Measurement requirements for geostationary observations of pollutants with the NASA GSFC GeoChem instrument

William Brune, Randy Kawa, Scott Janz, James Gleason, and P.K. Bhartia and Jack Fishman, …

collaborative poster in Session 4 (this session):
Air Quality Science and Regulatory Efforts Require Geostationary Satellite Measurements
Kenneth E. Pickering, Dale J. Allen and Jeffrey W. Stehr

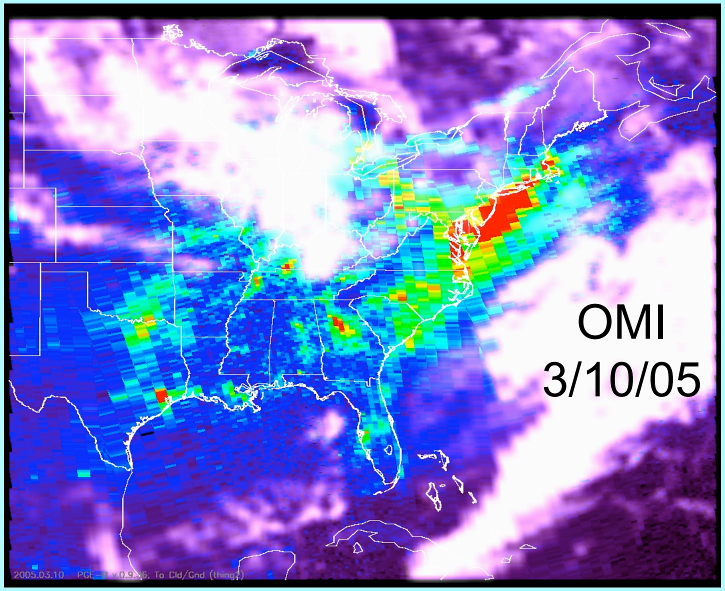
Science Questions From GeoTRACE proposal

What are the effects of local and regional pollution on the global atmosphere, and what are the effects of global pollution on regional air quality? [NASA 2000]

- What are the spatial and temporal emission patterns of the precursor chemicals for ozone and aerosols?
- What are the influences of weather in transforming and dispersing emissions, ozone, and aerosols into the global pollution?
- What is the evolution of ozone and aerosol, from chemical formation and transport to losses by chemistry and deposition?
- What are the regional budgets for carbon monoxide, ozone, and aerosols over North America?

Focus:

urban/regional air quality

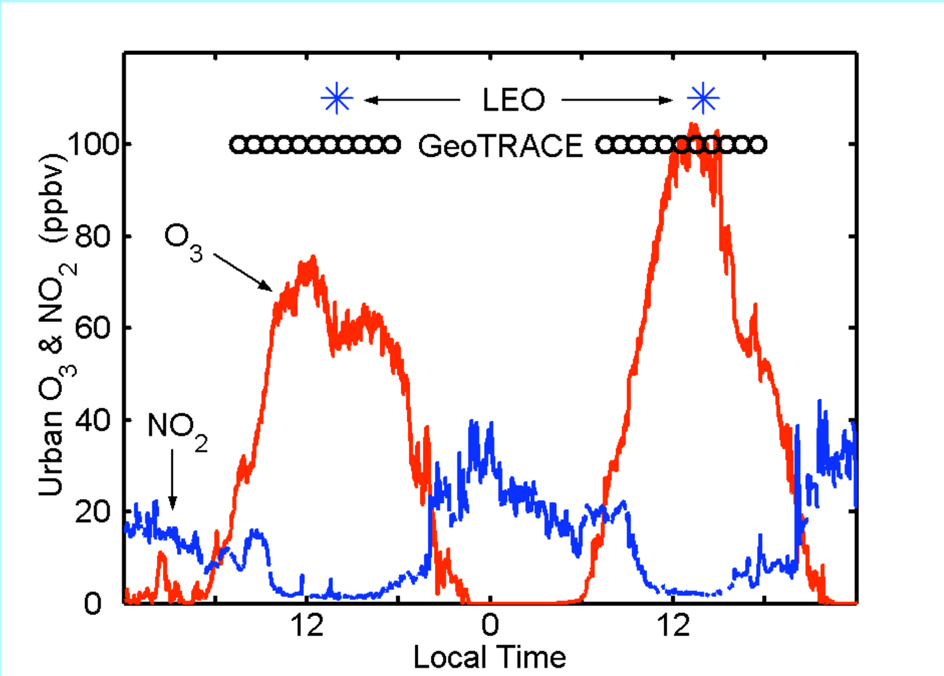


Science Measurement Requirements

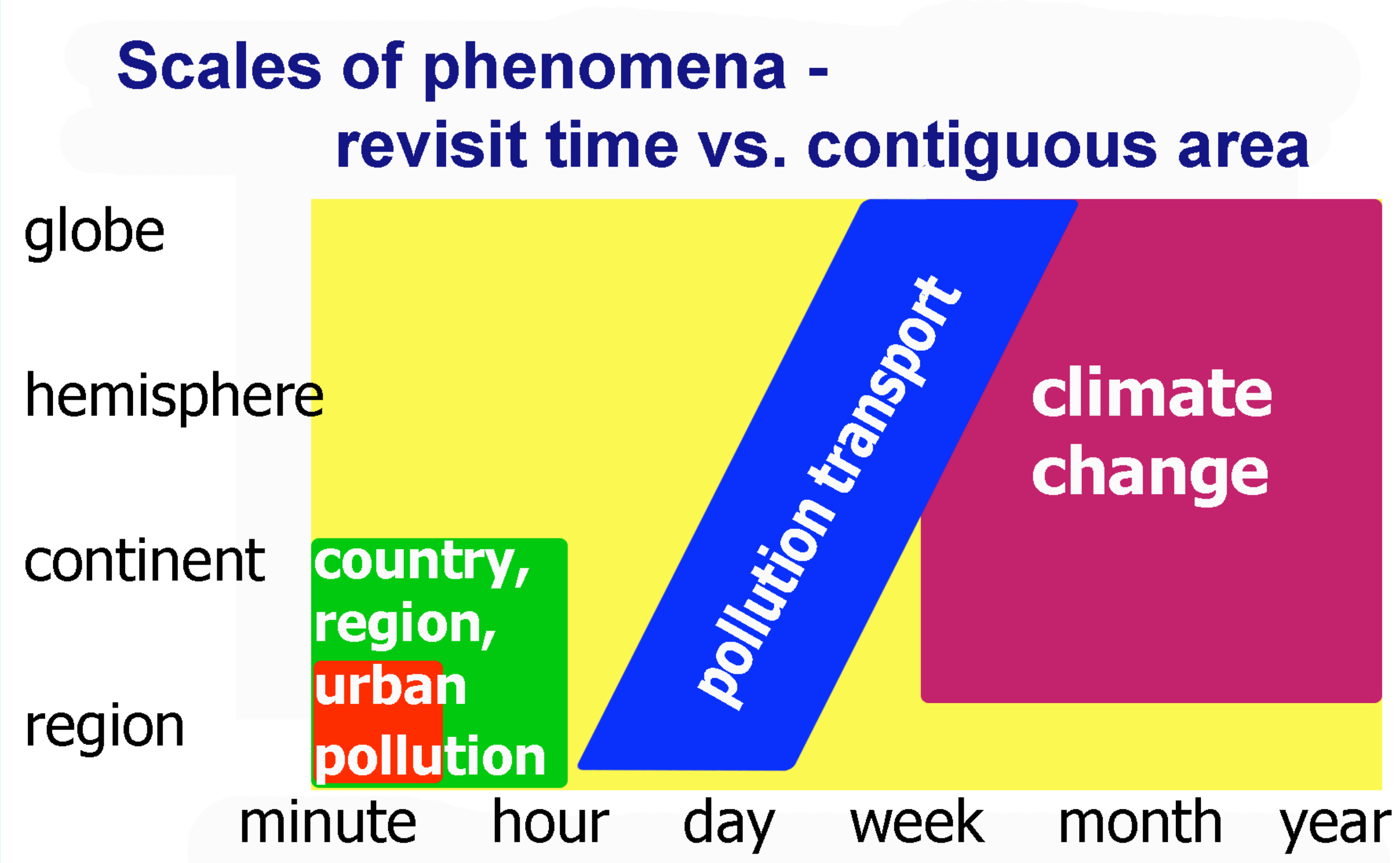
→ **Need to resolve small scale emission features, nonlinear photochemical transformations, and interaction with rapidly changing diurnal meteorology.**

- Measure main gaseous & particle pollutants of lower troposphere.
- Address key uncertainties in understanding & forecasting pollution:
  - interactions of emissions, chemistry, & deposition with planetary boundary growth & decay
  - human & natural emissions
  - air chemistry & surface deposition
  - interactions of pollutant transport & weather systems.

Requirements: ⇒ continuous measurements with high temporal & horizontal spatial resolution for continental regions with pollution.



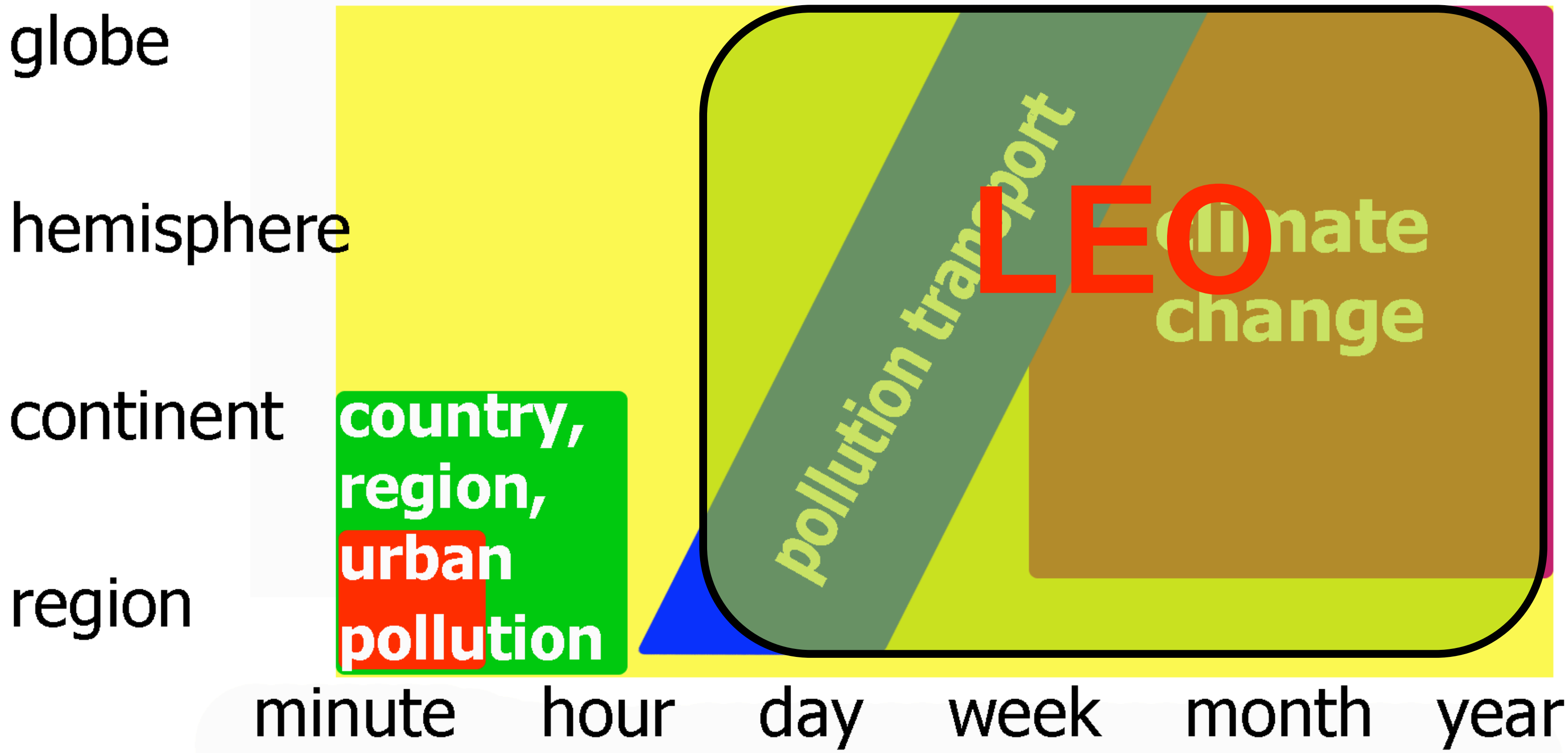
Needs for air quality measurements



* all at high horizontal resolution, higher resolution for smaller scales

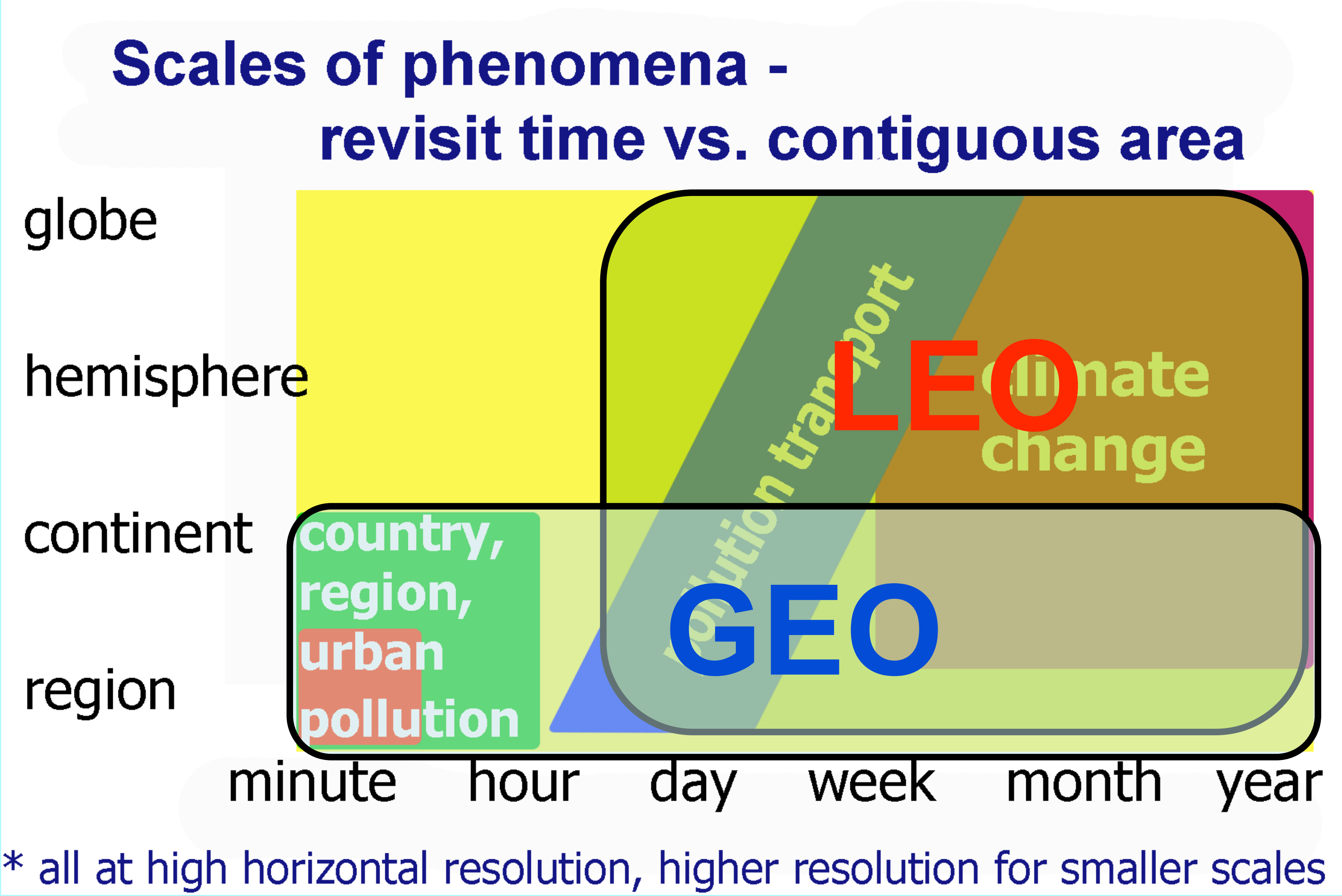
Needs for air quality measurements

Scales of phenomena - revisit time vs. contiguous area



* all at high horizontal resolution, higher resolution for smaller scales

Needs for air quality measurements



Measurement Concept

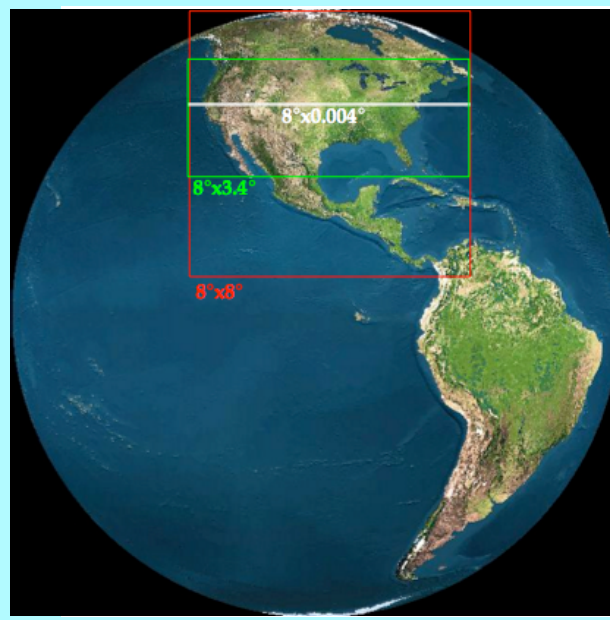
→ **Measure key tropospheric pollutant species at high temporal and spatial resolution over the US from geosynchronous orbit. Two instruments are needed.**

- Measured species (tropospheric column, with low resolution) :

- O_3, NO_2, H_2CO, SO_2, $C_2H_2O_2$, & aerosol by UV/visible spectrometer

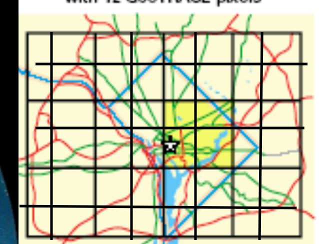
- CO by near-infrared spectrometer or gas correlation radiometer

