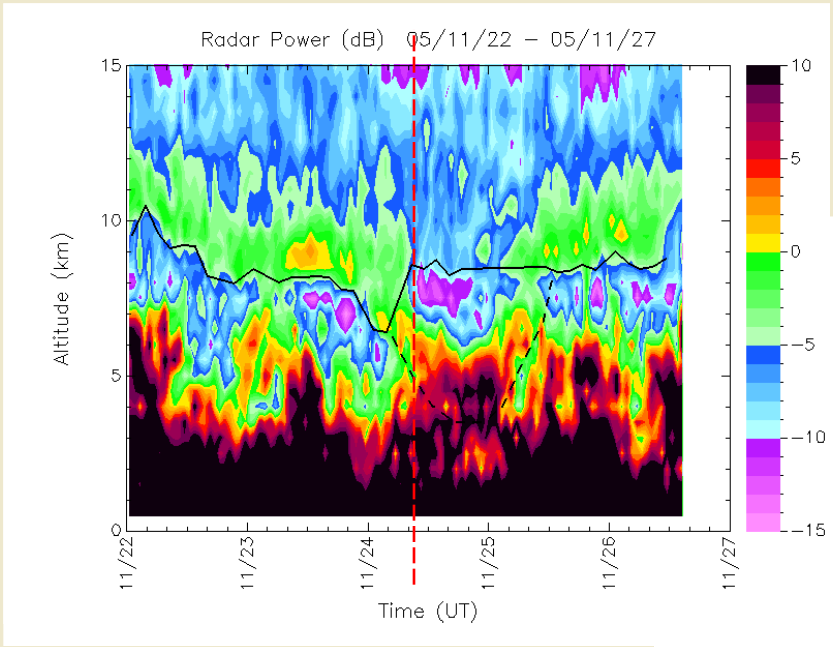

00 UTC, Nov. 24, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

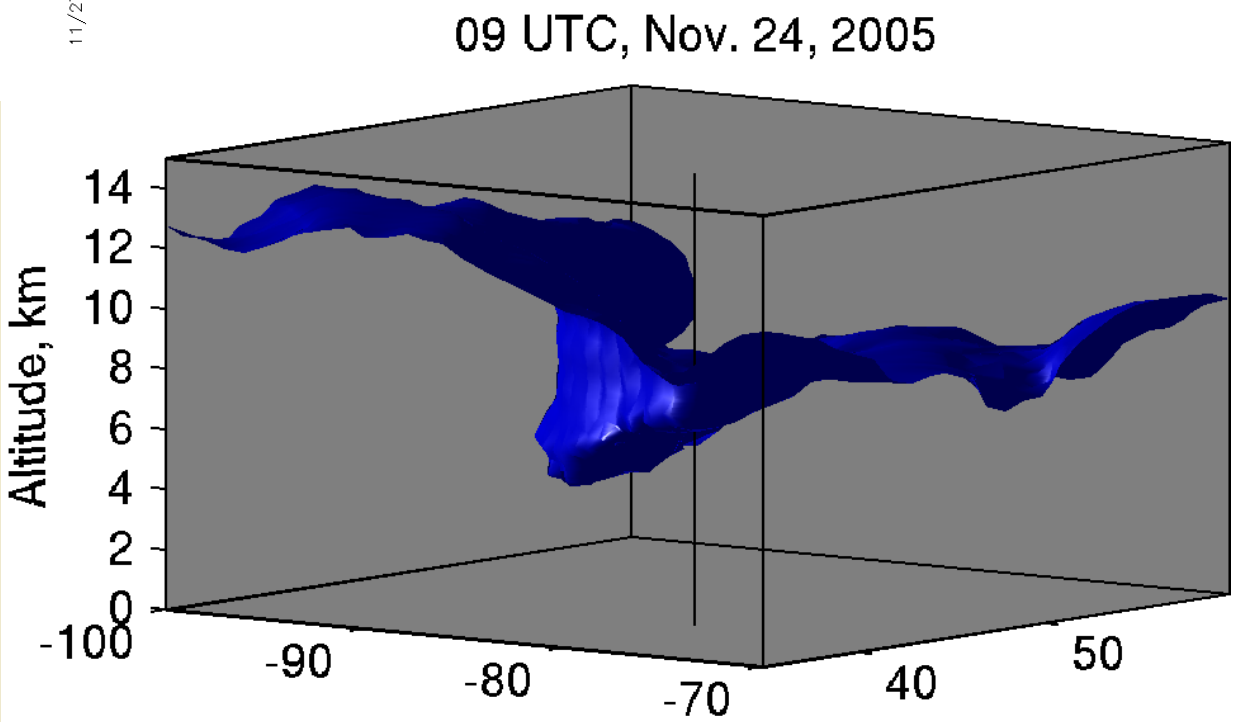

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
Time (UT)
11/22
11/23
11/24
11/25
11/26
11/27
15
10
5
0
10
5
0
−5
−10
−15

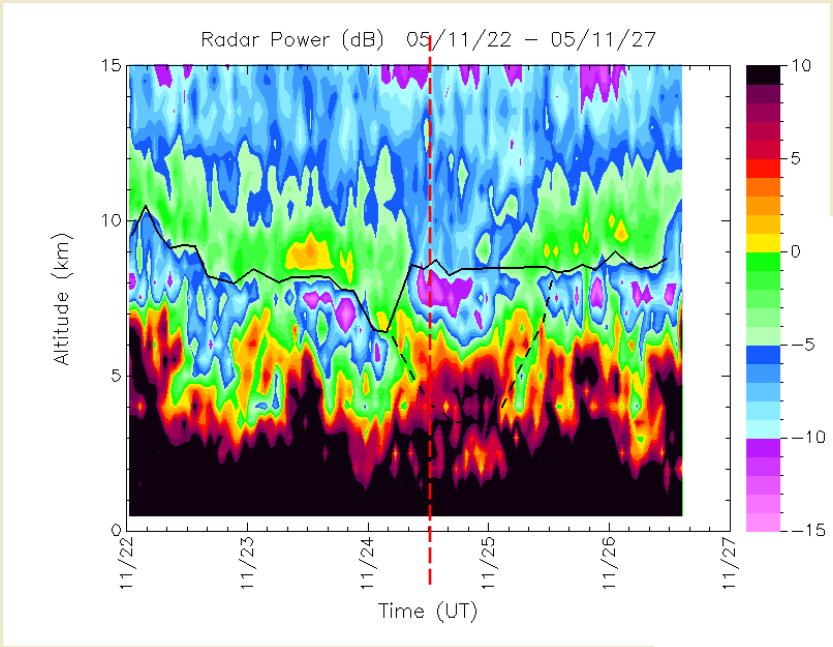

03 UTC, Nov. 24, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

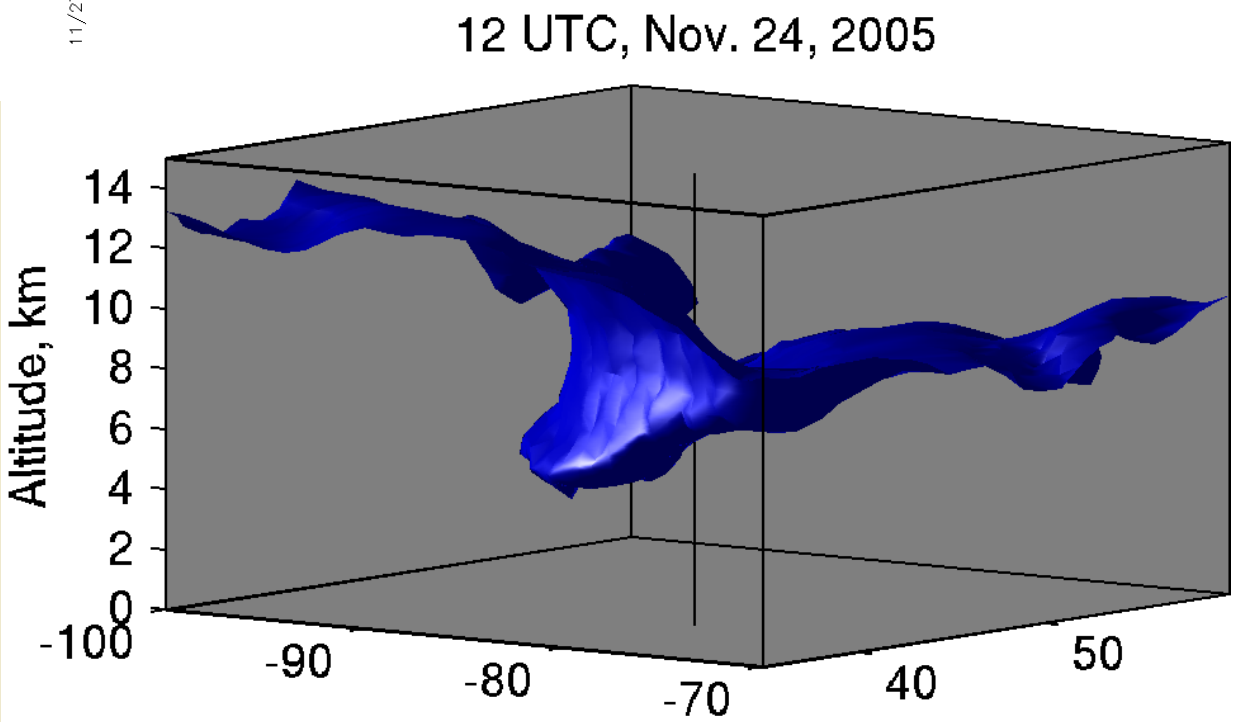

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
Time (UT)
11/22
11/23
11/24
11/25
11/26
11/27