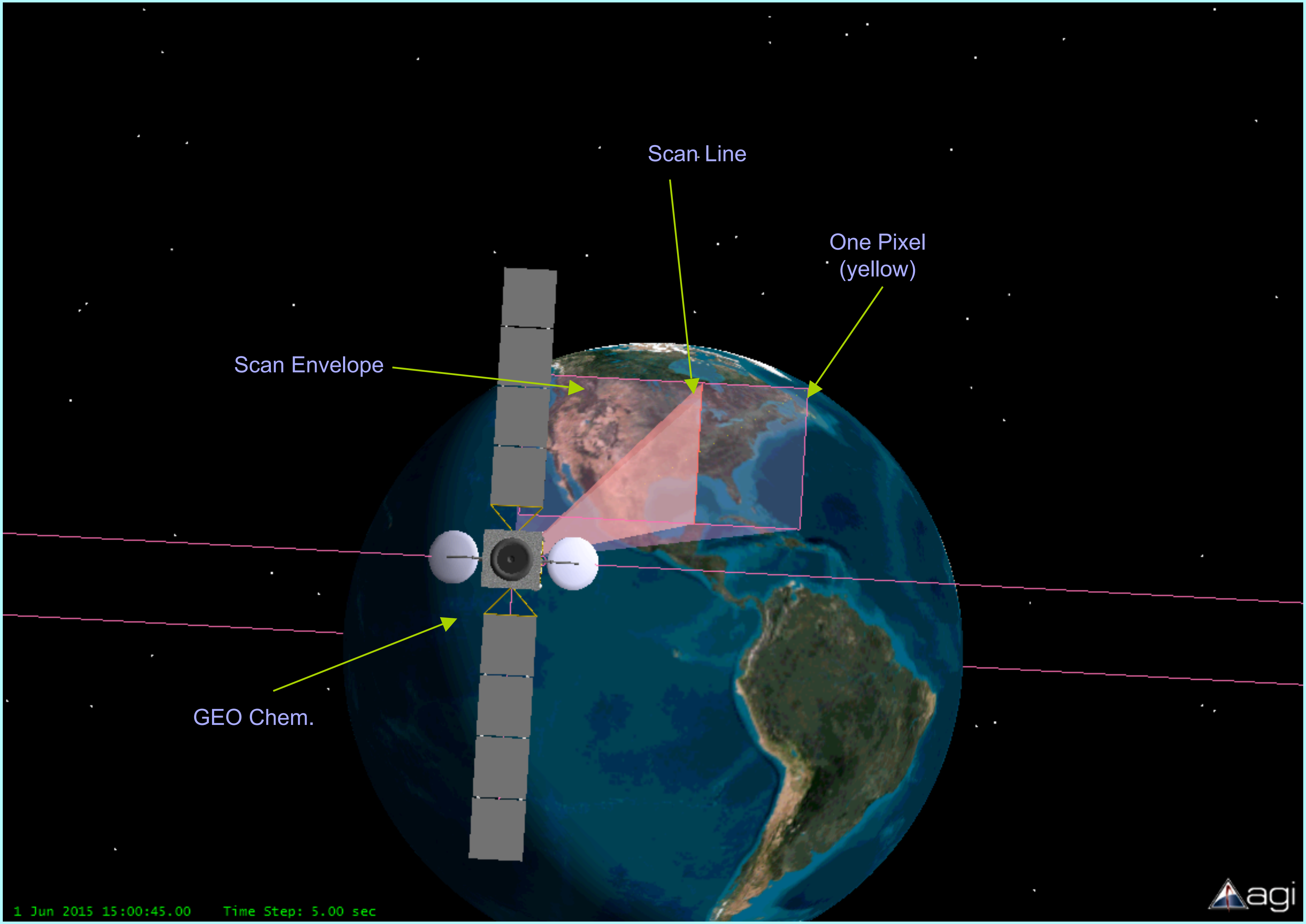
- Horizontal sampling: 2.5-km resolution; 5000x2500 km field of regard
- Temporal sampling: hourly during daylight
- Measurements go to the ground
- Technologies are mature now.
- Use with GOES & surface weather data
- See between the clouds (or wait for them to pass)

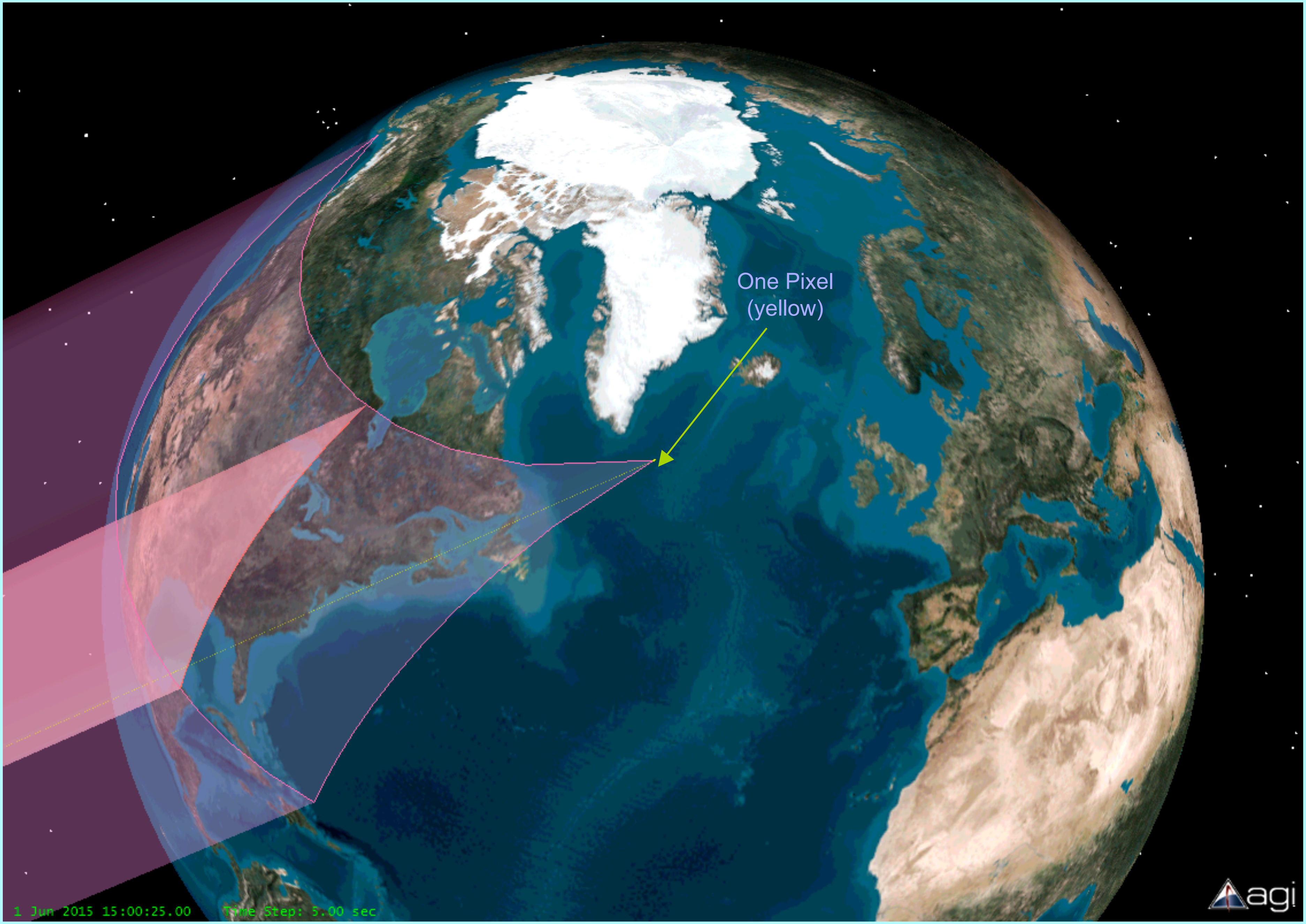


48

Washington, DC is imaged with 12 GeoTRACE pixels




Scan Line
One Pixel
(yellow)
Scan Envelope
GEO Chem.
1 Jun 2015 15:00:45.00
Time Step: 5.00 sec
agi

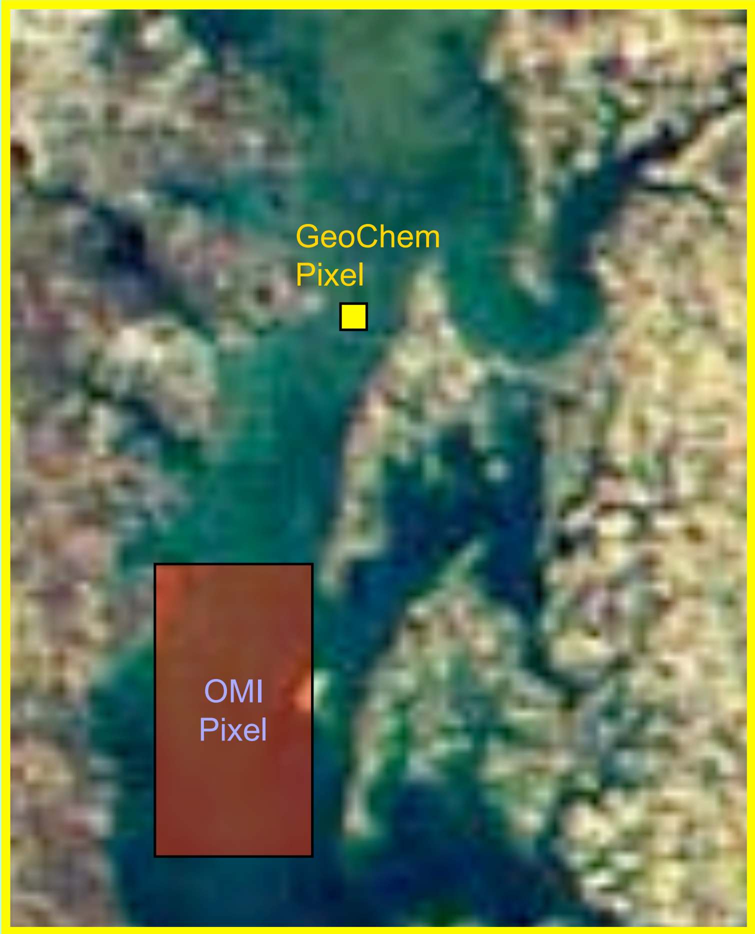

One Pixel
(yellow)
1 Jun 2015 15:00:25.00
Time Step: 5.00 sec

Spatial Resolution (GeoChem and OMI)

MODIS True-Color Image

- GeoChem Pixel 2.5 km x 2.5 km
- OMI Pixel (on orbit now) = 13 km x 24 km

http://earth.rice.edu/mtpe/geo/geosphere/hot/MODIS/Chesapeake_MODIS.html



GeoChem and Ozone Monitoring Instrument pixels at Chesapeake Bay near Annapolis. GeoChem pixel near Bay Bridge.

Spectrometer Performance Specifications

***Target Capabilities*. Channel 1 and 2 products measured with time resolution ≤ 500 ms/image line. Channel 3 unlikely to be included**								
Channel 1 UV/VIS 310-500 nm @1 nm*			Channel 2 VIS/NIR 480-900 nm @2.0 nm*			Channel 3 SWIR 2200-2400 nm @0.2 nm*		
Product	SNR	Res. [km]	Product	SNR	Res. [km]	Product	SNR	Res. [km]
Column O_3	200	2.5	O_3 boundary	1000	3.75	CO	1500	16
Column SO_2	500	2.5	NO_2 boundary	2000	7.5	CH_4	200	2.25
Column CH_2O	500	2.5				N_2O	800	9
Column NO_2	2000	7.5						
			Aerosols	200	0.75			
Aerosols	200	2.5						
*Spectral sampling grid will be ≤ 1/3 of a resolution element								

Requirements and Design Parameters

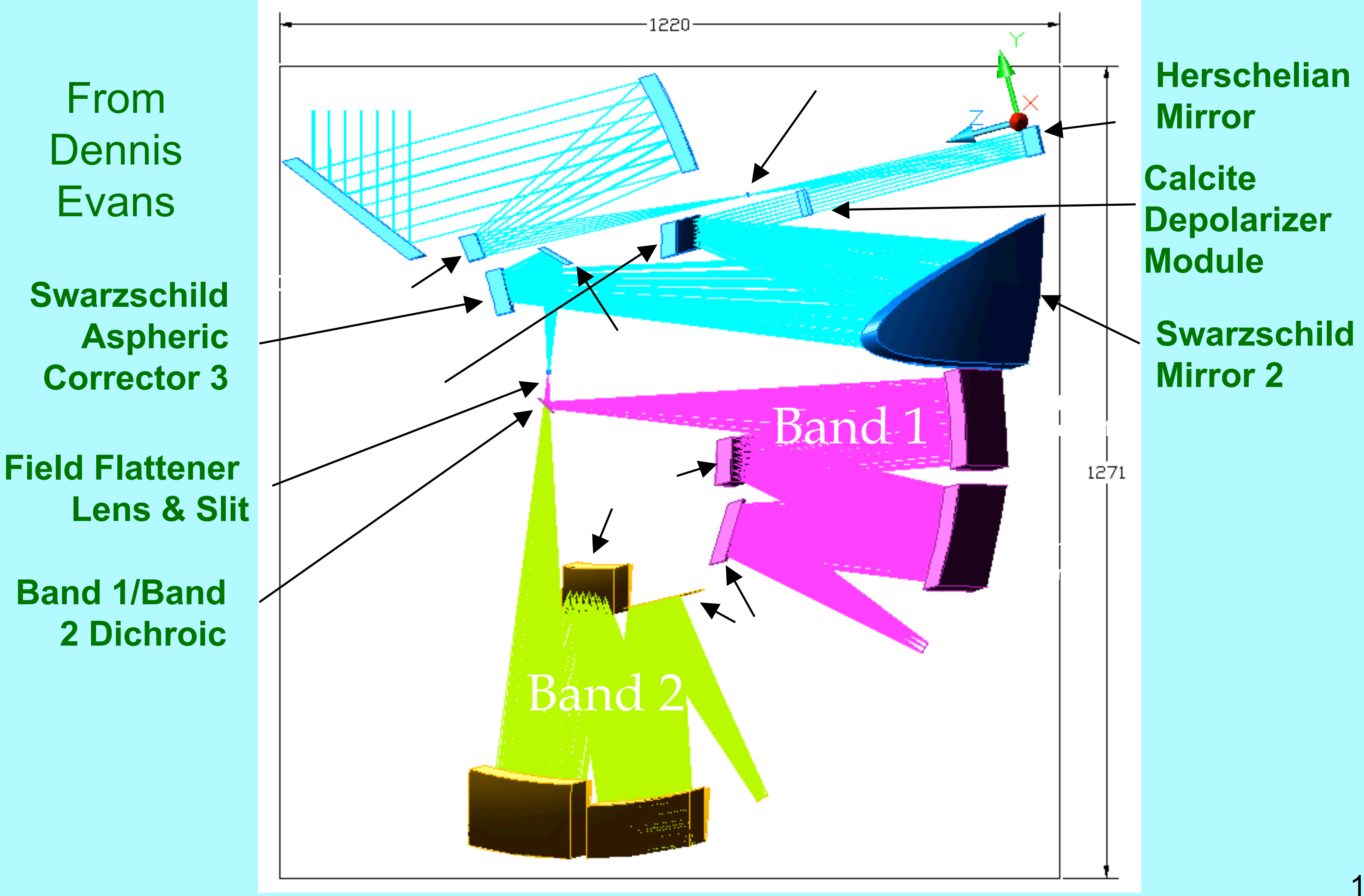
- **Geosynchronous Orbit for CONUS (35,786 km above the equator)**
- **Scan**
  - **Field of regard = 5000 km by 2500 km**
  - **Complete east to west & fly back for CONUS scan in 1 hour**
- **Telescope**
  - **One telescope feeds all spectrographs**
  - **Anamorphic ratio = 4 to 1 (spatial versus spectral)**
  - **IFOV 4 degrees by 0.004 degrees**
  - **Horizontal sampling = 2.5 km**
  - **IFOV is 2525 km by 2.5 km at nadir**
- **Two Channels**
  - **UV / Vis and Vis /NIR Spectrographs**
  - **Each spectrograph has its own slit**
- **One detector array for each channel**
  - **Frame transfer silicon CCD array with 1K x 1K pixels**
  - **Pixel pitch = 18 microns**
- **Dichroic beamsplitter to spit the beam between spectrographs**

Requirements & Design Parameters (cont.)

- **Time and Step resolution**
  - **5000 km / 2.5 km per scan line = 2000 scan lines (images) per scan**
  - **Integration time plus time to move scan mirror and settle on next line = 3600 sec / 2000 lines = 1.8 seconds per scan line**
  - **Move mirror to next line and settle = driven by mechanism design = 0.5 second. This number may be able to be reduced.**
  - **Integration time baselined at one second for this study. If move to next line and settle is 0.5 seconds, then integration time could increase to 1.8 – 0.5 = 1.3 seconds.**
  - **Two-axis scan**
  - **Step resolution (east/west) to meet 2.5 km spatial resolution**
  - **Required step resolution (north/south) much less (could be of order of 1 degree)**

UV/Vis AutoCAD Assembly Baseline
GeoChem - ISAL Baseline - October 2005

From Dennis Evans



GeoChem characteristics for 5 km resolution

GeoChem Performance Requirements and Characteristics		
Overall Requirements		
GOES station	East	
Pointing	< 1 arcsec/s	
Expected mission life	3 years	
UV/Vis instrument		
Size	0.8 x 0.5 m (d x h cylinder)	scaled from GSFC ISAL design of 11/2005
Mass	50 kg	
Power	100 W	
Data rate	4 Mb/s	
SWIR/IR instrument		
Size	0.5 x 0.5 x 0.5	Estimated from SWIR/IR instrument in 2001 ESSP proposal (GeoTRACE)
Mass	40 kg	
Power	200 W	
Data rate	10 Mb/s	

(A possible better approach is to reduce the field of regard to <1000 km and the resolution to < 1 km and target. Would be useful for Ocean and Ecology communities.)

Emerging Conclusions for Discussion

- LEO is better than 1 GEO for long-range pollution transport, global coverage, & climate change.
- GEO is better than LEO for urban to regional pollution (hour timescales & regional horizontal scales).
- Good vertical resolution is needed for long-range pollution transport but not for urban to regional pollution (PBL / FT will do).
- Good horizontal resolution (< 1 km?) is essential for both GEO and LEO.
- Must see to the ground for urban / regional air quality.

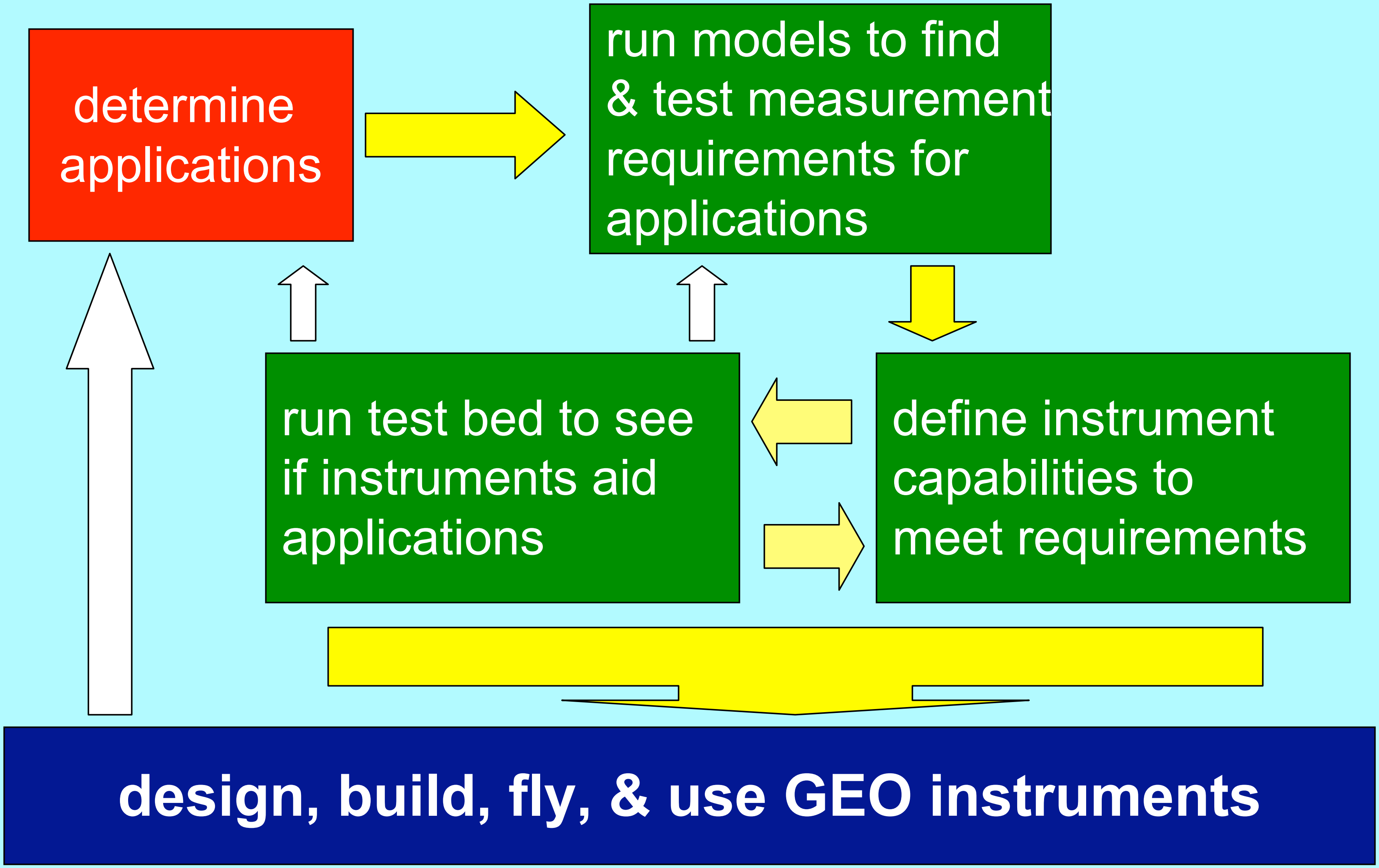
GEO & LEO are complementary; both are needed, just as they are for weather.

- We have LEO with untapped potential; we need GEO.

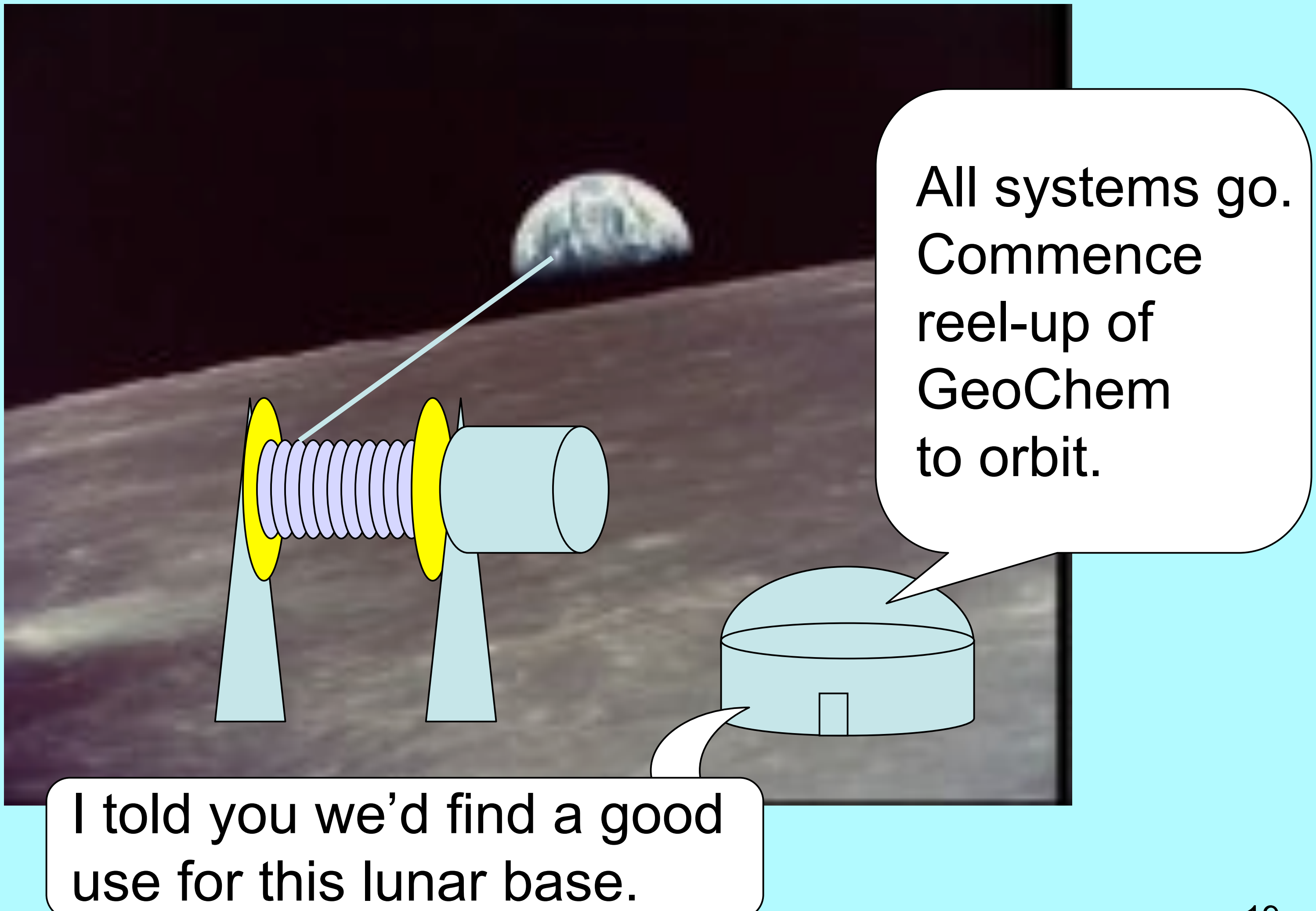
A process to define optimum GEO instruments

- **Determine current and future applications**
  - chemical forecasting for regulatory purposes
  - chemical transport model improvement
  - dispersion monitoring for health warnings
  - applications other areas (oceans-productivity, ecology-growth, etc.)
- **Run models to find and test measurement needs for applications**
  - sub-hour temporal resolution
  - horizontal spatial resolution of order of future models (< 1km)
  - good spectral resolution from UV to Visible to near IR
  - some horizontal resolution by some means (PBL, residual layer, higher FT)
  - quantitative down to the surface
- **Define instrument capabilities to meet measurement needs**
  - done initially in individual groups, then jointly
- **Run test bed to see if instruments aid applications**
  - define case studies for everyone to use
  - designate people to run the test bed
- **Iterate**

A process to define optimum GEO instruments



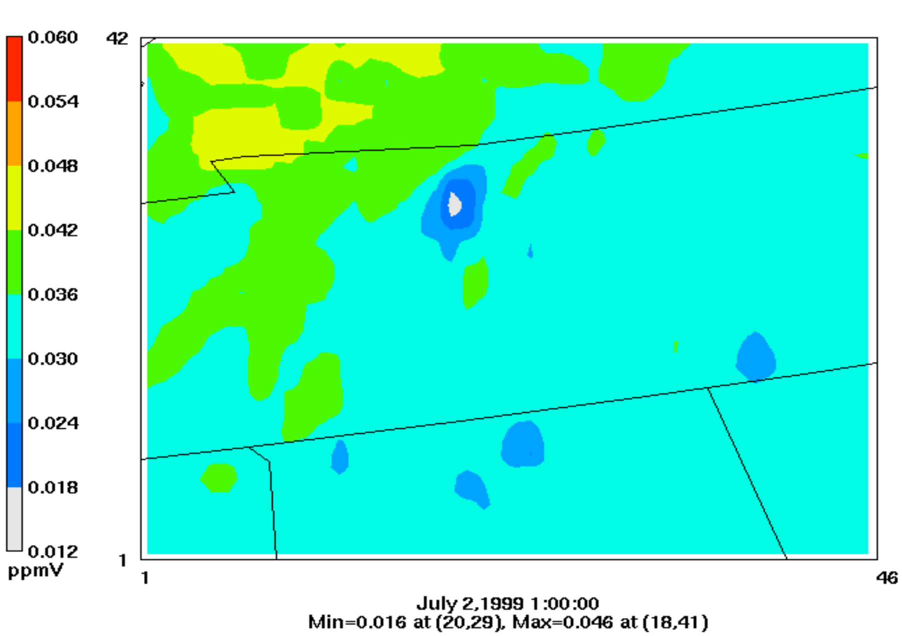
Getting GeoChem to orbit – a new approach



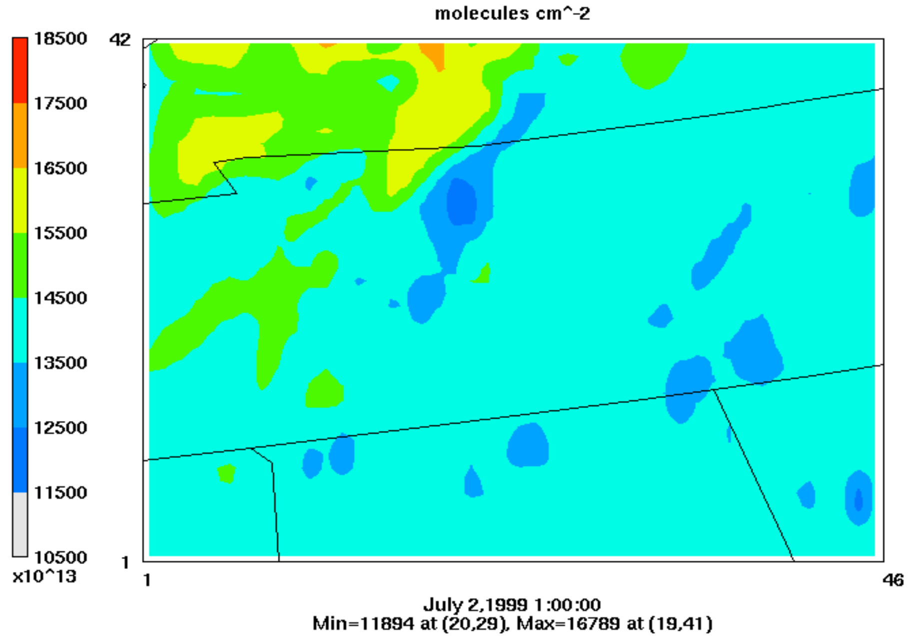
Diurnal O_3 movie

1 second delay

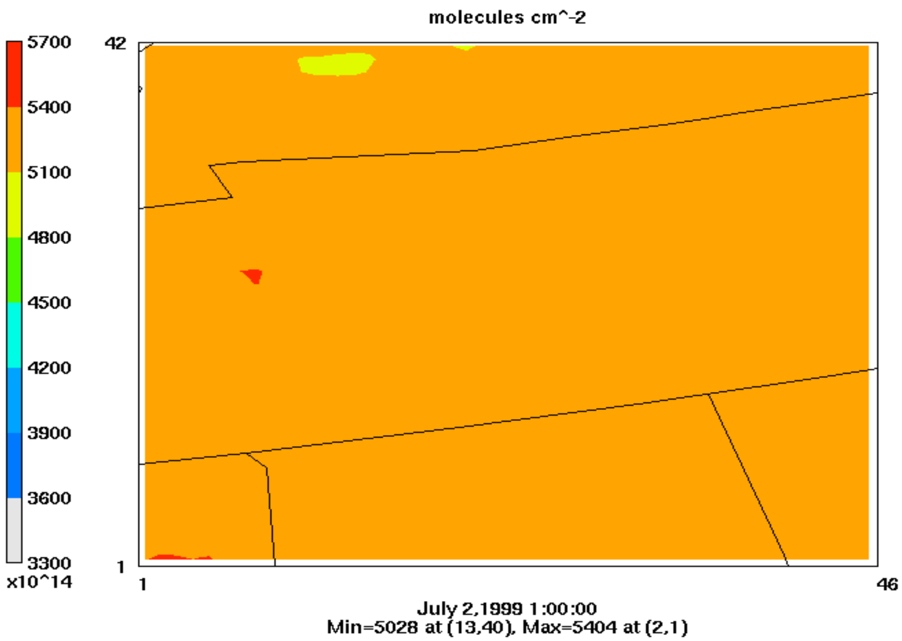
Hourly Surface Ozone Concentrations (ppmv)



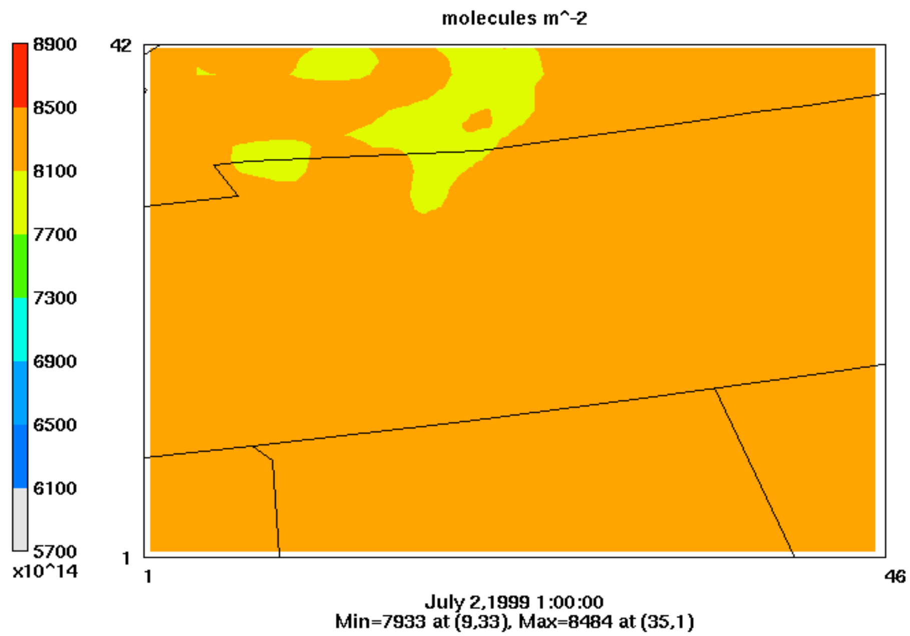
Ozone column abundance in PBL (0.0 - 1.5 km)

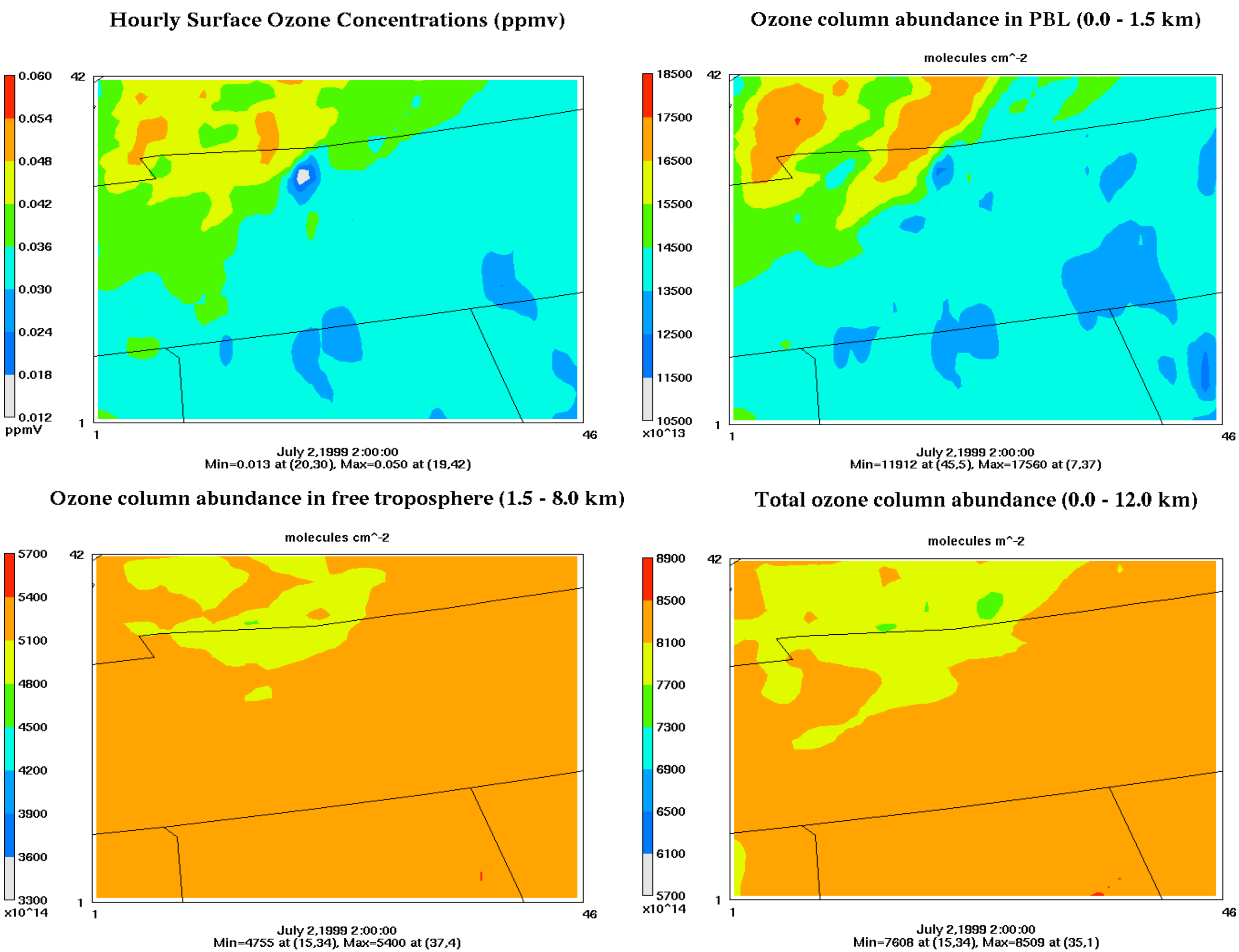


Ozone column abundance in free troposphere (1.5 - 8.0 km)

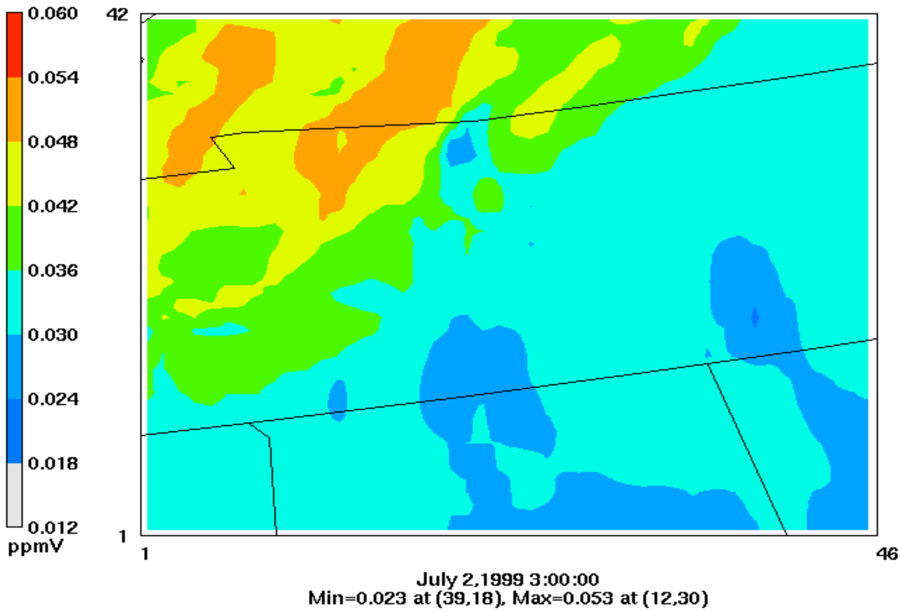


Total ozone column abundance (0.0 - 12.0 km)