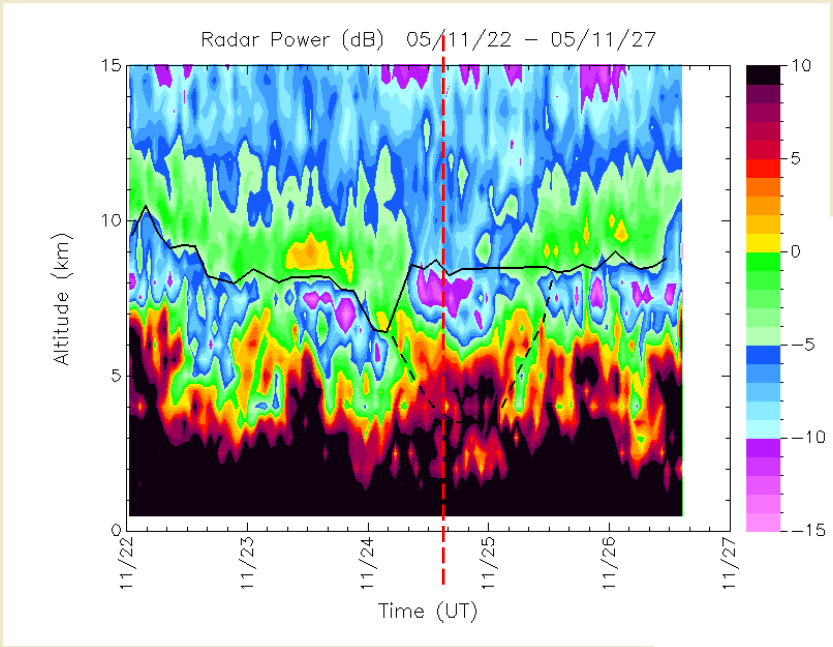

06 UTC, Nov. 24, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

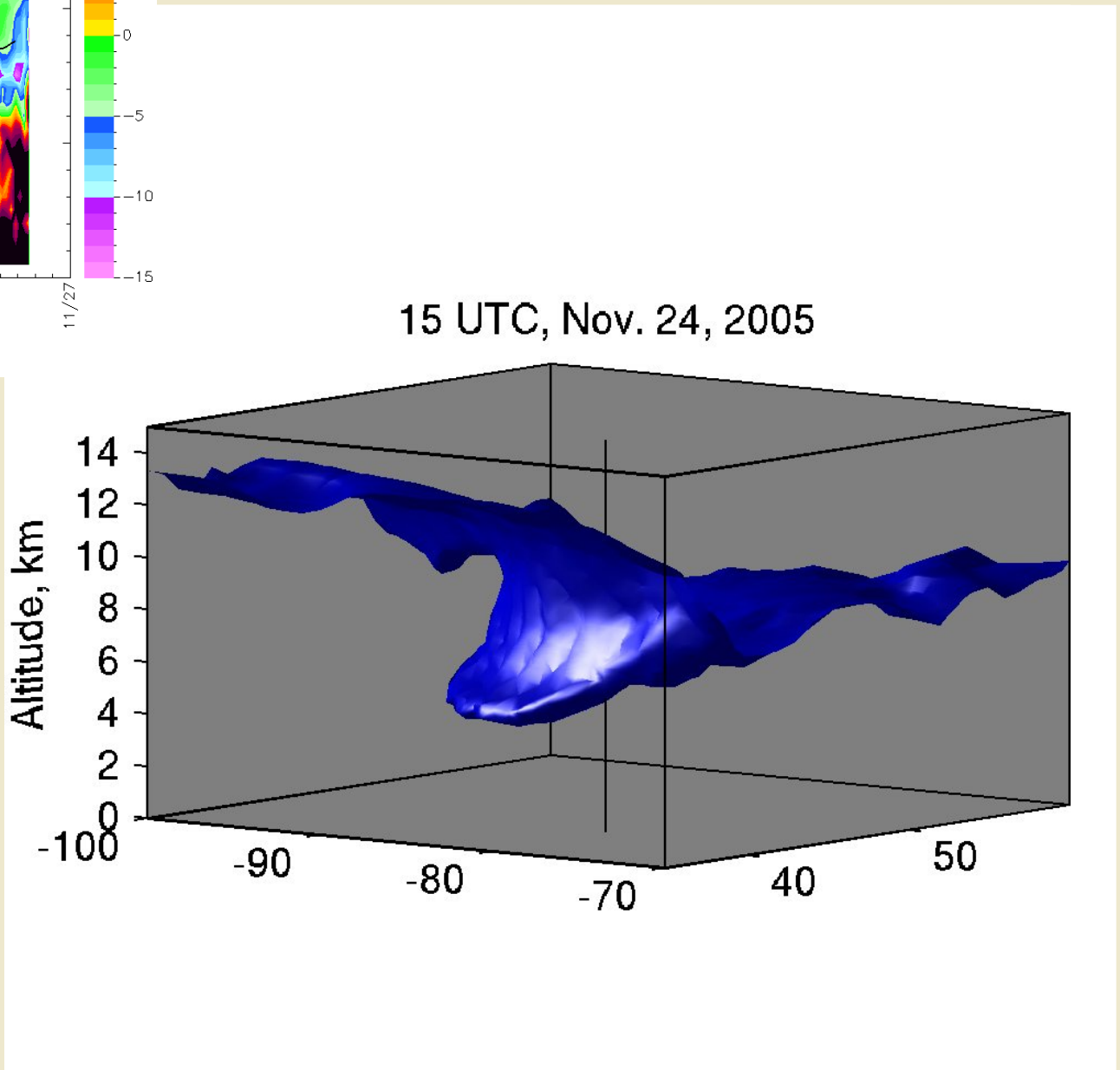

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
Time (UT)
11/22
11/23
11/24
11/25
11/26
11/27