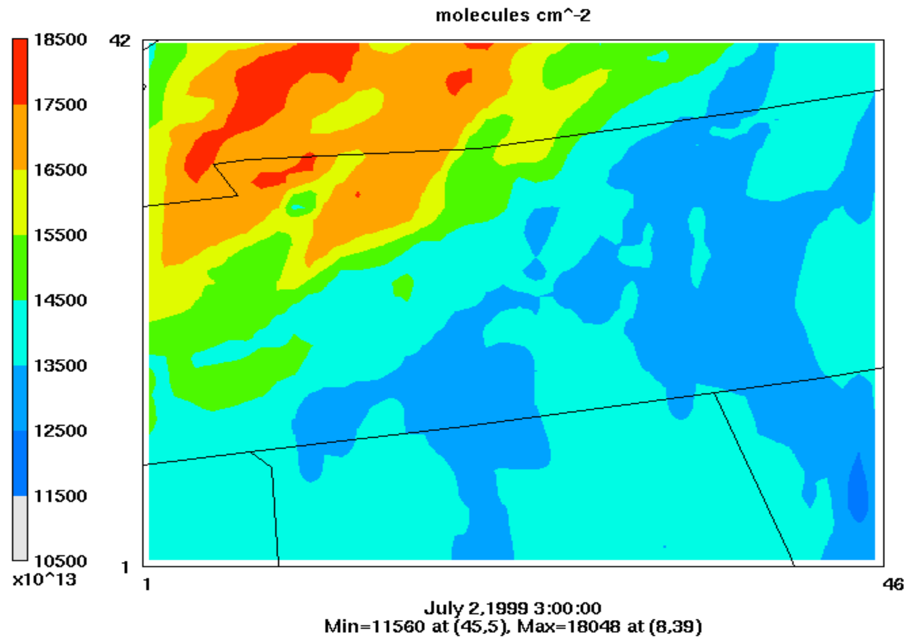



Hourly Surface Ozone Concentrations (ppmv)
0.060
0.054
0.048
0.042
0.036
0.030
0.024
0.018
0.012
ppmV
42
1
1
46
July 2,1999 2:00:00
Min=0.013 at (20,30), Max=0.050 at (19,42)
Ozone column abundance in PBL (0.0 - 1.5 km)
molecules cm^-2
18500
17500
16500
15500
14500
13500
12500
11500
10500
x10^13
42
1
1
46
July 2,1999 2:00:00
Min=11912 at (45,5), Max=17560 at (7,37)
Ozone column abundance in free troposphere (1.5 - 8.0 km)
molecules cm^-2
5700
5400
5100
4800
4500
4200
3900
3600
3300
x10^14
42
1
1
46
July 2,1999 2:00:00
Min=4755 at (15,34), Max=5400 at (37,4)
Total ozone column abundance (0.0 - 12.0 km)
molecules m^-2
8900
8500
8100
7700
7300
6900
6500
6100
5700
x10^14
42
1
1
46
July 2,1999 2:00:00
Min=7608 at (15,34), Max=8509 at (35,1)

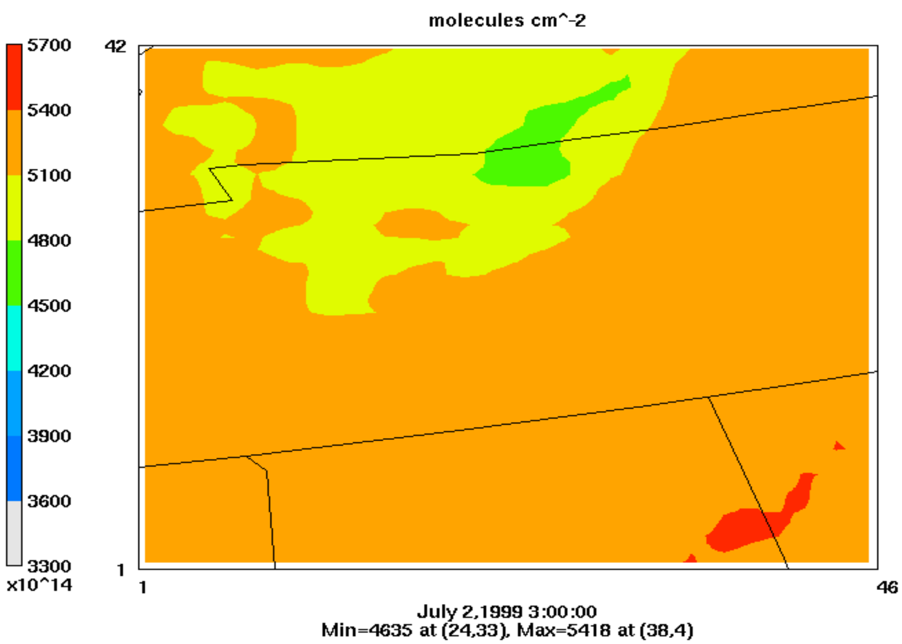
Hourly Surface Ozone Concentrations (ppmv)



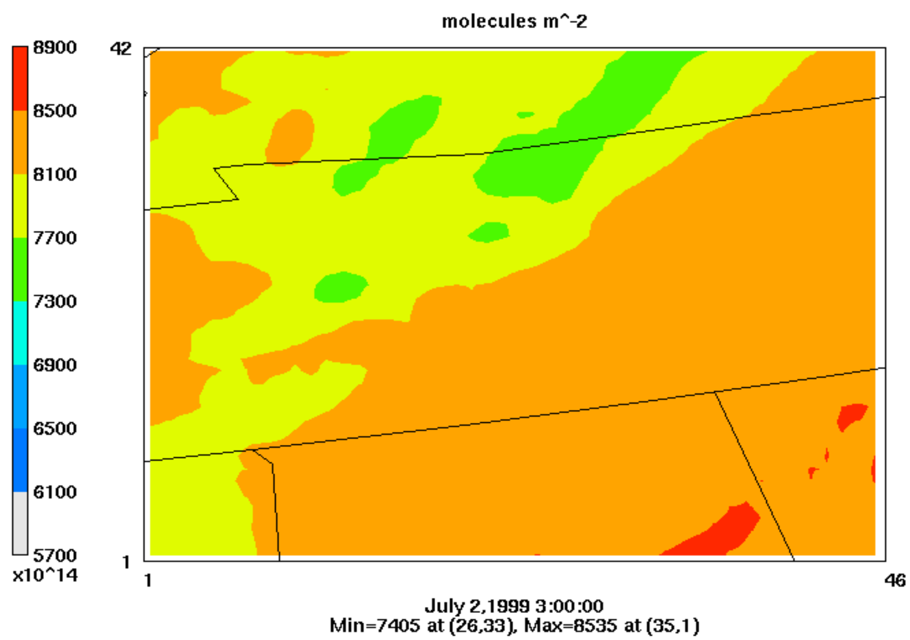
Ozone column abundance in PBL (0.0 - 1.5 km)



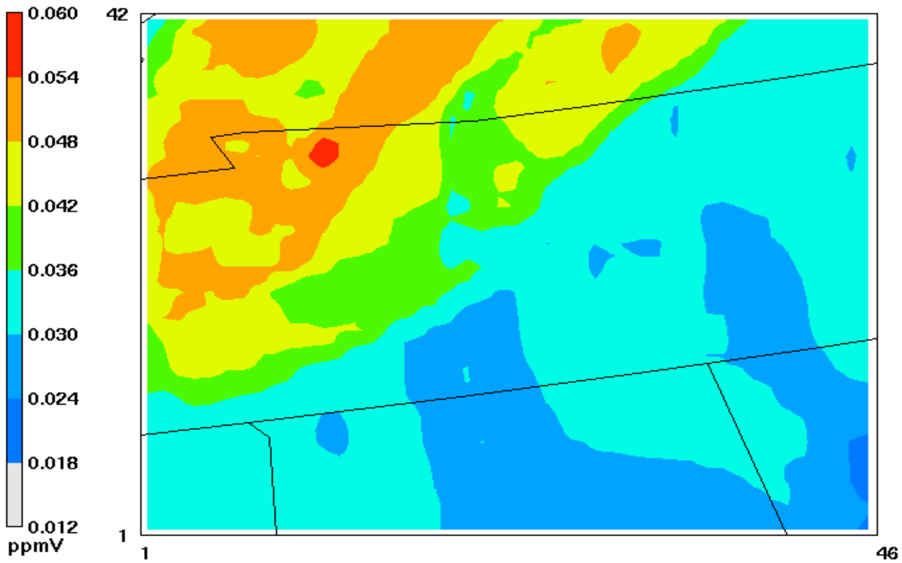
Ozone column abundance in free troposphere (1.5 - 8.0 km)



Total ozone column abundance (0.0 - 12.0 km)

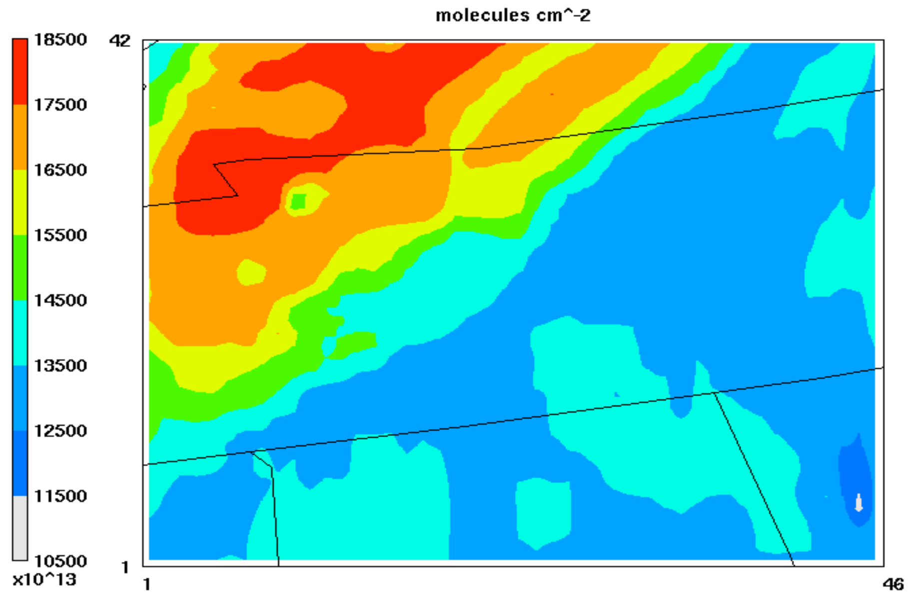


Hourly Surface Ozone Concentrations (ppmv)



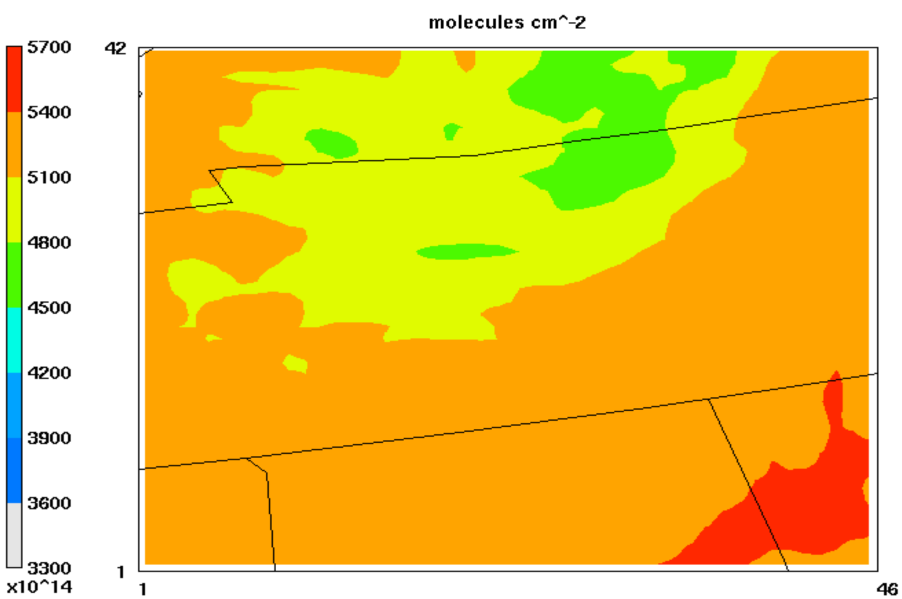
July 2,1999 4:00:00
Min=0.022 at (46,5), Max=0.059 at (12,31)

Ozone column abundance in PBL (0.0 - 1.5 km)



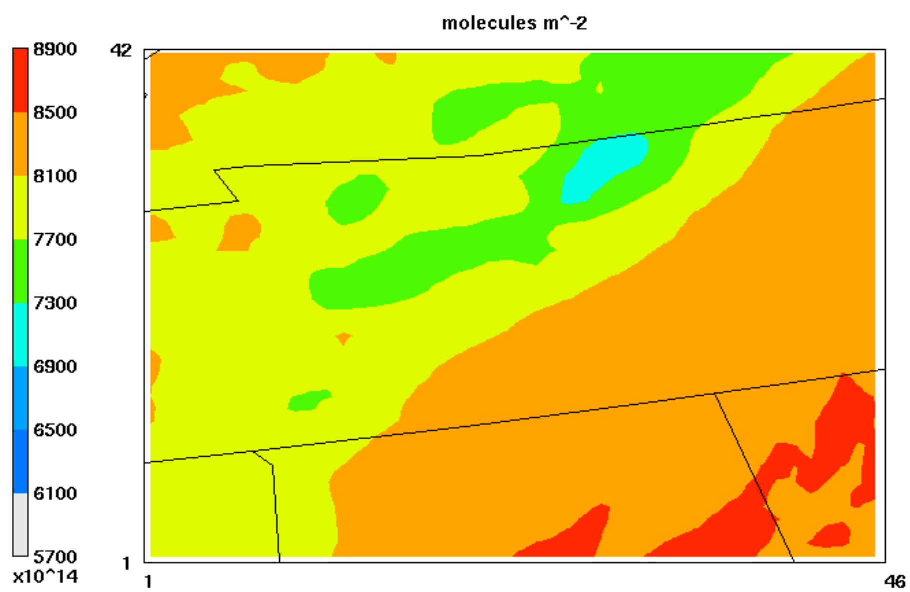
July 2,1999 4:00:00
Min=11207 at (45,5), Max=18514 at (17,40)

Ozone column abundance in free troposphere (1.5 - 8.0 km)

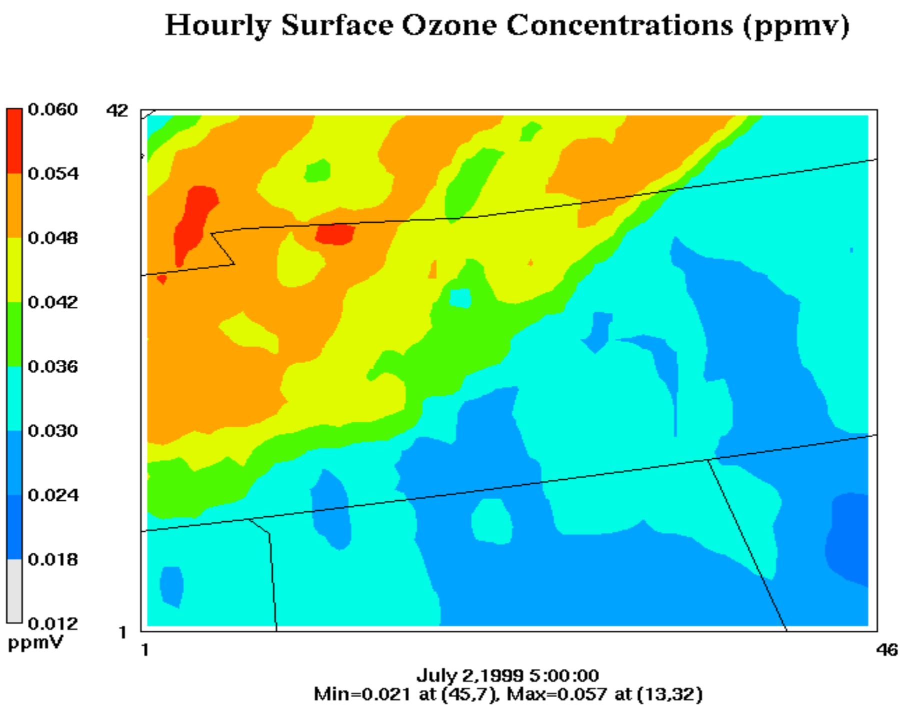


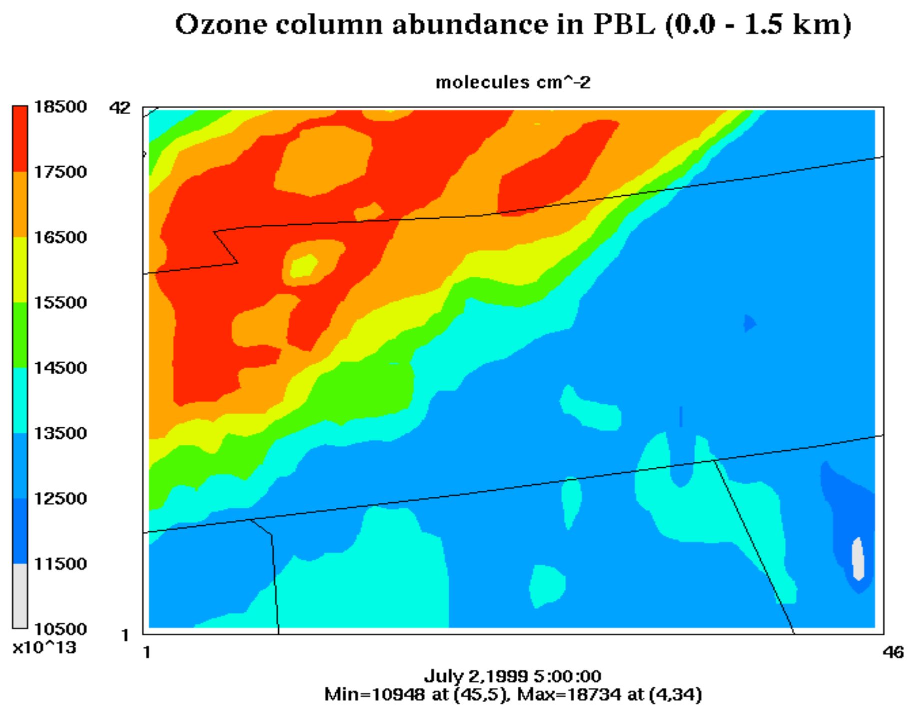
July 2,1999 4:00:00
Min=4524 at (29,33), Max=5439 at (37,3)

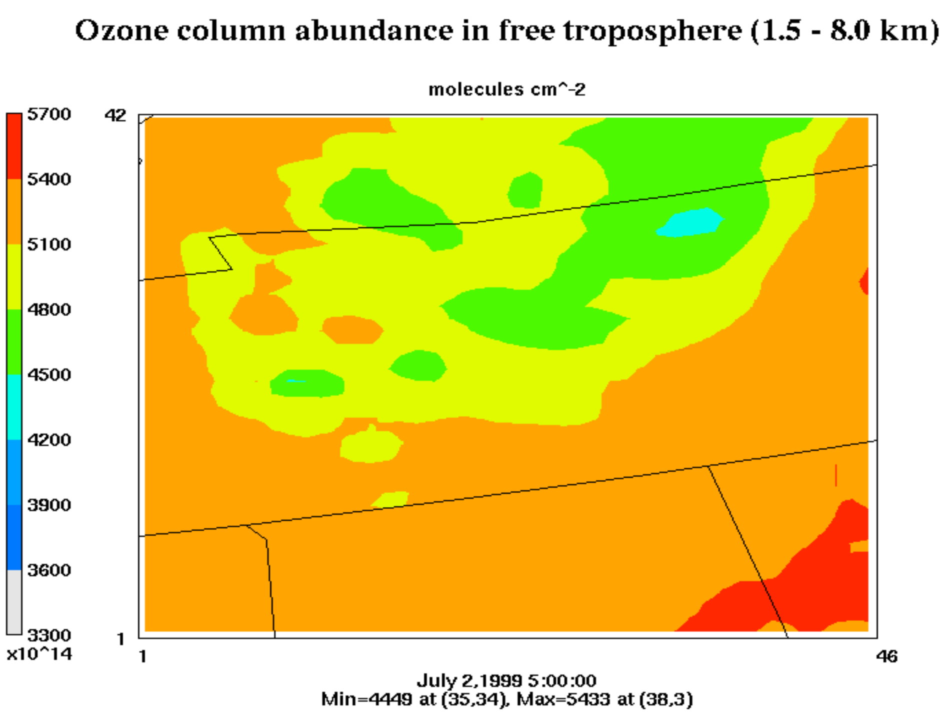
Total ozone column abundance (0.0 - 12.0 km)