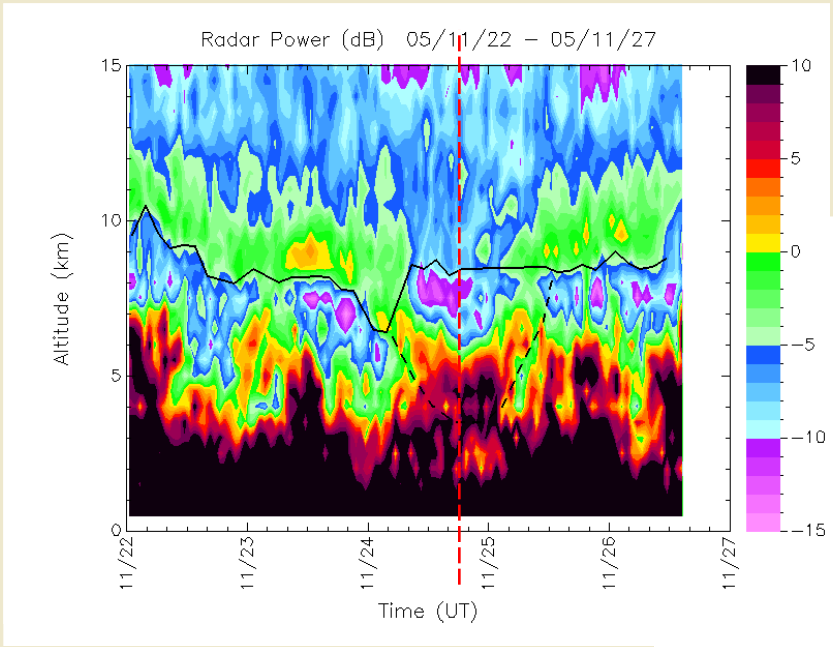

09 UTC, Nov. 24, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

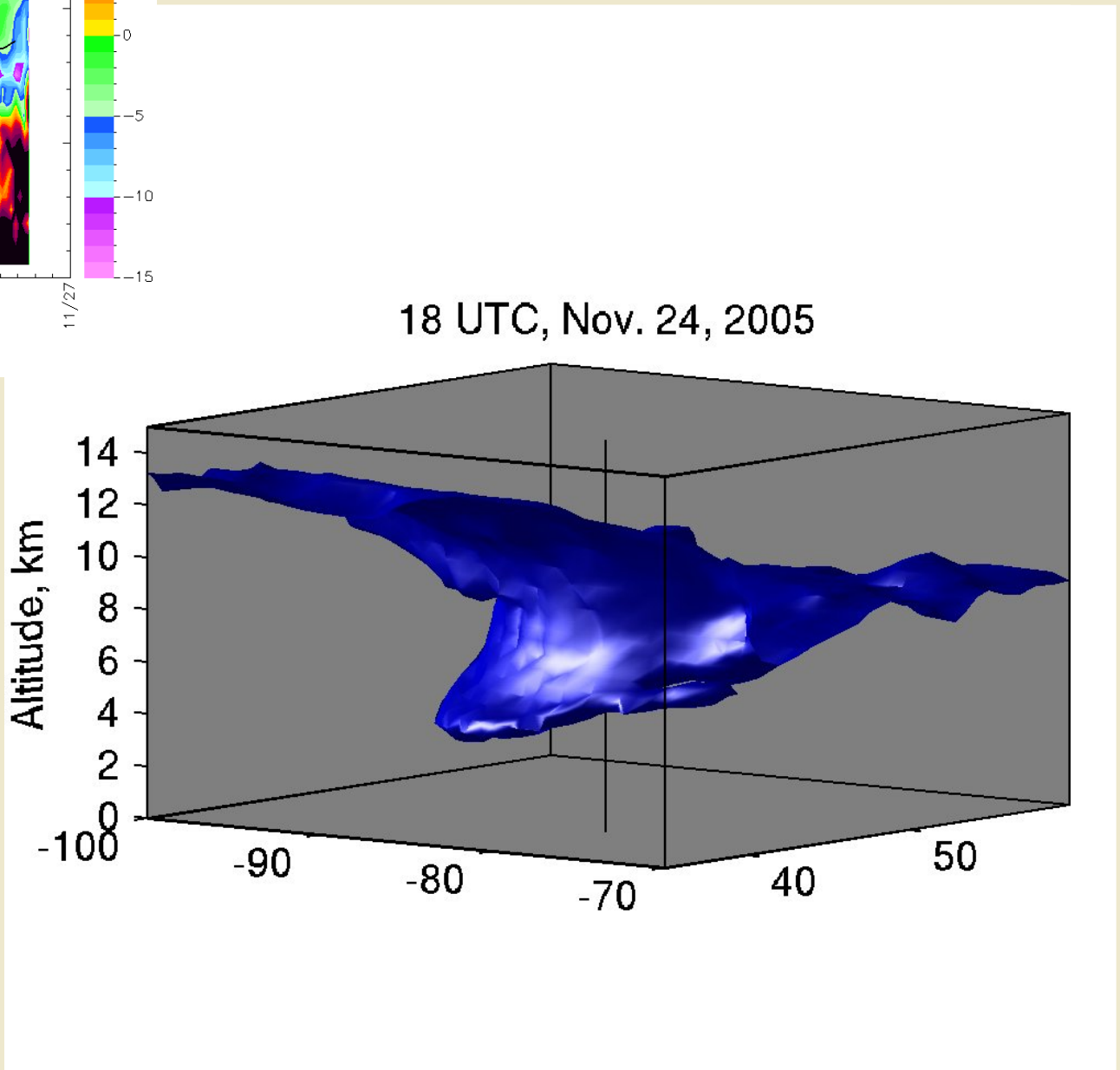

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
Time (UT)
11/22
11/23
11/24
11/25
11/26
11/27

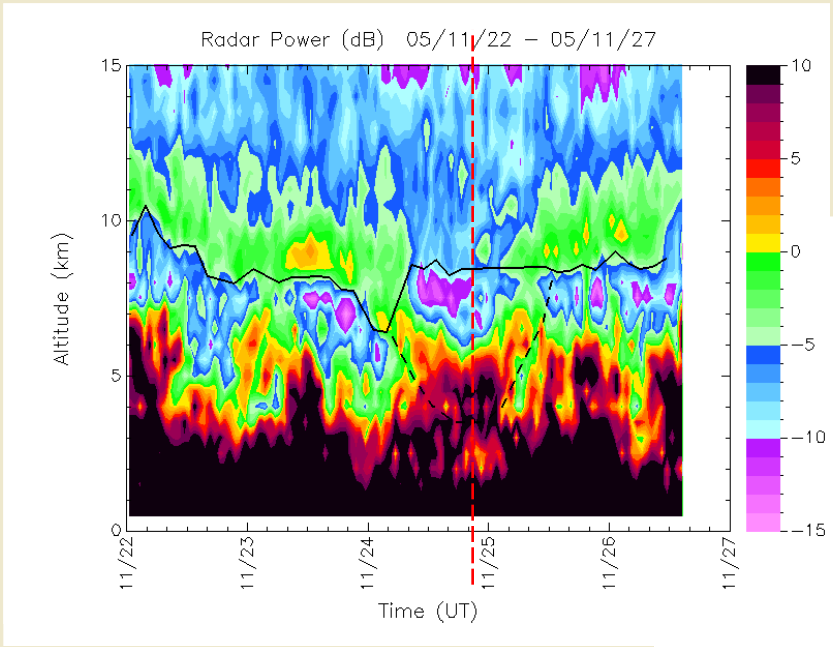

12 UTC, Nov. 24, 2005
Altitude, km
-100
-90
-80
-70
40
50

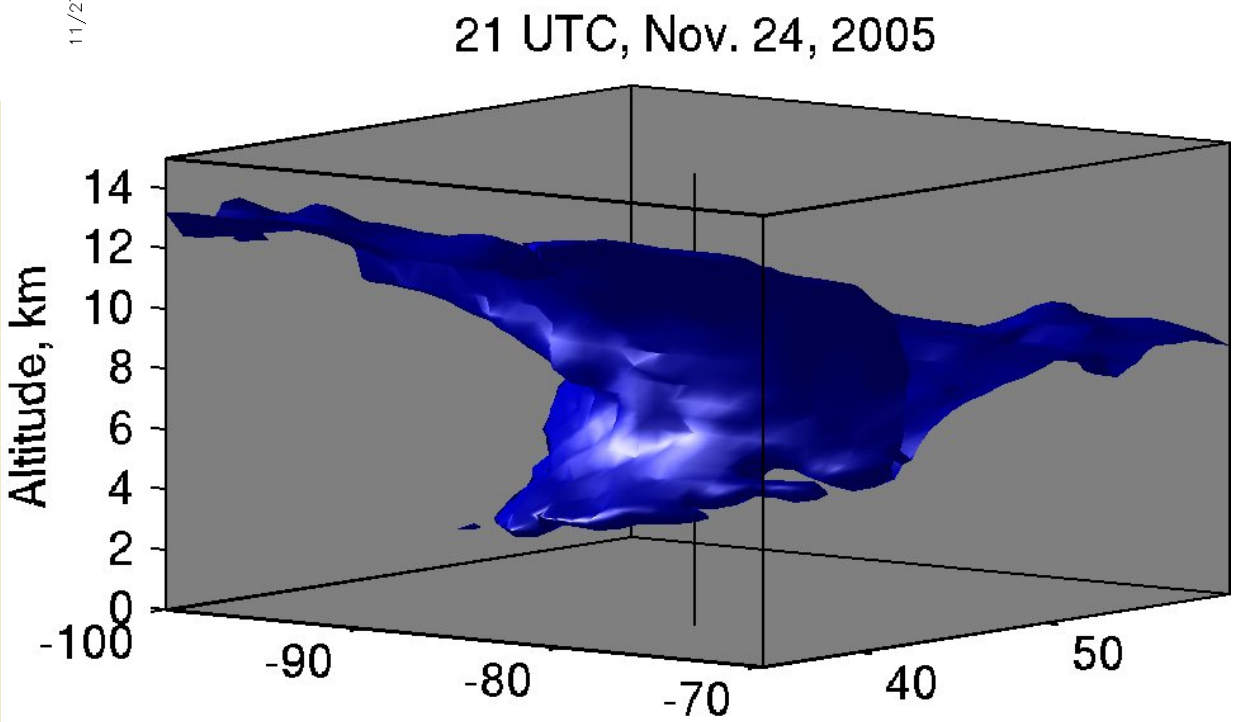

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
15
10
5
0
10
5
0
−5
−10
−15
11/22
11/23
11/24
11/25
11/26
11/27
Time (UT)

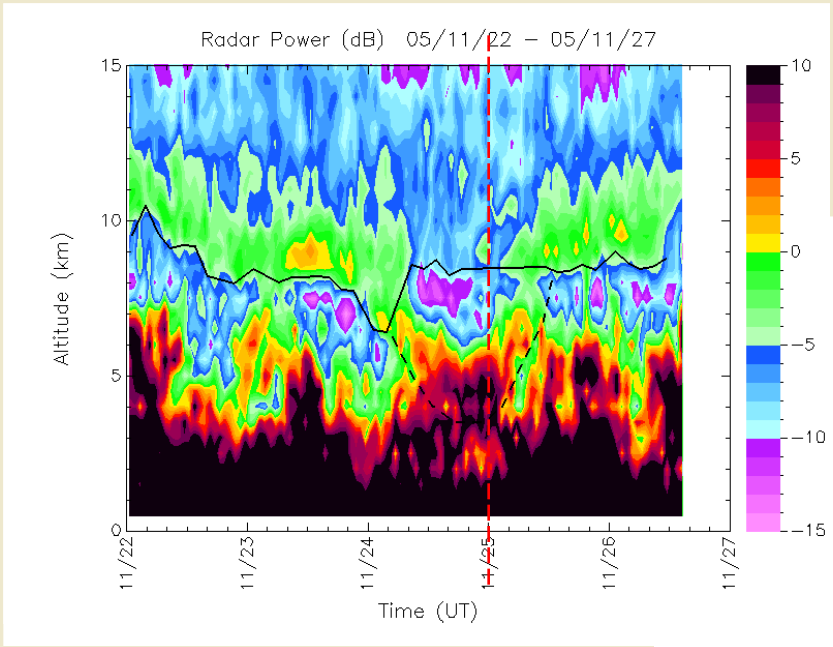

15 UTC, Nov. 24, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

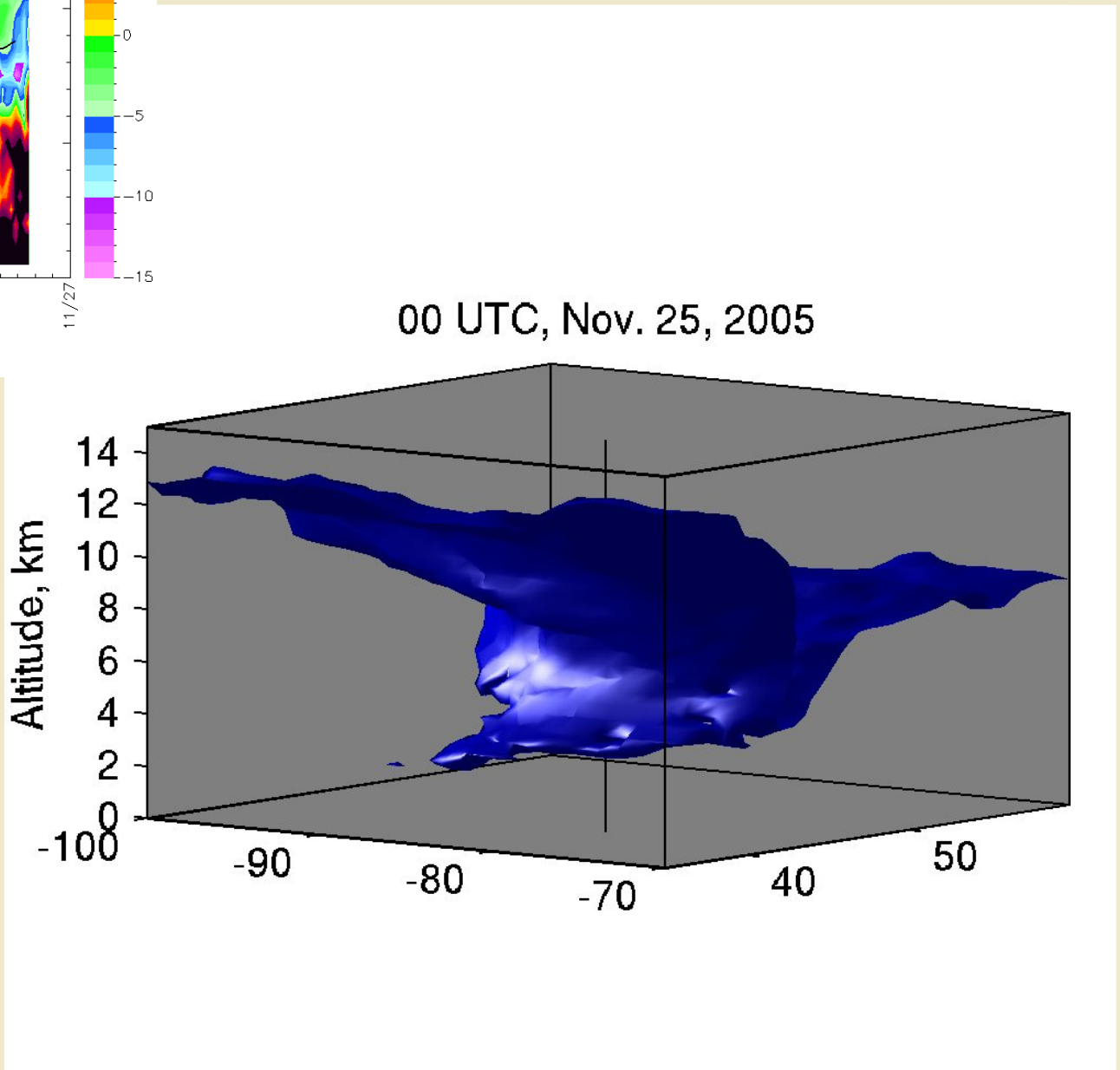

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
15
10
5
0
10
5
0
−5
−10
−15
11/22
11/23
11/24
11/25
11/26
11/27
Time (UT)

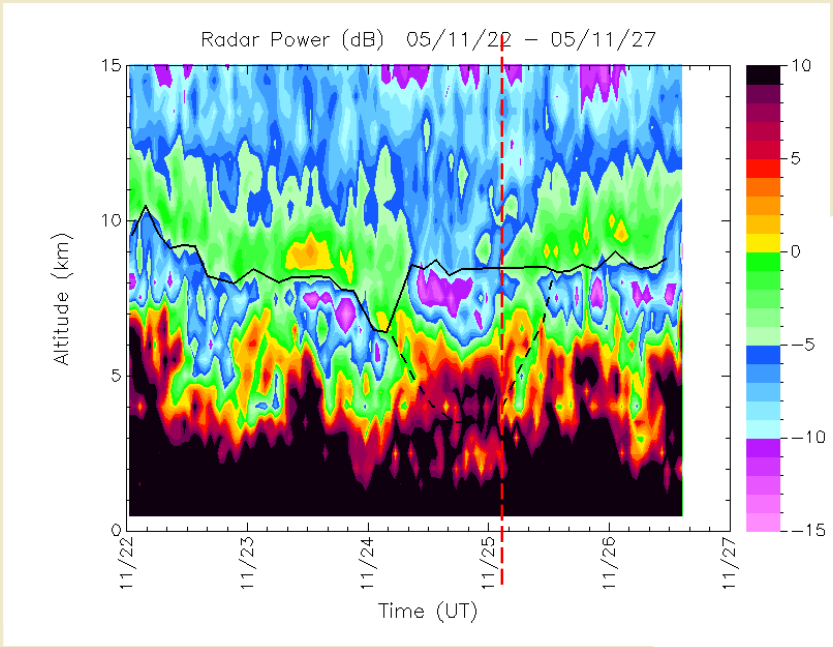

18 UTC, Nov. 24, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

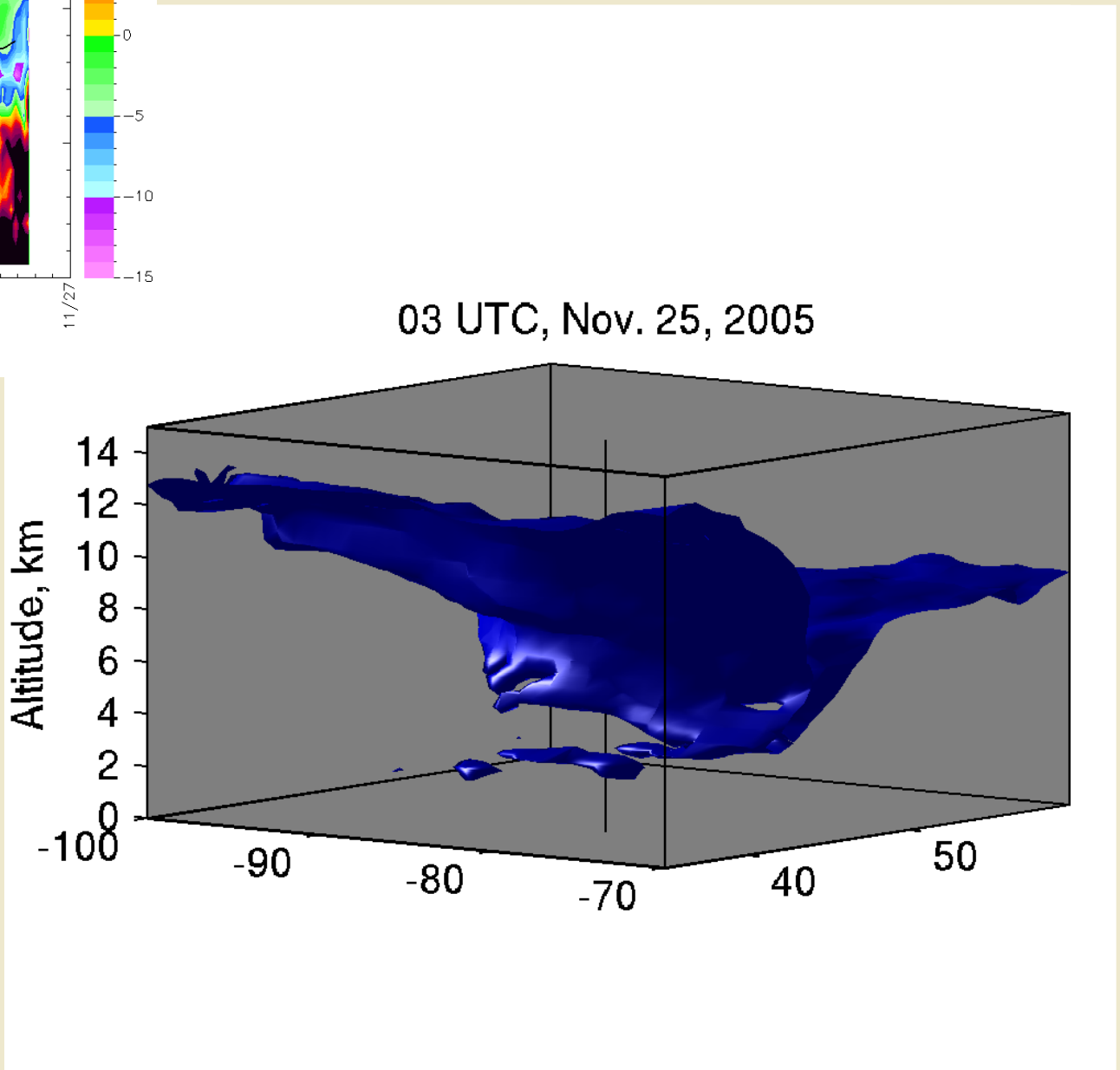

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
Time (UT)
11/22
11/23
11/24
11/25
11/26
11/27