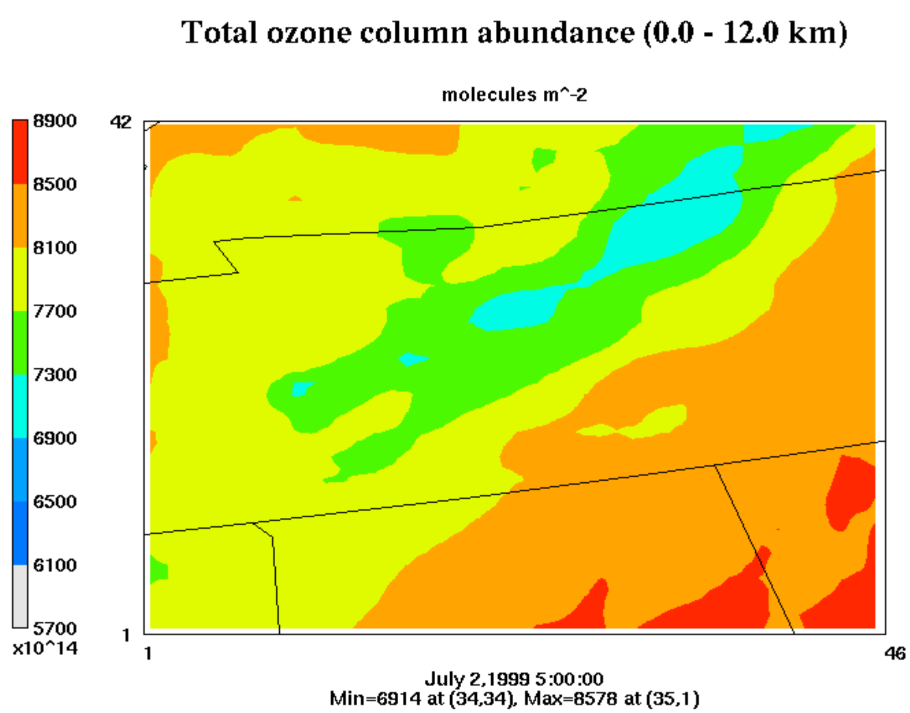


July 2,1999 4:00:00
Min=7116 at (29,33), Max=8559 at (35,1)

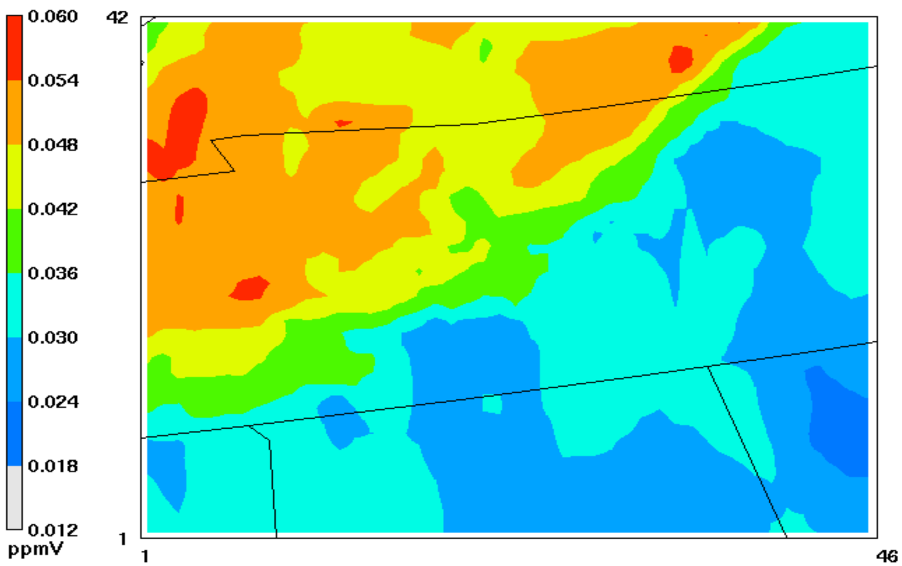

Hourly Surface Ozone Concentrations (ppmv)
0.060
0.054
0.048
0.042
0.036
0.030
0.024
0.018
0.012
ppmV
42
1
1
46
July 2,1999 5:00:00
Min=0.021 at (45,7), Max=0.057 at (13,32)


Ozone column abundance in PBL (0.0 - 1.5 km)
molecules cm^-2
18500
17500
16500
15500
14500
13500
12500
11500
10500
x10^13
42
1
1
46
July 2,1999 5:00:00
Min=10948 at (45,5), Max=18734 at (4,34)


Ozone column abundance in free troposphere (1.5 - 8.0 km)
molecules cm^-2
5700
5400
5100
4800
4500
4200
3900
3600
3300
x10^14
42
1
1
46
July 2,1999 5:00:00
Min=4449 at (35,34), Max=5433 at (38,3)

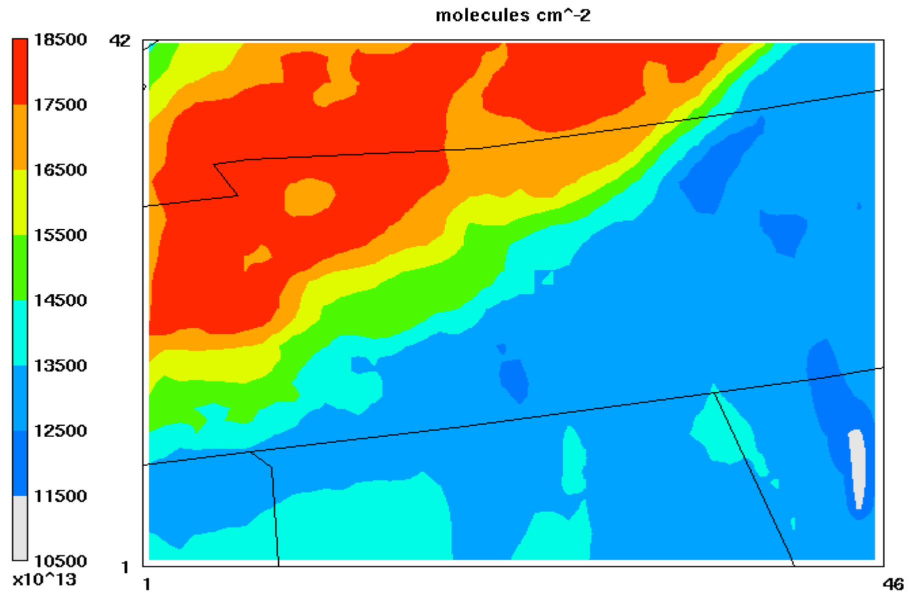

Total ozone column abundance (0.0 - 12.0 km)
molecules m^-2
8900
8500
8100
7700
7300
6900
6500
6100
5700
x10^14
42
1
1
46
July 2,1999 5:00:00
Min=6914 at (34,34), Max=8578 at (35,1)

Hourly Surface Ozone Concentrations (ppmv)



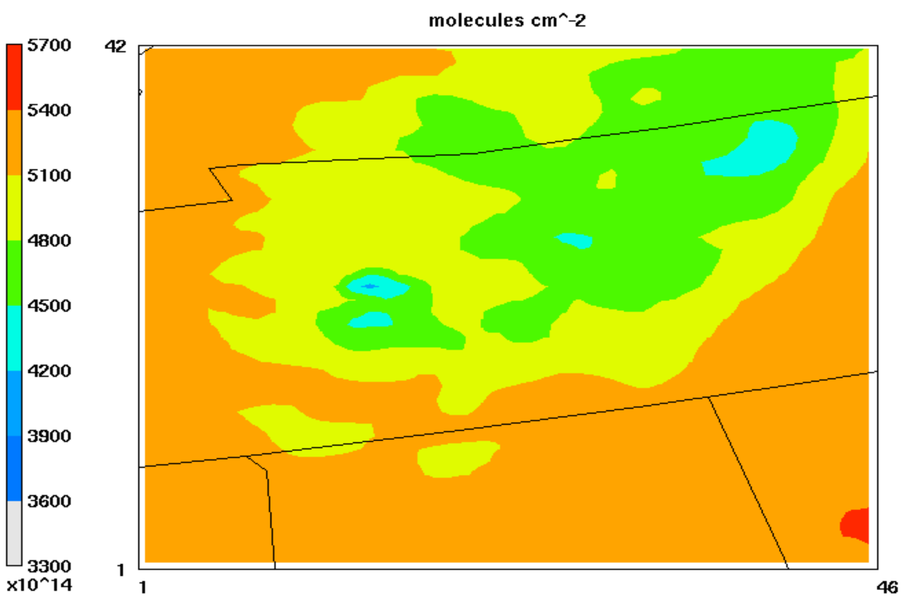
July 2,1999 6:00:00
Min=0.021 at (44,9), Max=0.058 at (4,35)

Ozone column abundance in PBL (0.0 - 1.5 km)



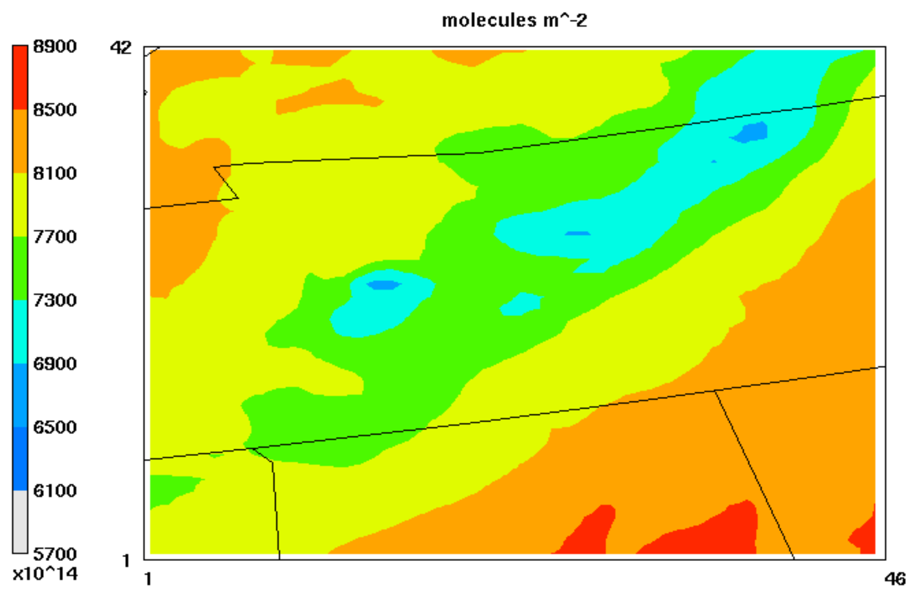
July 2,1999 6:00:00
Min=10819 at (45,9), Max=18780 at (4,35)

Ozone column abundance in free troposphere (1.5 - 8.0 km)



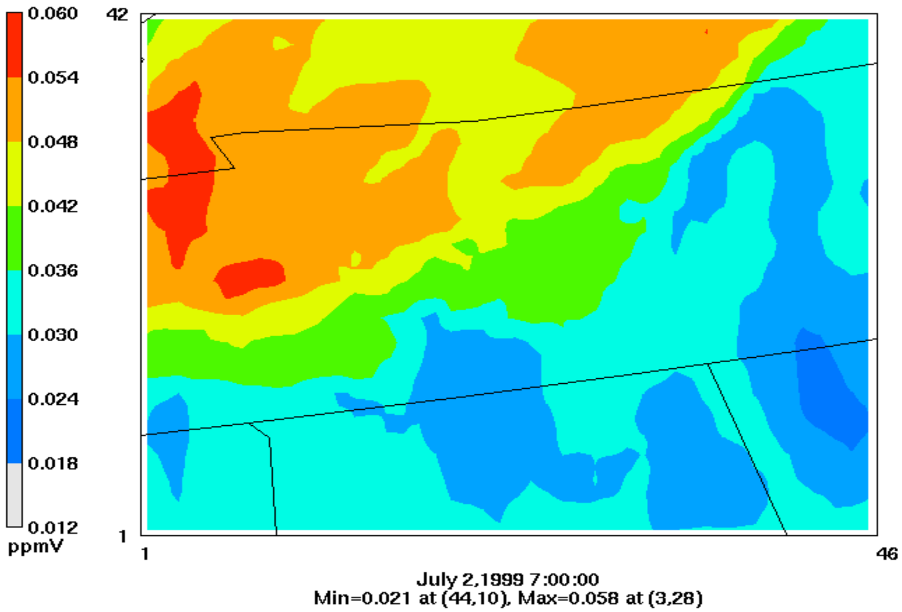
July 2,1999 6:00:00
Min=4123 at (15,23), Max=5420 at (46,4)

Total ozone column abundance (0.0 - 12.0 km)

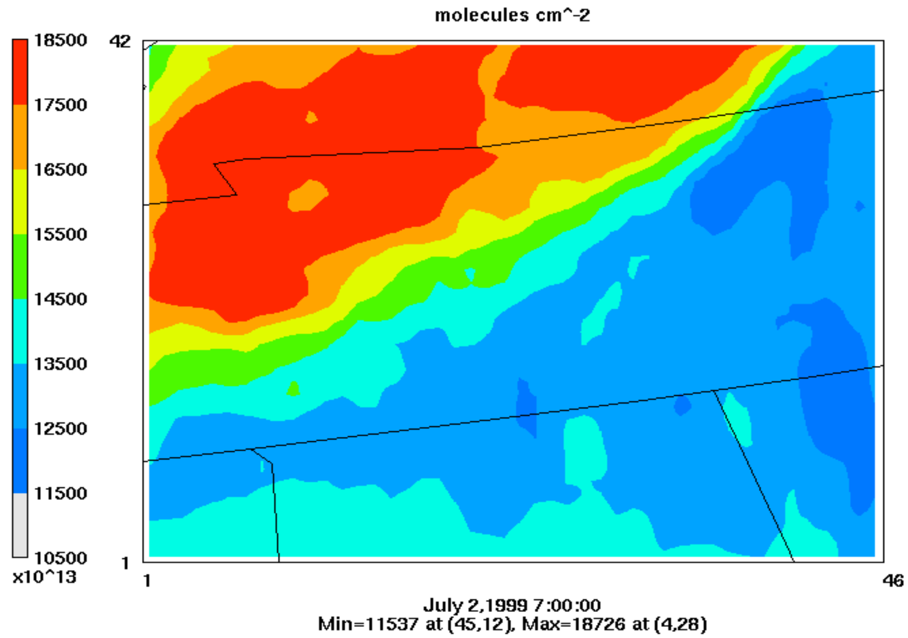


July 2,1999 6:00:00
Min=6762 at (15,23), Max=8596 at (35,1)

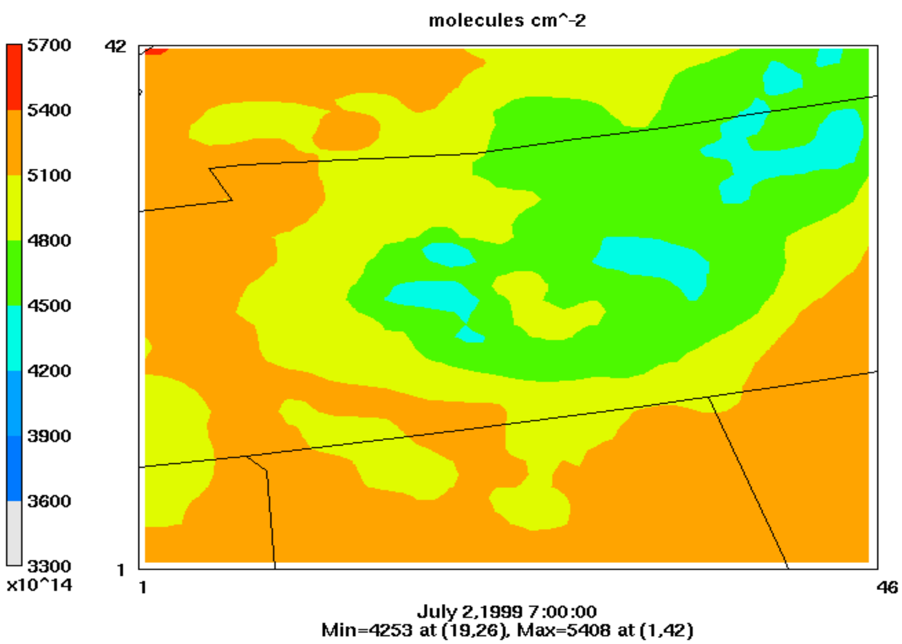
Hourly Surface Ozone Concentrations (ppmv)



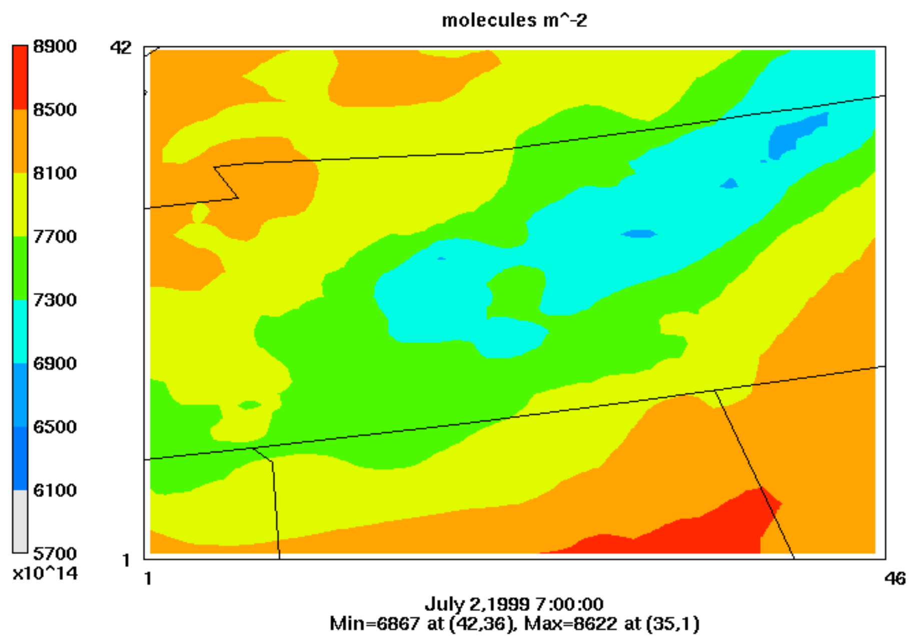
Ozone column abundance in PBL (0.0 - 1.5 km)



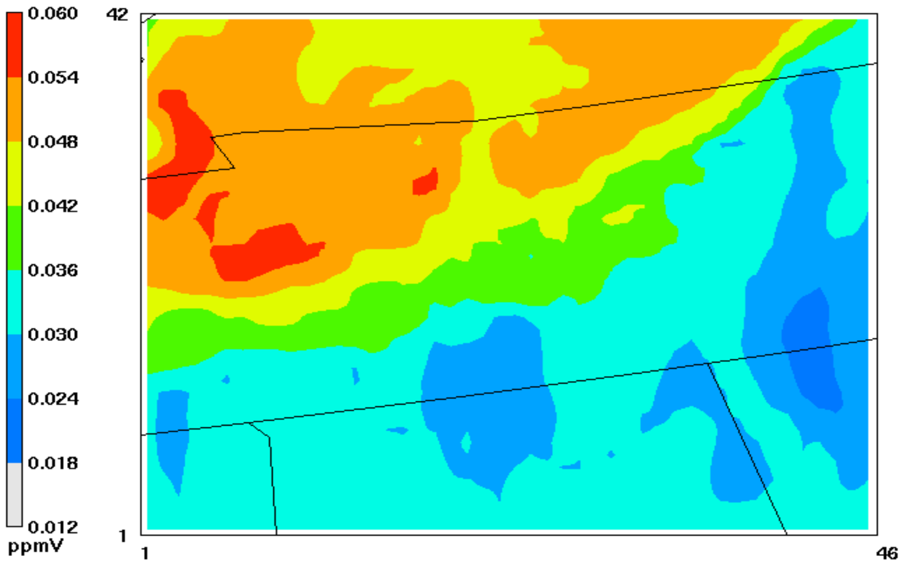
Ozone column abundance in free troposphere (1.5 - 8.0 km)