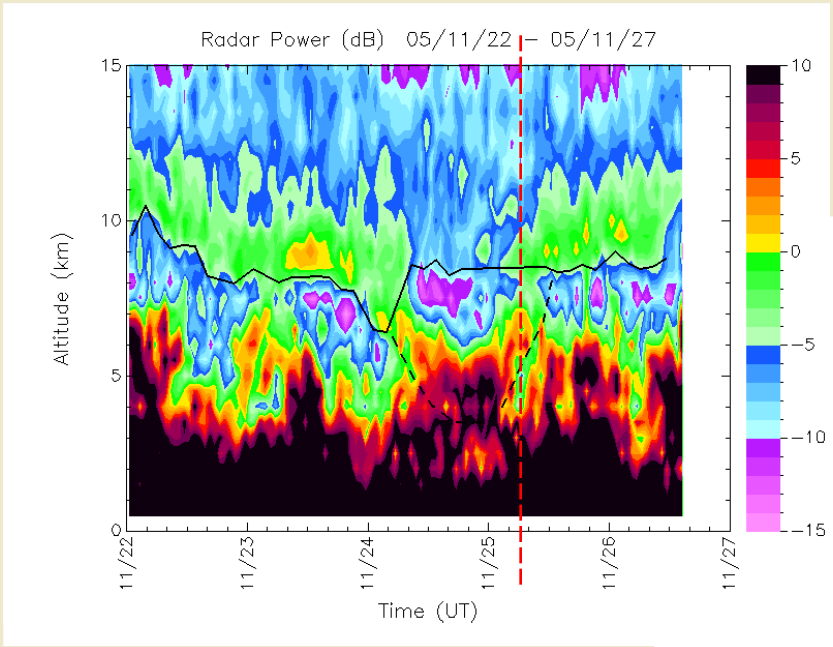

21 UTC, Nov. 24, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

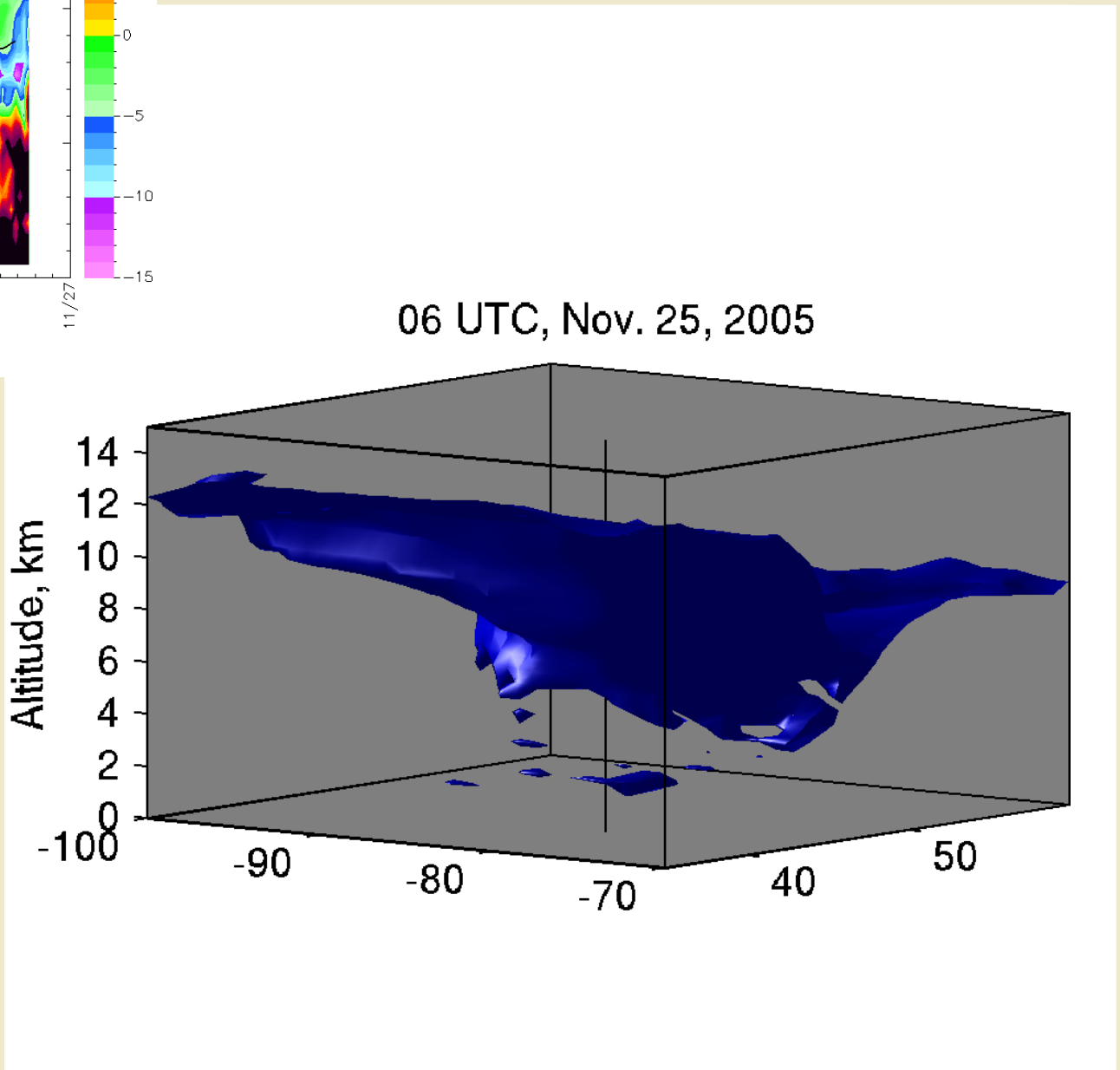

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
Time (UT)
11/22
11/23
11/24
11/25
11/26
11/27
0
5
10
15
10
5
0
−5
−10
−15

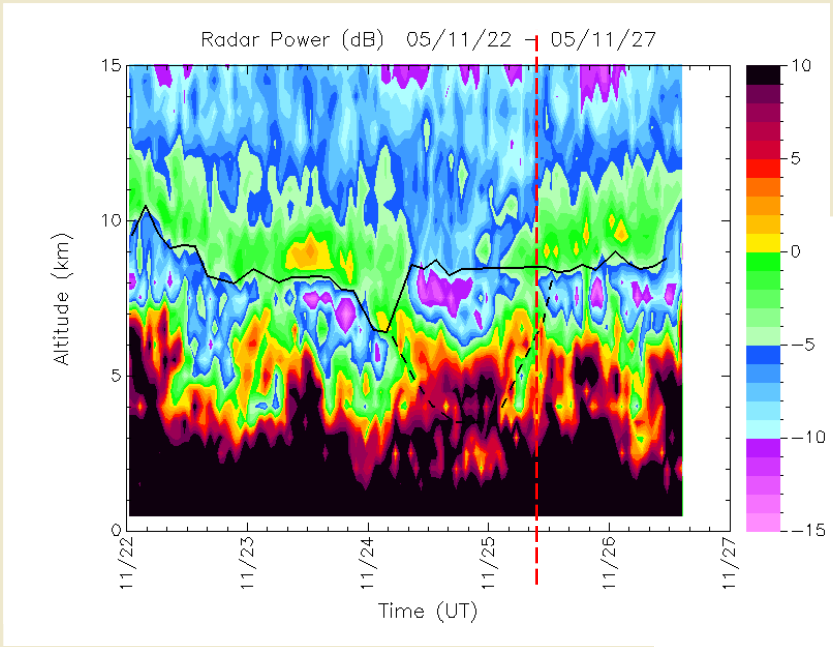

00 UTC, Nov. 25, 2005
Altitude, km
0
2
4
6
8
10
12
14
-100
-90
-80
-70
40
50

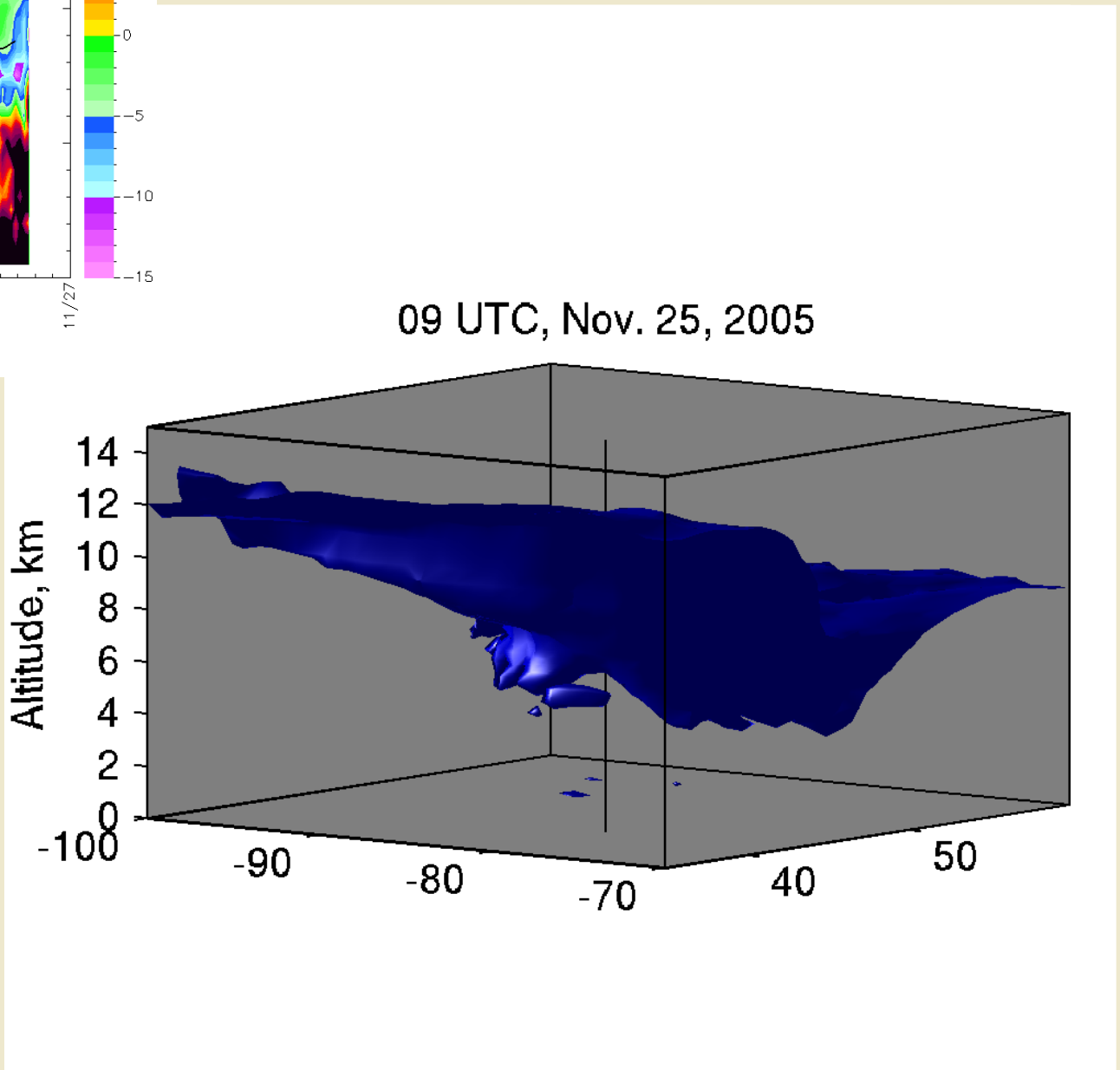

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
15
10
5
0
10
5
0
−5
−10
−15
11/22
11/23
11/24
11/25
11/26
11/27
Time (UT)

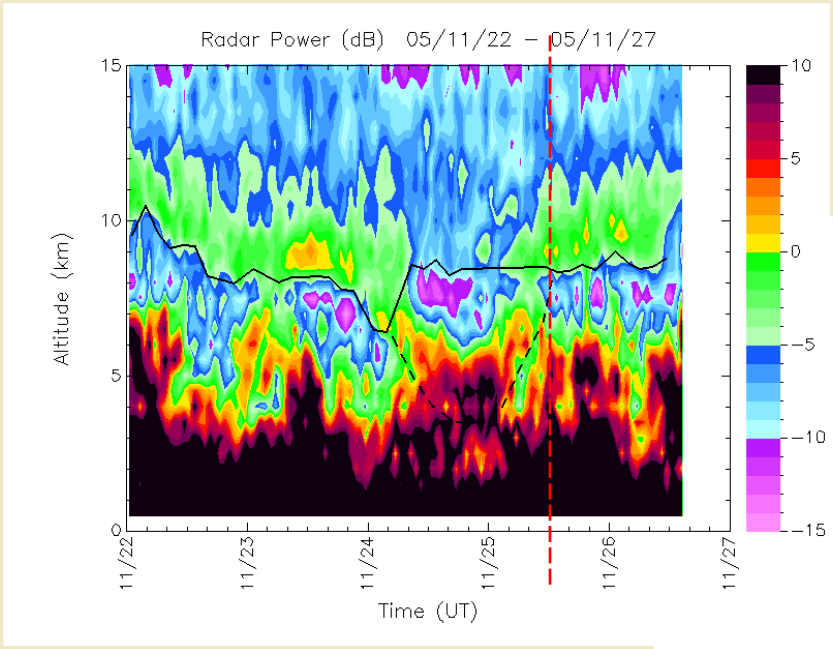

03 UTC, Nov. 25, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

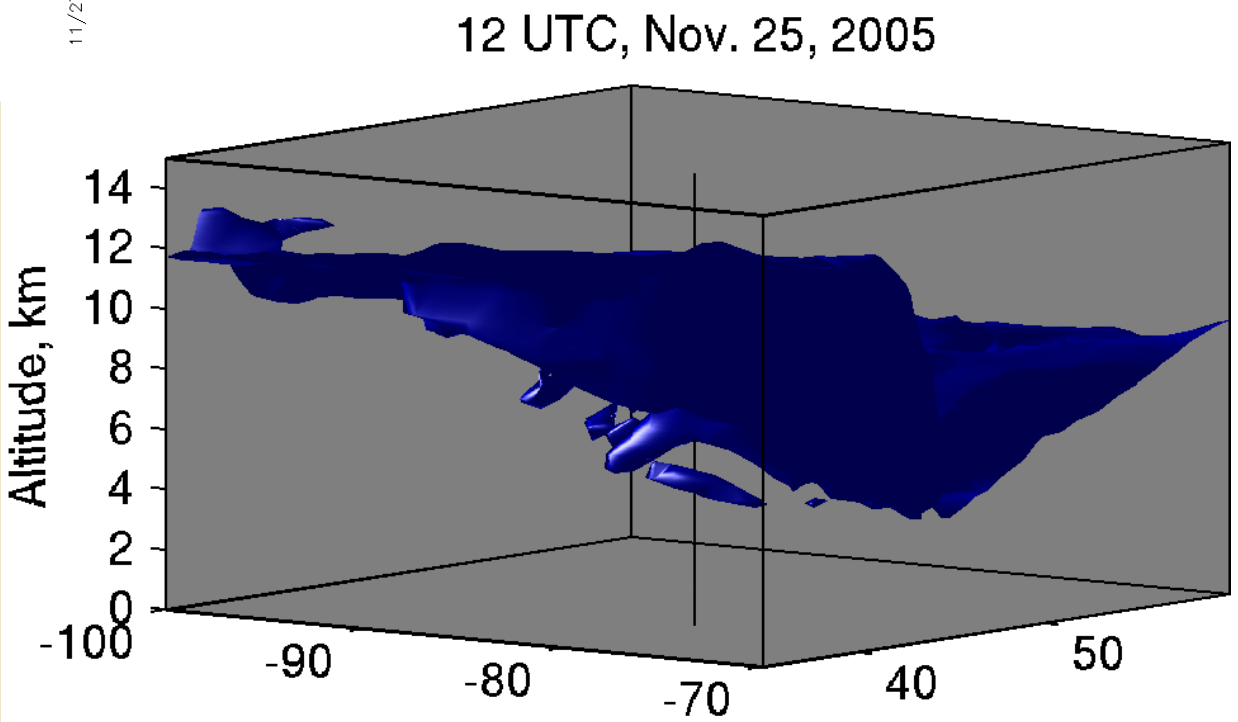

Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
Time (UT)
11/22
11/23
11/24
11/25
11/26
11/27
0
5
10
15
10
5
0
−5
−10
−15


06 UTC, Nov. 25, 2005
Altitude, km
0
2
4
6
8
10
12
14
-100
-90
-80
-70
40
50


Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
15
10
5
0
10
5
0
−5
−10
−15
11/22
11/23
11/24
11/25
11/26
11/27
Time (UT)