Total ozone column abundance (0.0 - 12.0 km)

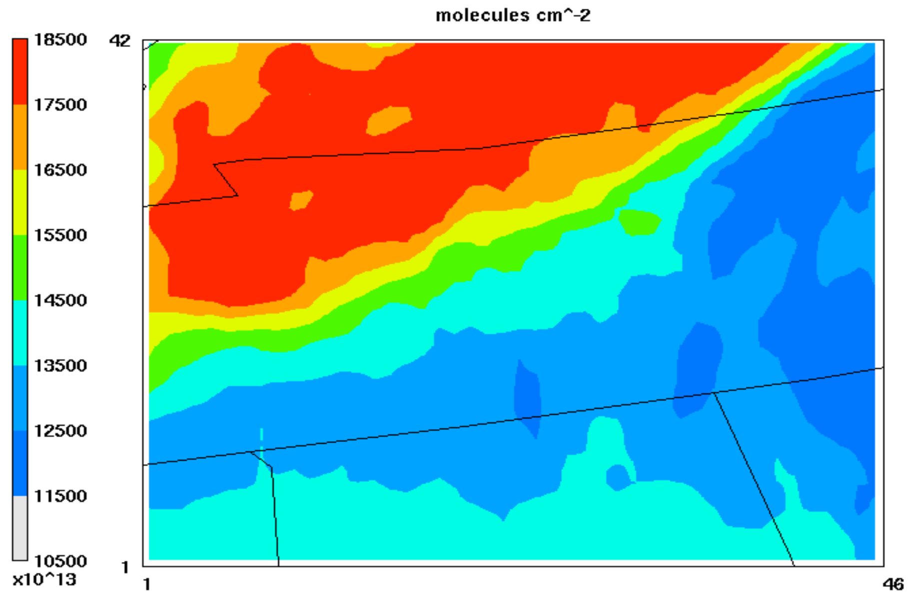


Hourly Surface Ozone Concentrations (ppmv)



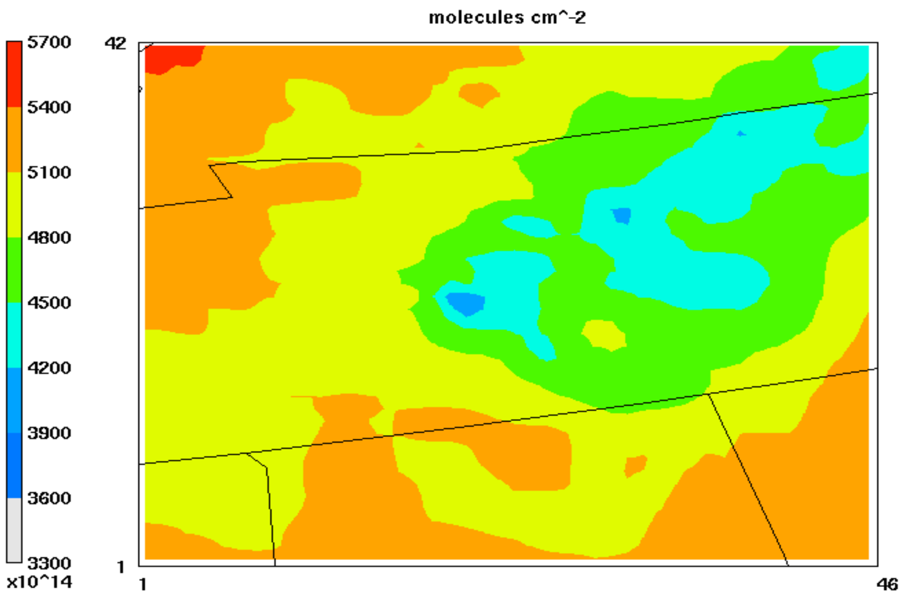
July 2,1999 8:00:00
Min=0.021 at (43,13), Max=0.058 at (4,32)

Ozone column abundance in PBL (0.0 - 1.5 km)



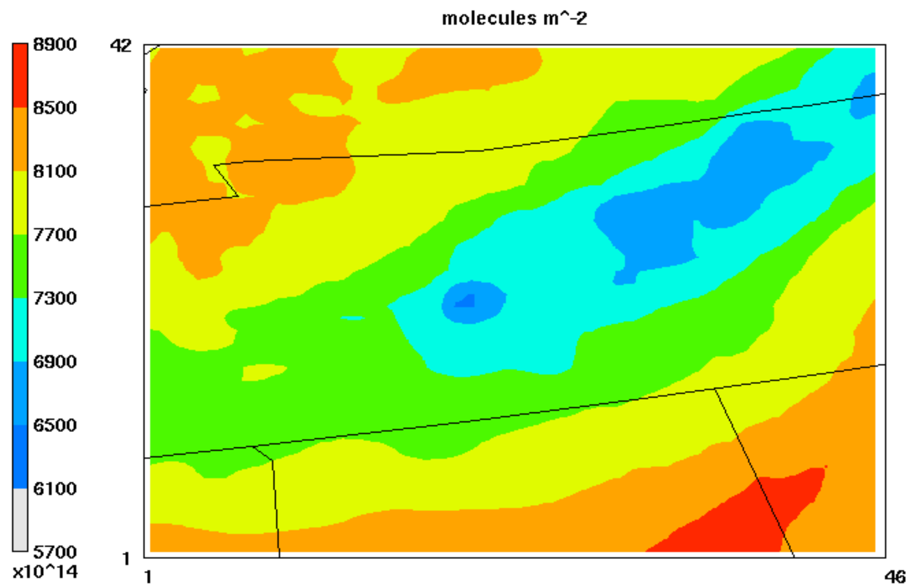
July 2,1999 8:00:00
Min=11816 at (43,33), Max=18721 at (7,23)

Ozone column abundance in free troposphere (1.5 - 8.0 km)



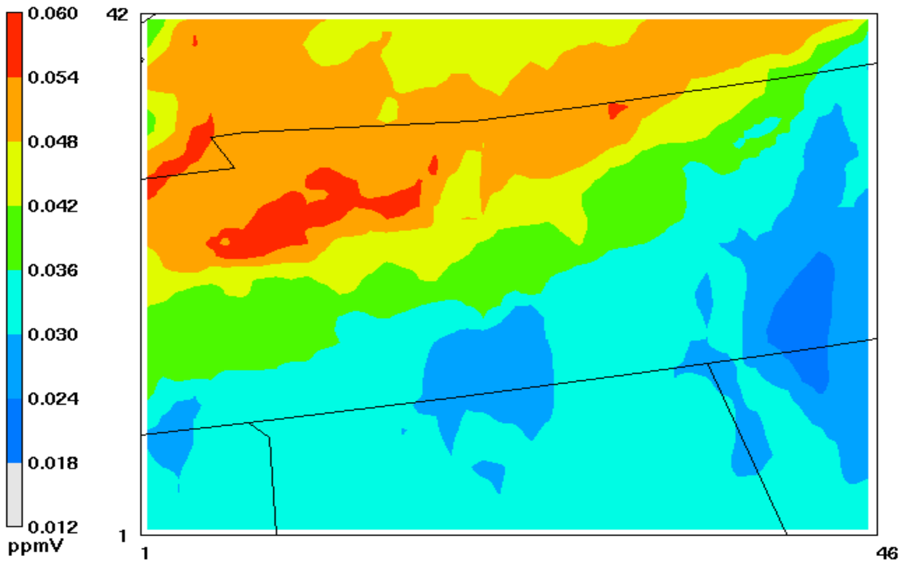
July 2,1999 8:00:00
Min=4027 at (21,21), Max=5447 at (4,41)

Total ozone column abundance (0.0 - 12.0 km)



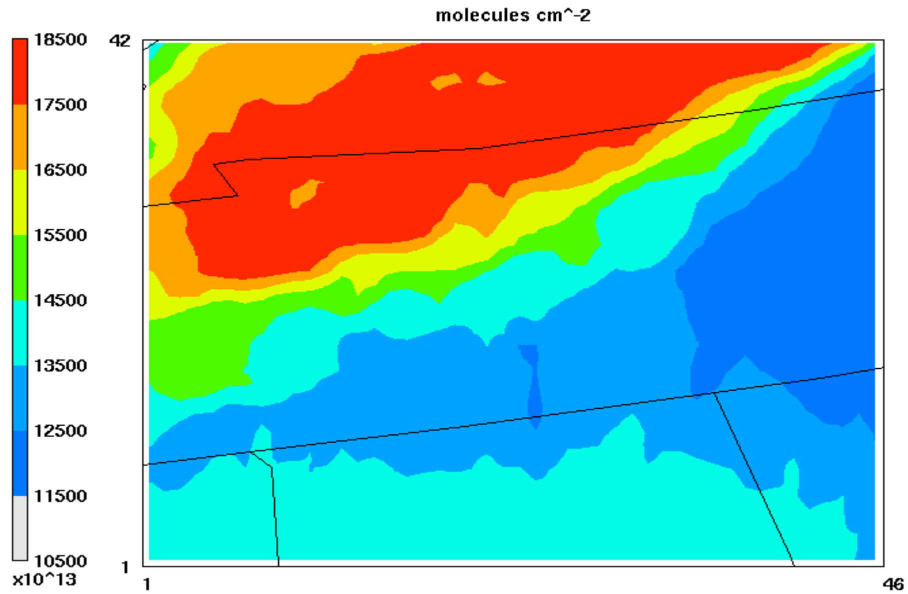
July 2,1999 8:00:00
Min=6445 at (20,21), Max=8634 at (35,1)

Hourly Surface Ozone Concentrations (ppmv)



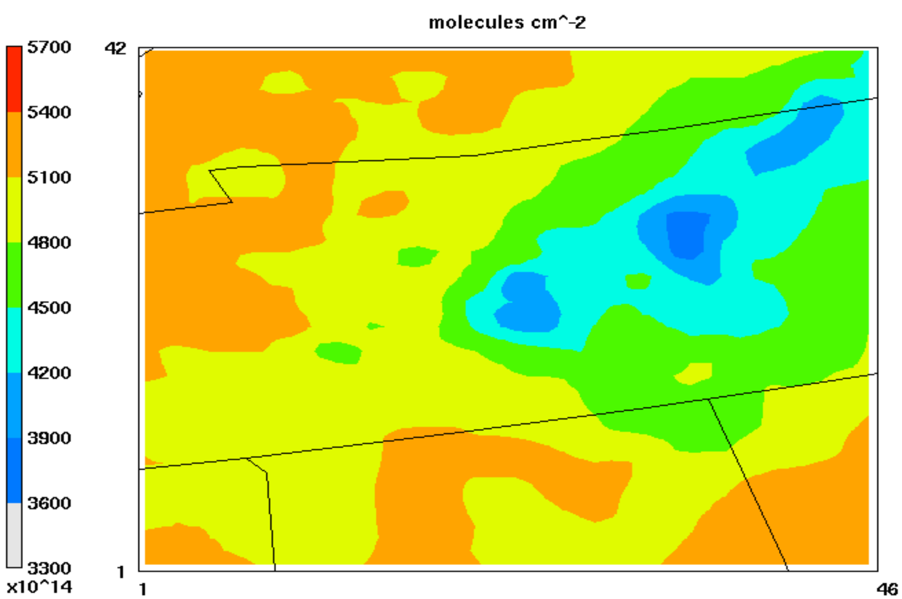
July 2,1999 9:00:00
Min=0.022 at (42,14), Max=0.057 at (8,24)

Ozone column abundance in PBL (0.0 - 1.5 km)



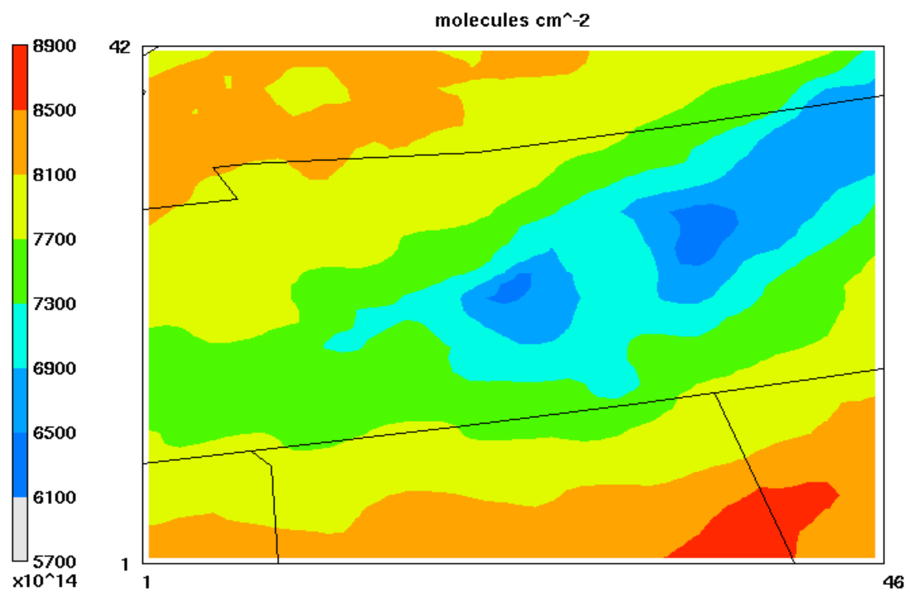
July 2,1999 9:00:00
Min=11745 at (43,32), Max=18821 at (10,28)

Ozone column abundance in free troposphere (1.5 - 8.0 km)



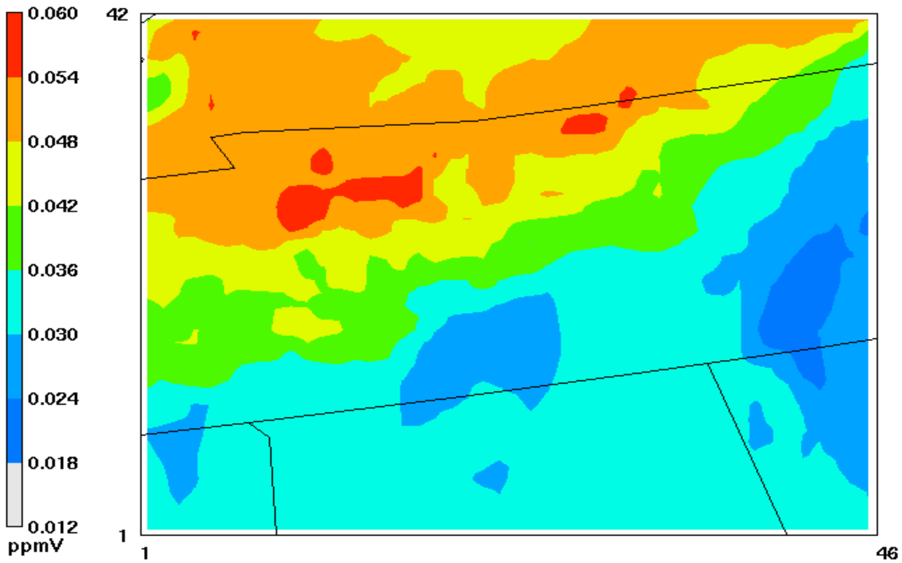
July 2,1999 9:00:00
Min=3795 at (35,26), Max=5385 at (3,39)

Total ozone column abundance (0.0 - 12.0 km)



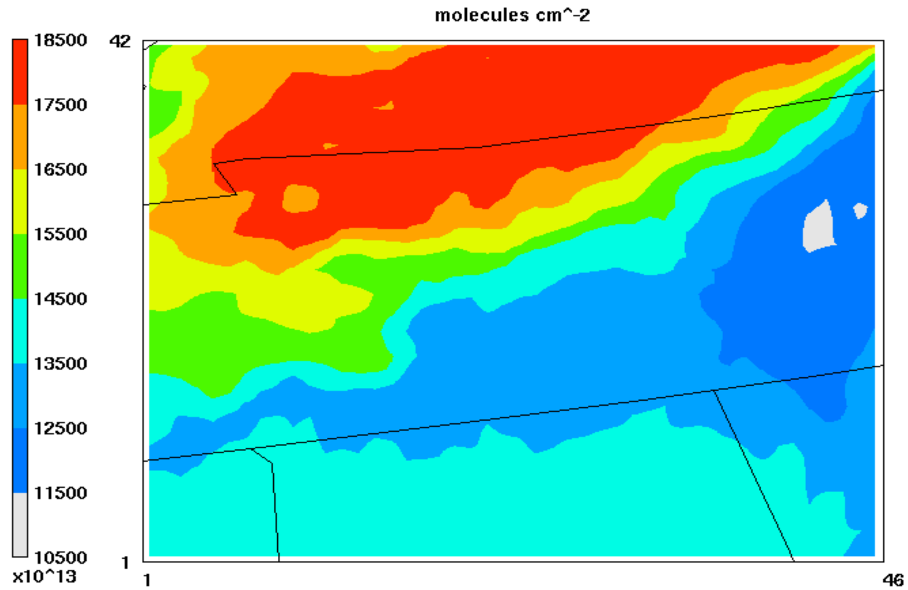
July 2,1999 9:00:00
Min=6288 at (35,26), Max=8594 at (38,3)

Hourly Surface Ozone Concentrations (ppmv)



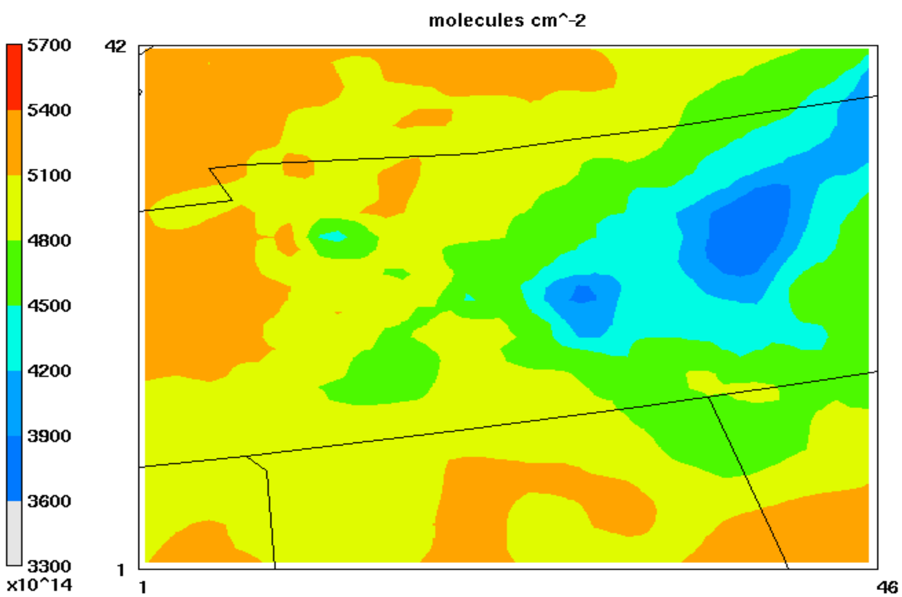
July 2,1999 10:00:00
Min=0.021 at (43,20), Max=0.057 at (11,27)

Ozone column abundance in PBL (0.0 - 1.5 km)



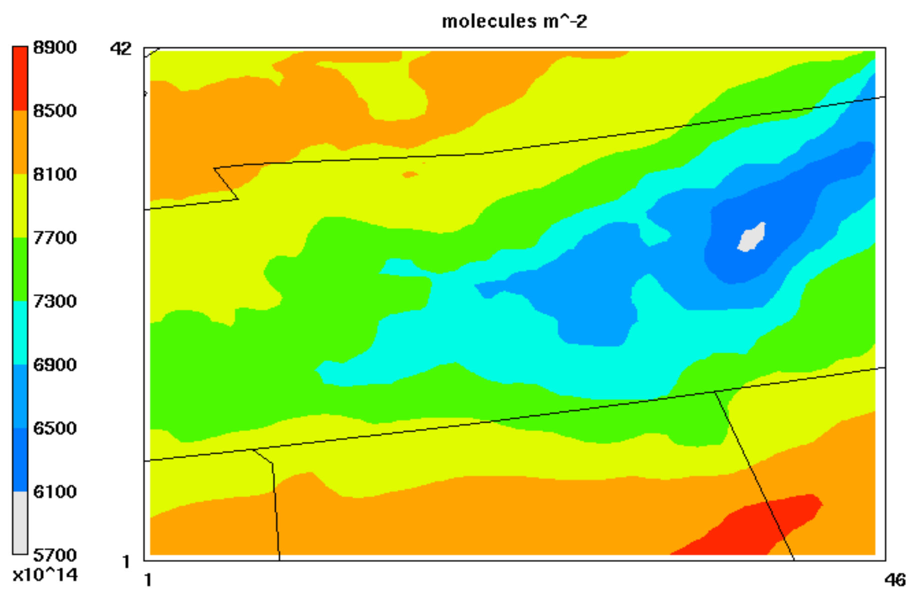
July 2,1999 10:00:00
Min=11385 at (43,27), Max=18587 at (31,36)

Ozone column abundance in free troposphere (1.5 - 8.0 km)



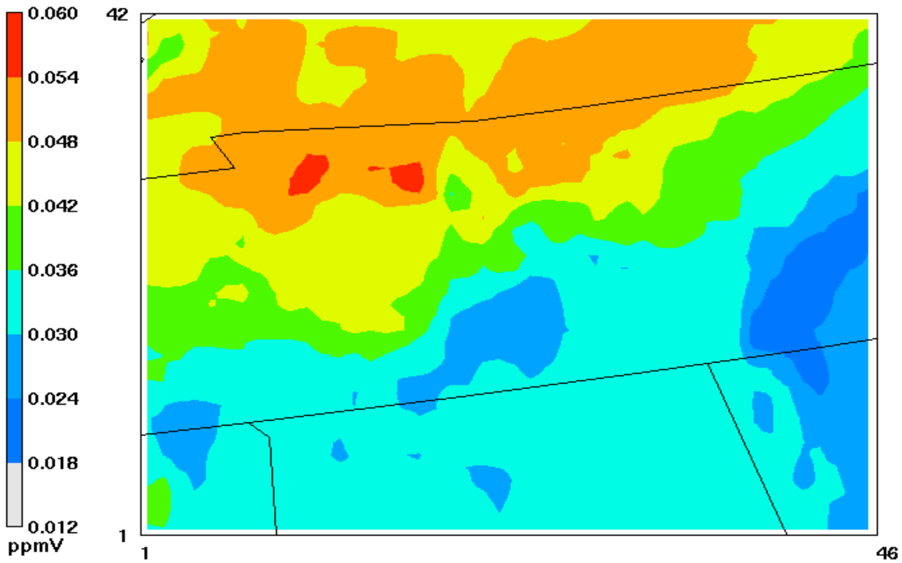
July 2,1999 10:00:00
Min=3624 at (38,26), Max=5348 at (7,37)

Total ozone column abundance (0.0 - 12.0 km)



July 2,1999 10:00:00
Min=6044 at (38,27), Max=8558 at (38,3)

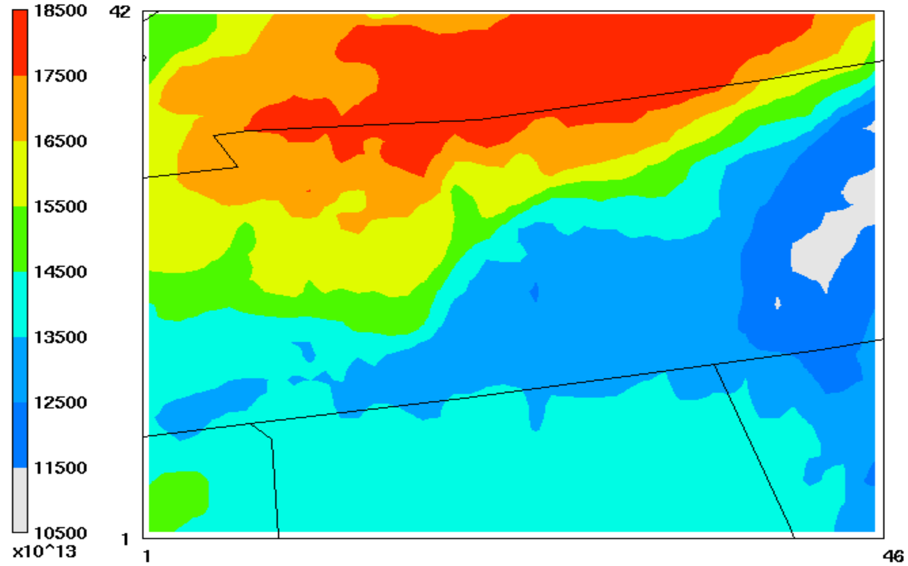
Hourly Surface Ozone Concentrations (ppmv)



July 2,1999 11:00:00
Min=0.019 at (43,20), Max=0.057 at (18,29)

Ozone column abundance in PBL (0.0 - 1.5 km)

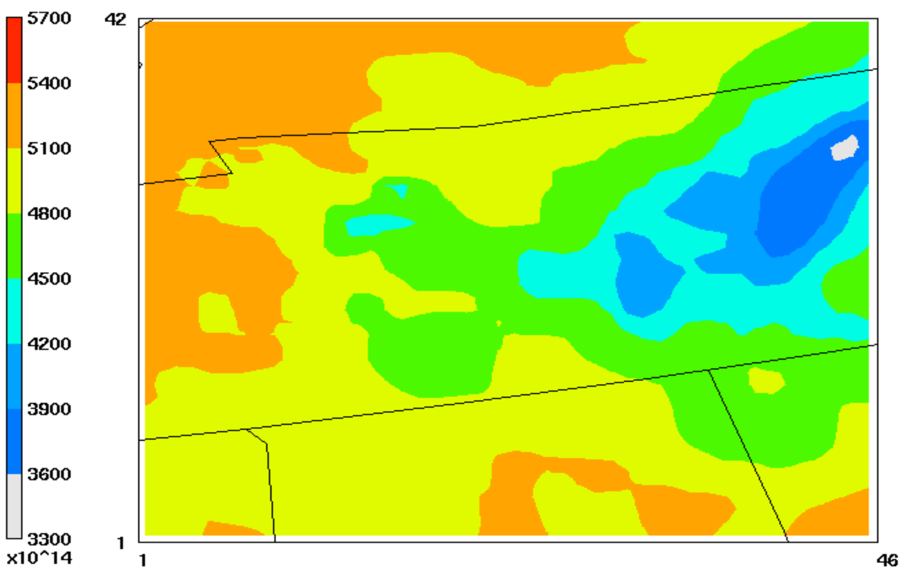
molecules cm^-2



July 2,1999 11:00:00
Min=10951 at (46,28), Max=18692 at (32,39)

Ozone column abundance in free troposphere (1.5 - 8.0 km)

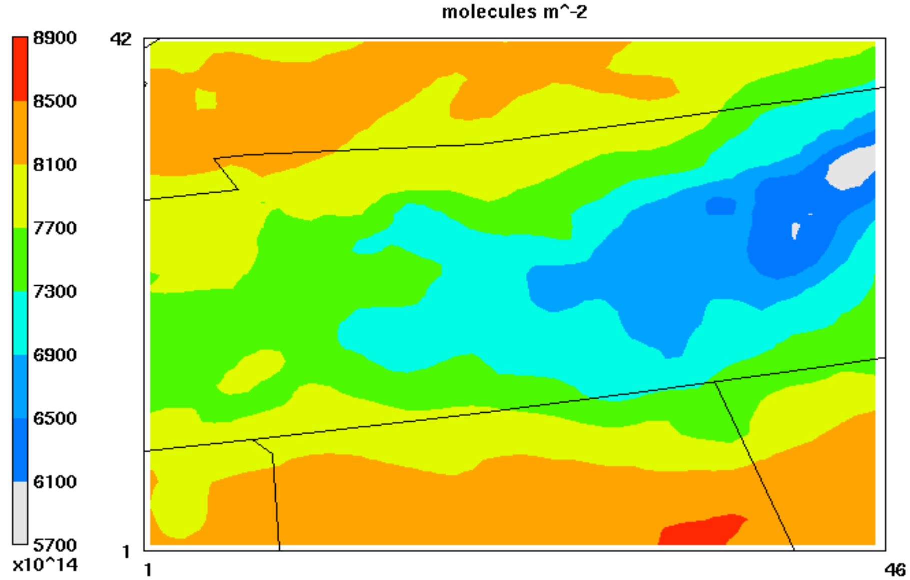
molecules cm^-2



July 2,1999 11:00:00
Min=3526 at (45,32), Max=5362 at (1,35)

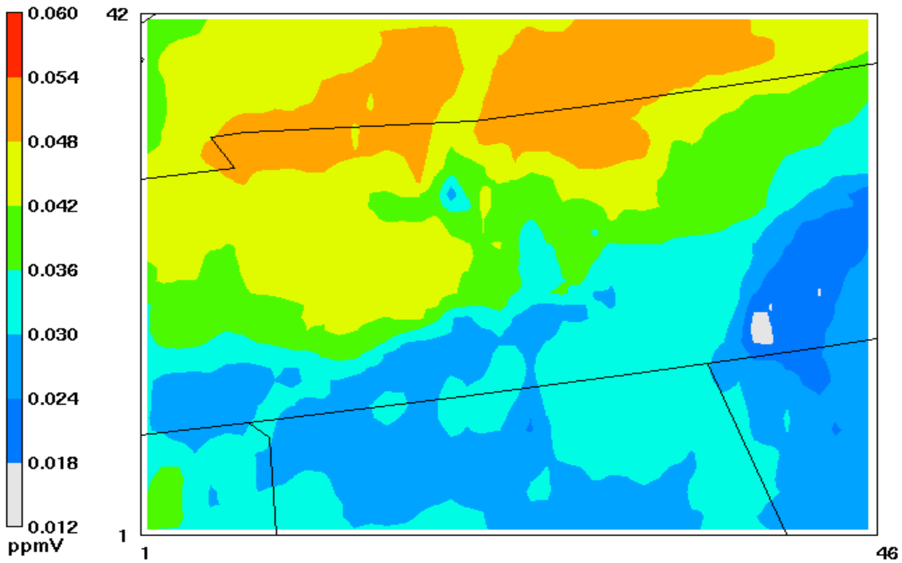
Total ozone column abundance (0.0 - 12.0 km)

molecules m^-2



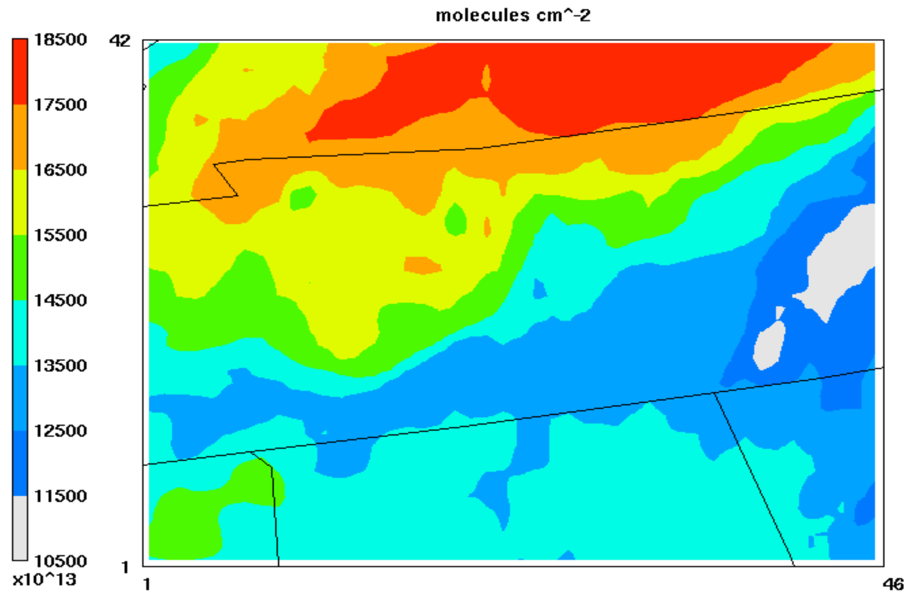
July 2,1999 11:00:00
Min=5795 at (45,32), Max=8554 at (35,1)

Hourly Surface Ozone Concentrations (ppmv)



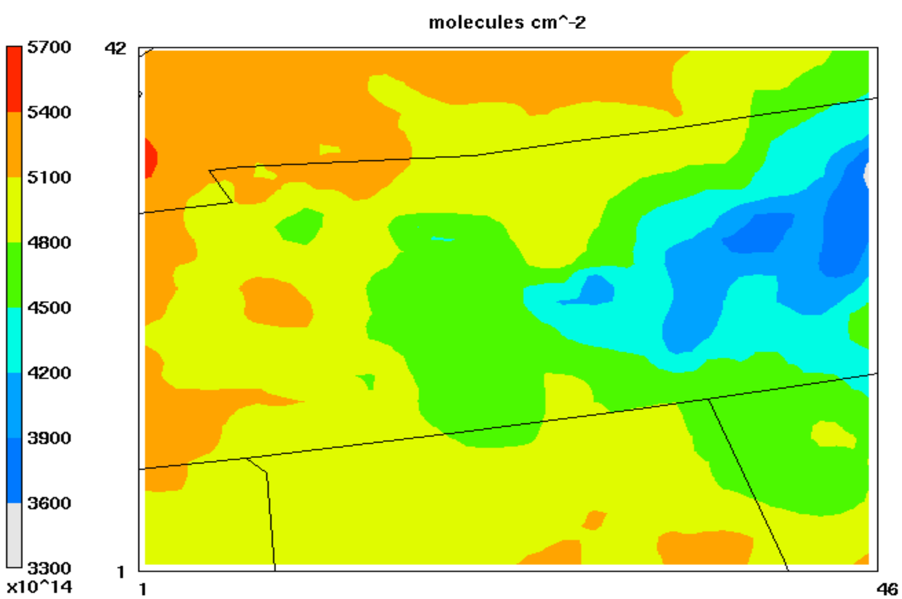
July 2,1999 12:00:00
Min=0.015 at (39,17), Max=0.052 at (12,31)

Ozone column abundance in PBL (0.0 - 1.5 km)



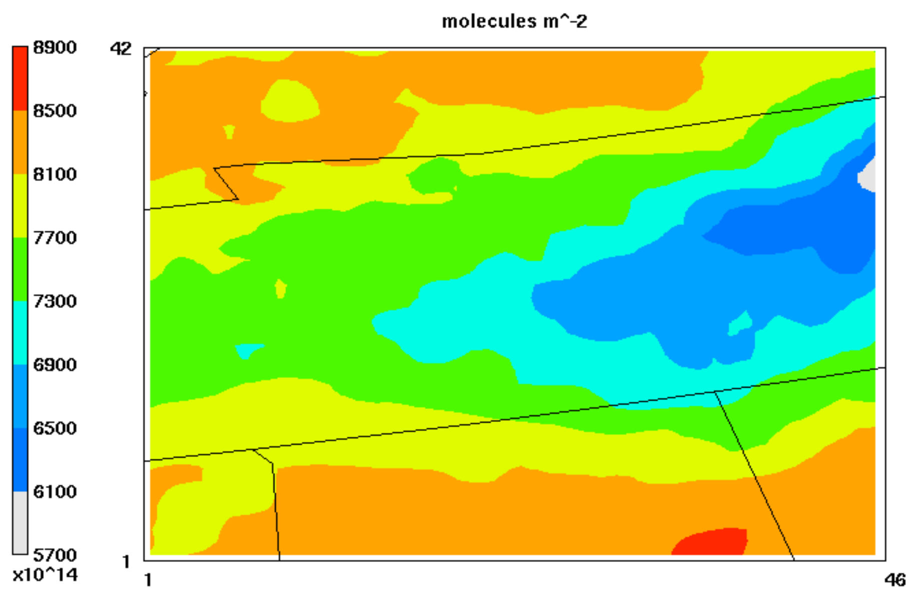
July 2,1999 12:00:00
Min=10821 at (46,28), Max=18497 at (33,40)

Ozone column abundance in free troposphere (1.5 - 8.0 km)



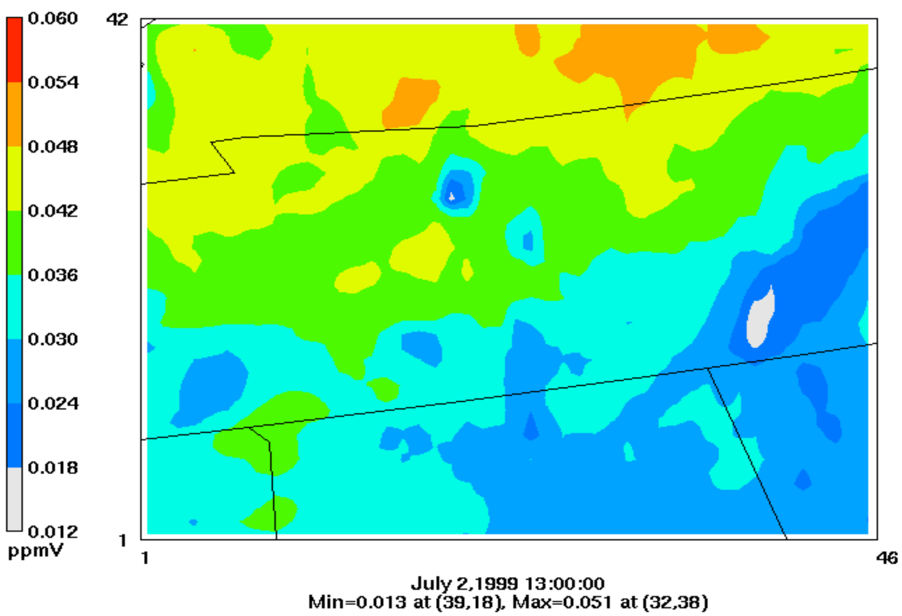
July 2,1999 12:00:00
Min=3537 at (46,32), Max=5419 at (1,34)

Total ozone column abundance (0.0 - 12.0 km)

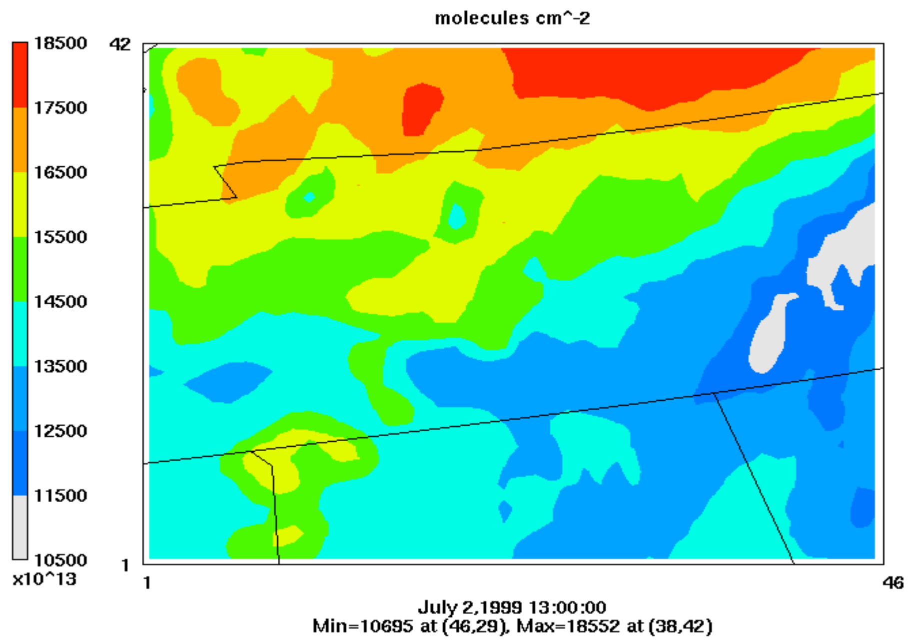


July 2,1999 12:00:00
Min=5924 at (46,32), Max=8575 at (35,1)