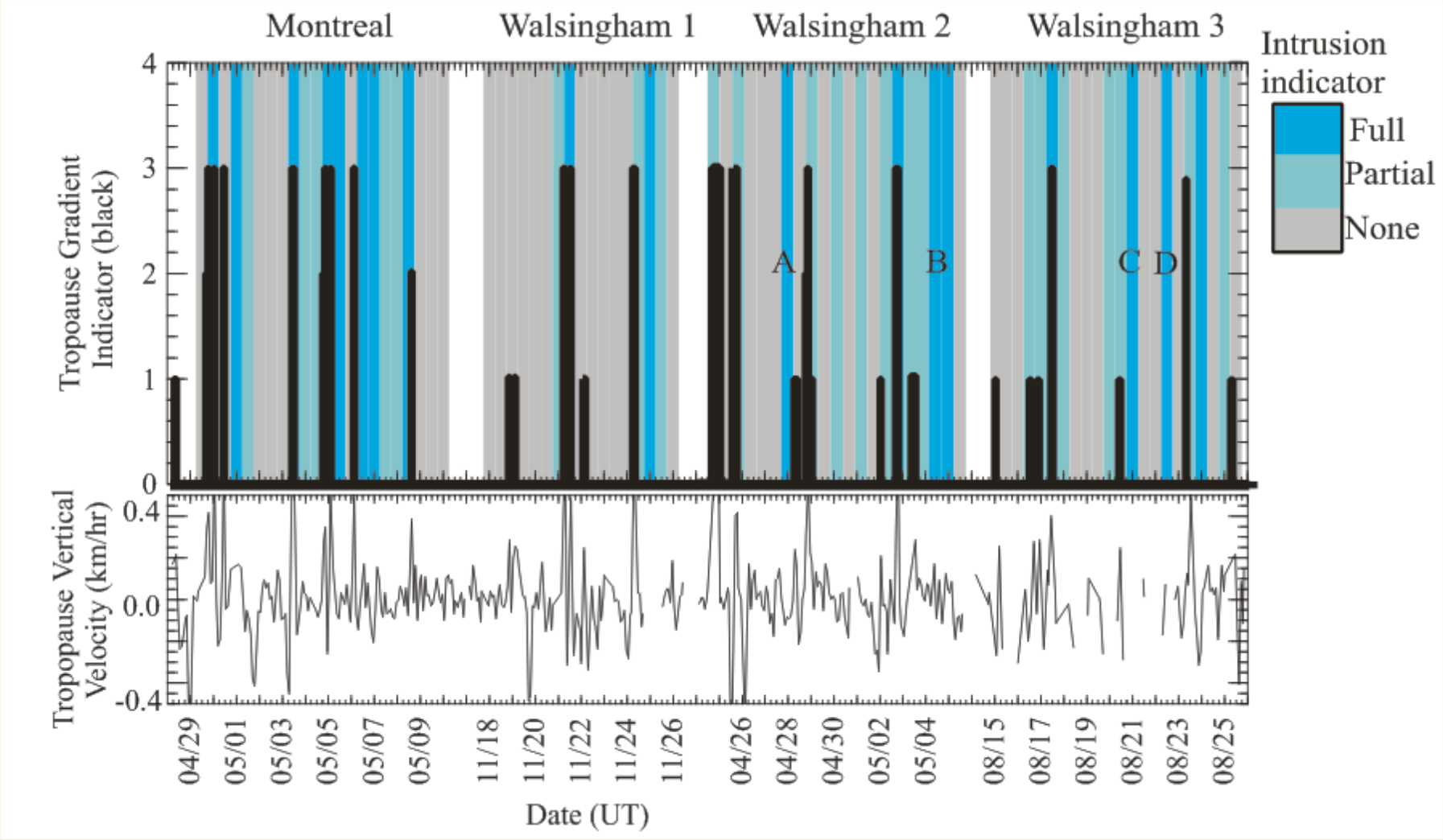

09 UTC, Nov. 25, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50


Radar Power (dB) 05/11/22 – 05/11/27
Altitude (km)
Time (UT)
11/22
11/23
11/24
11/25
11/26
11/27


12 UTC, Nov. 25, 2005
Altitude, km
14
12
10
8
6
4
2
0
-100
-90
-80
-70
40
50

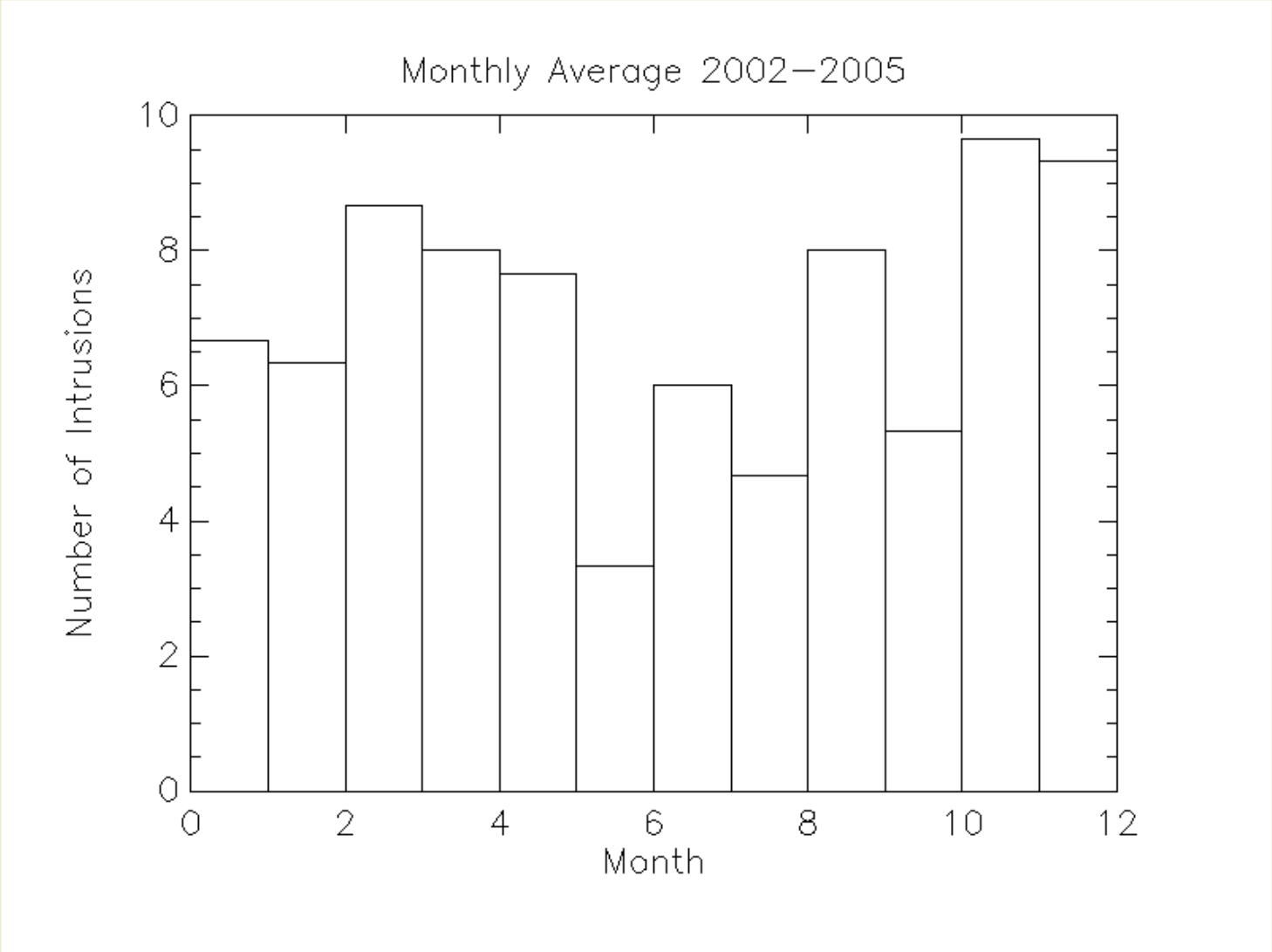
Tropopause height -- ozone intrusion relation

A comparison between sharp increases in the tropopause and stratospheric intrusion events shows good agreement.

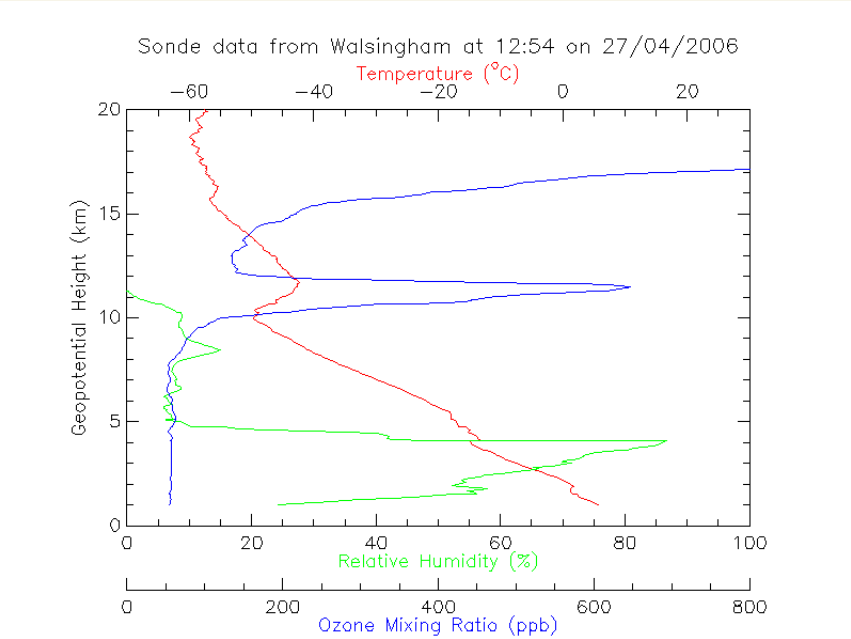


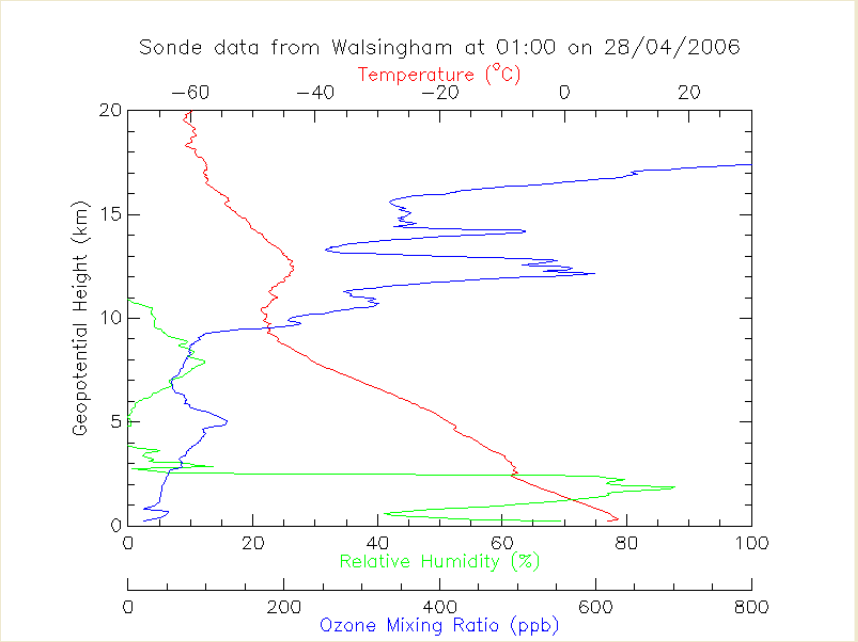
Seasonal intrusion trends from tropopause data

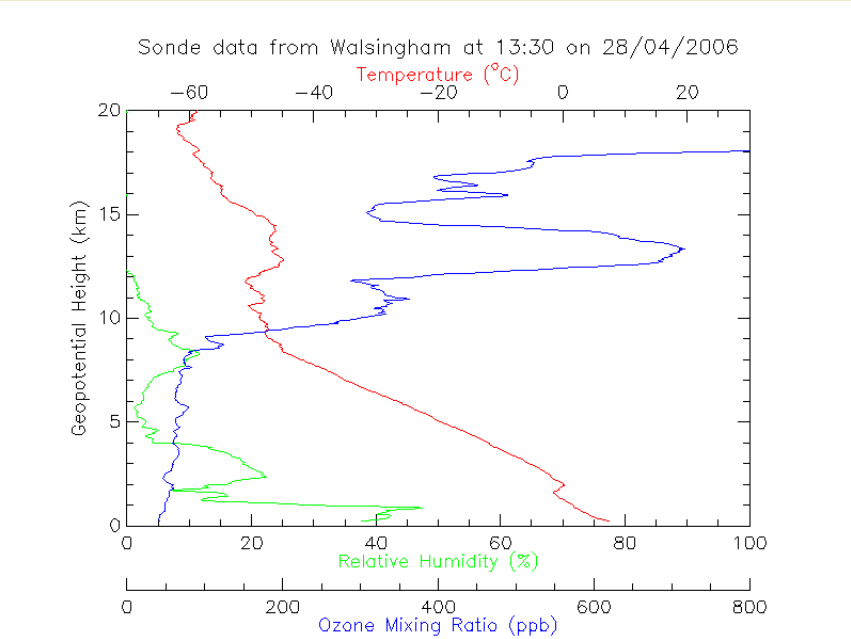
- Three years of radar tropopause data from Montreal.
- Intrusion occurs when the tropopause velocity > 0.4 km/hr.

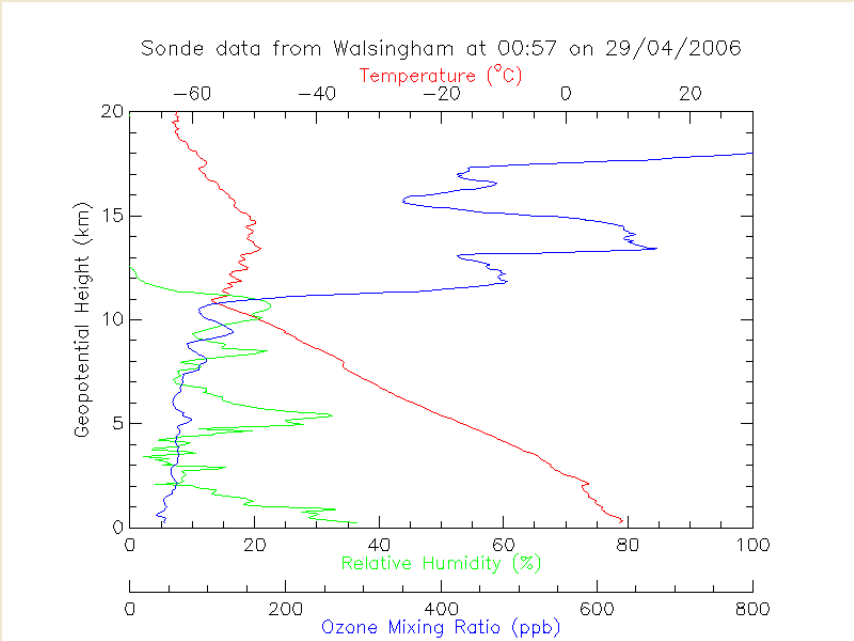


Walsingham -- April/May 2006

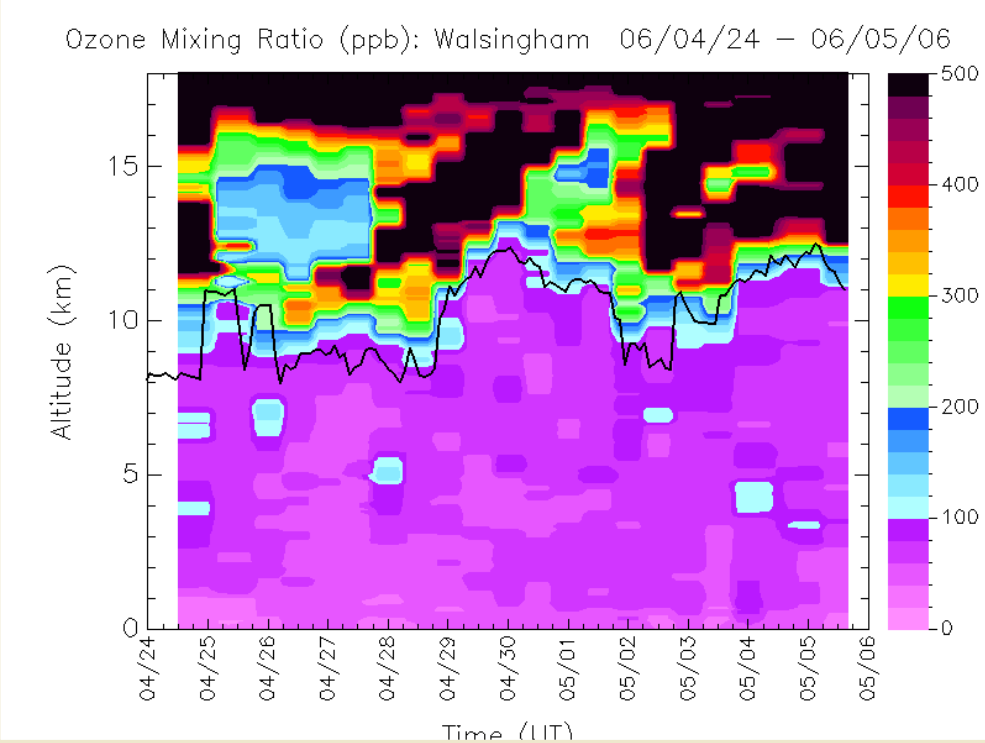


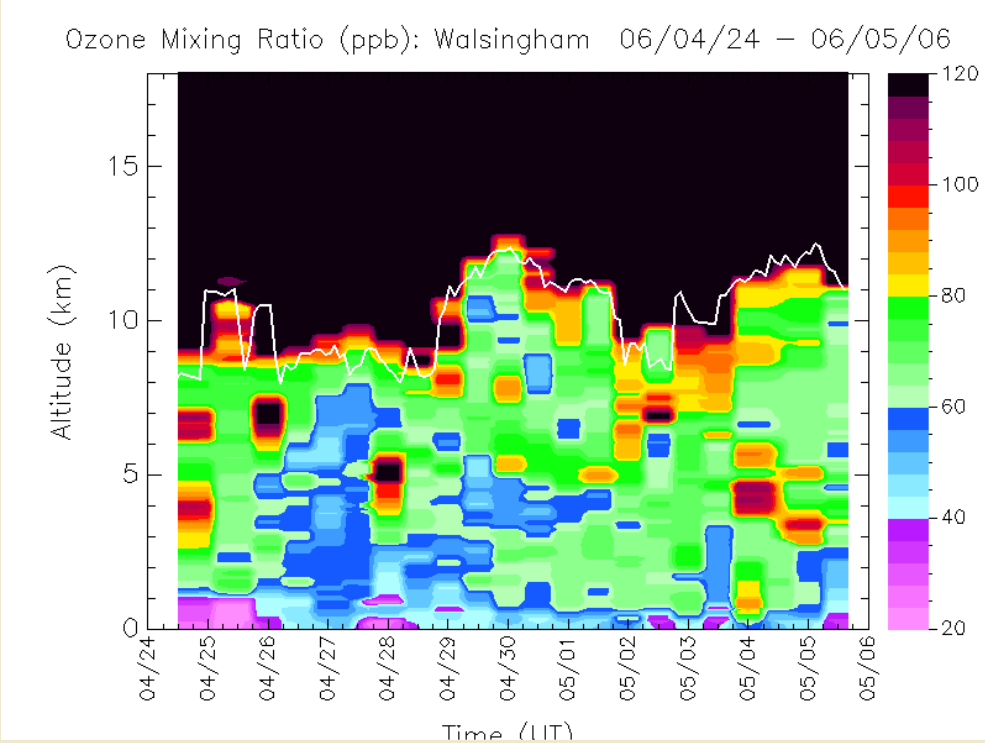






Walsingham -- April/May 2006





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