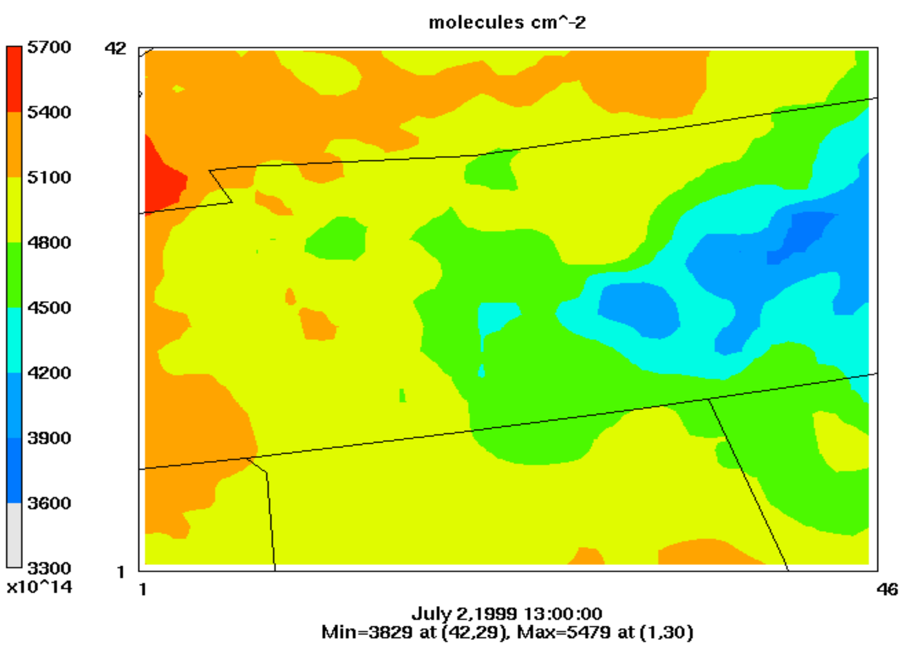
Hourly Surface Ozone Concentrations (ppmv)



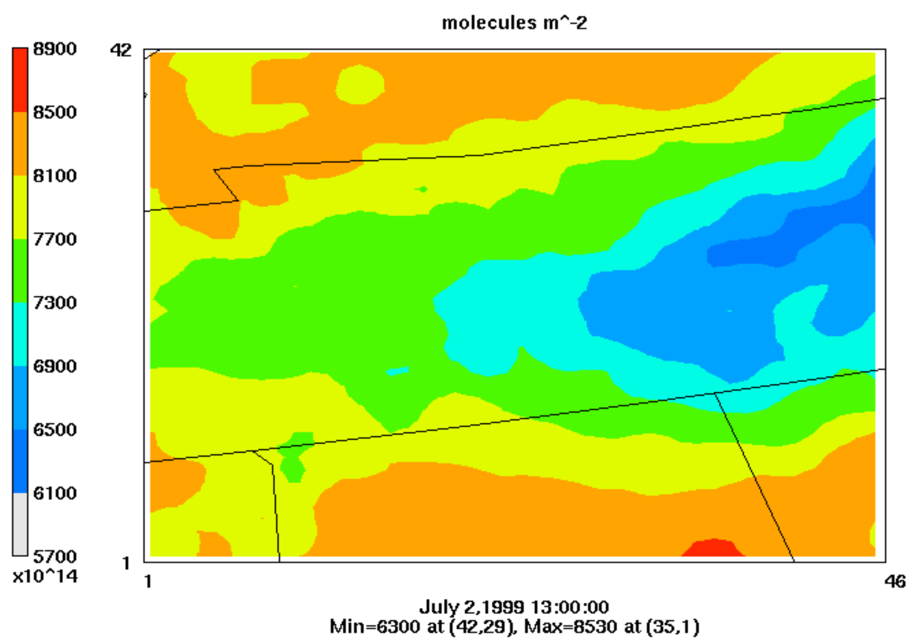
Ozone column abundance in PBL (0.0 - 1.5 km)



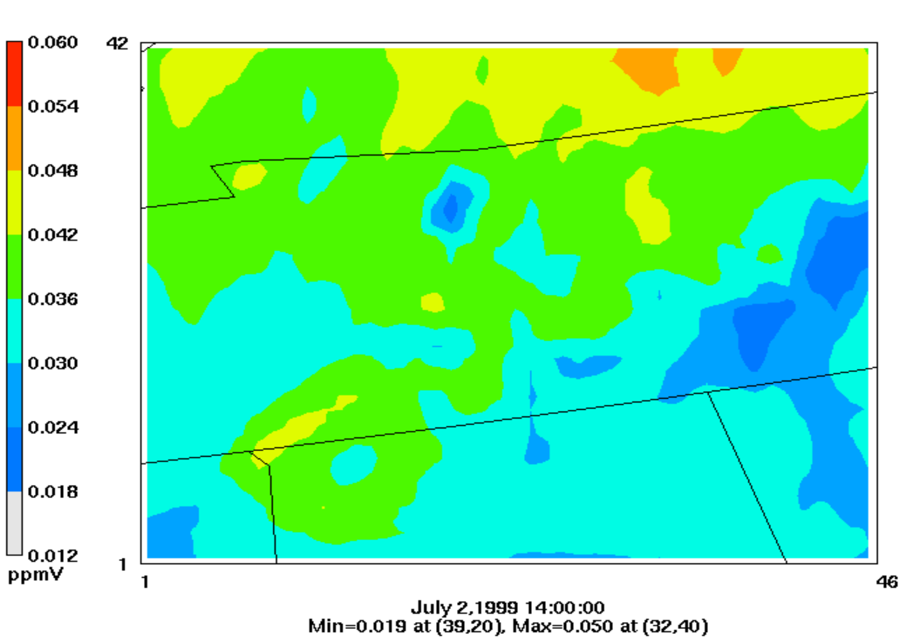
Ozone column abundance in free troposphere (1.5 - 8.0 km)



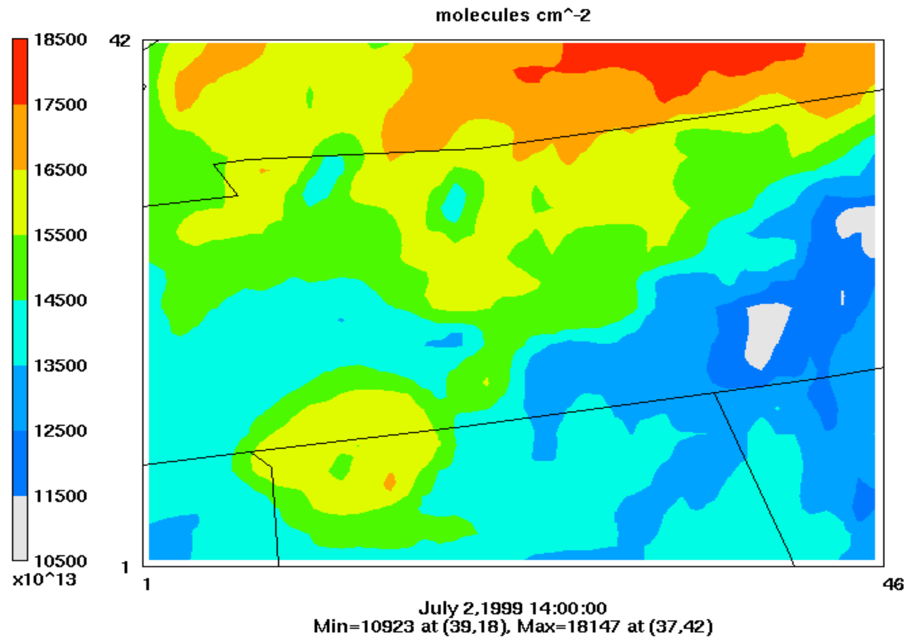
Total ozone column abundance (0.0 - 12.0 km)



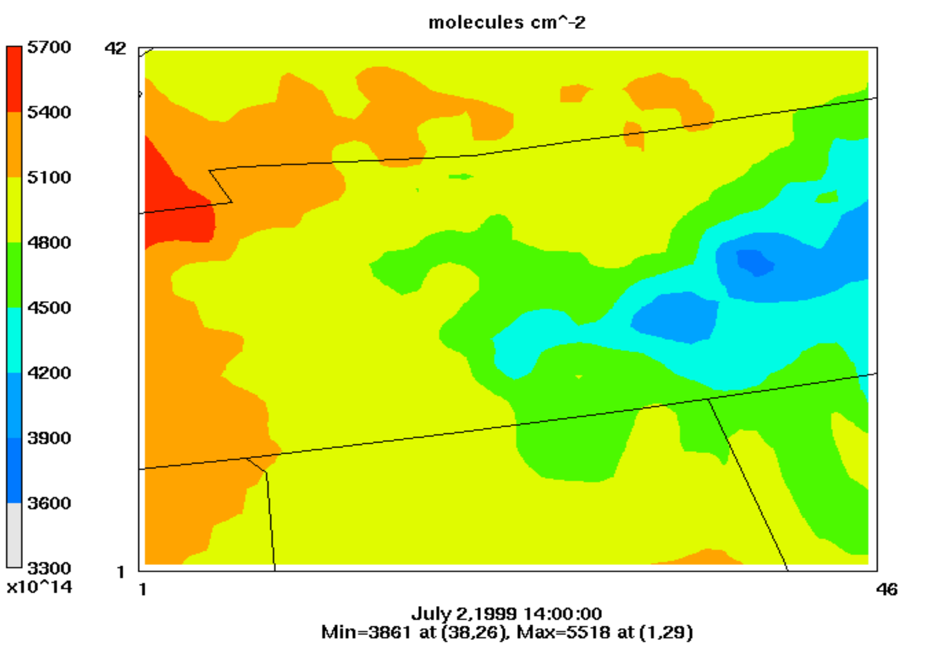
Hourly Surface Ozone Concentrations (ppmv)



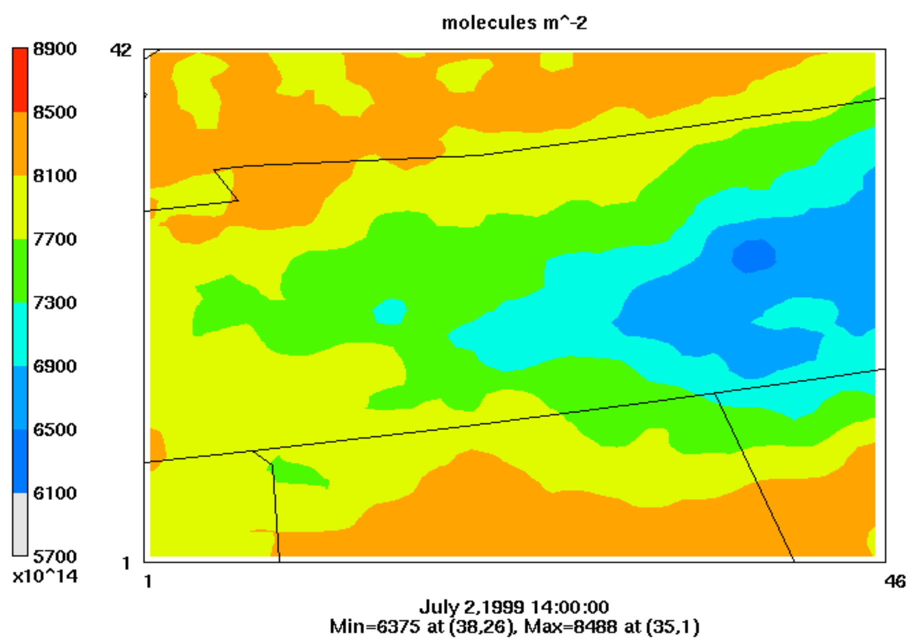
Ozone column abundance in PBL (0.0 - 1.5 km)



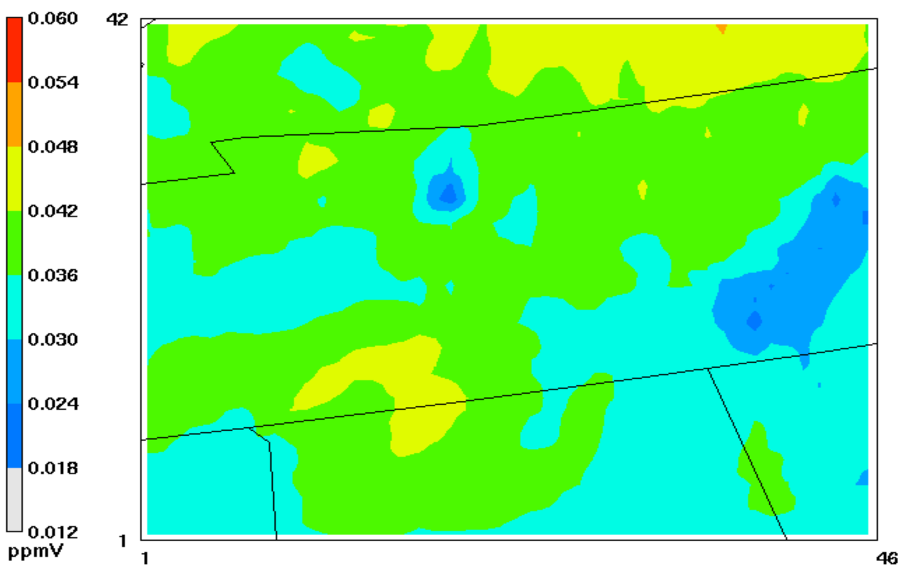
Ozone column abundance in free troposphere (1.5 - 8.0 km)



Total ozone column abundance (0.0 - 12.0 km)

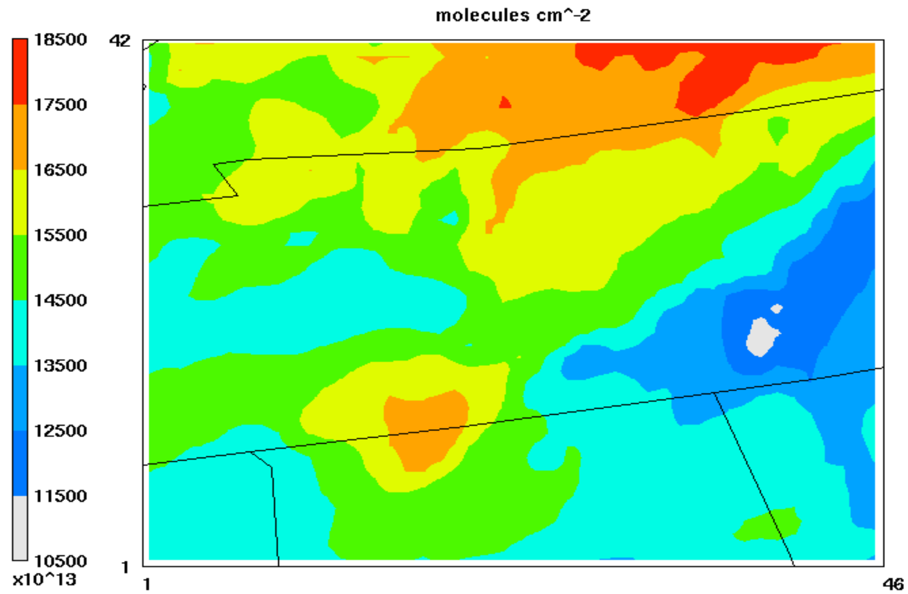


Hourly Surface Ozone Concentrations (ppmv)



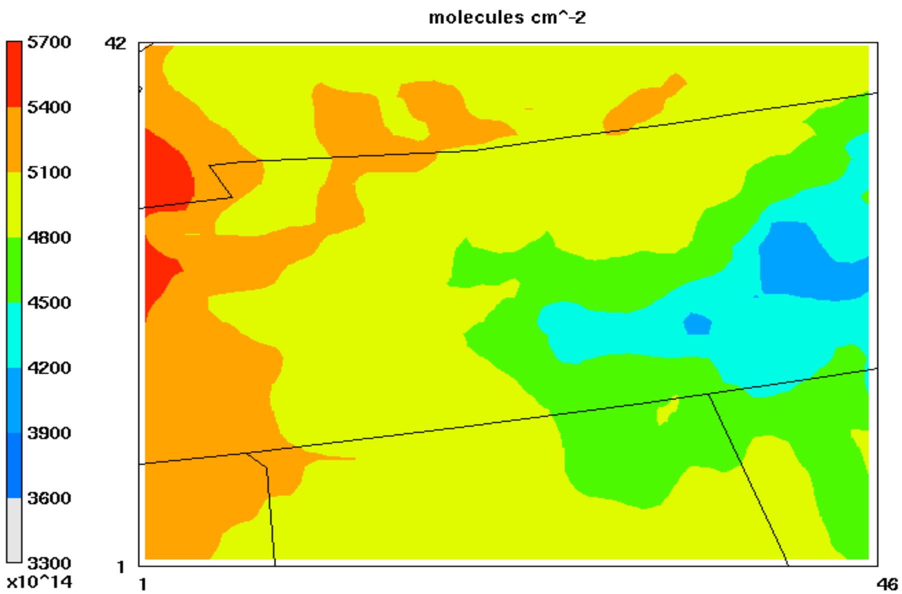
July 2,1999 15:00:00
Min=0.020 at (20,28), Max=0.048 at (37,42)

Ozone column abundance in PBL (0.0 - 1.5 km)



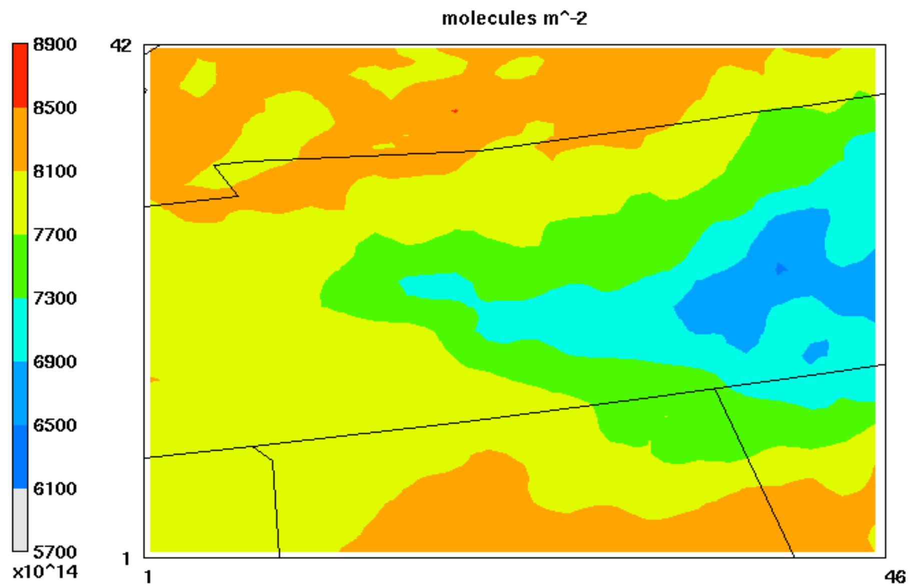
July 2,1999 15:00:00
Min=10855 at (39,18), Max=17948 at (37,42)

Ozone column abundance in free troposphere (1.5 - 8.0 km)



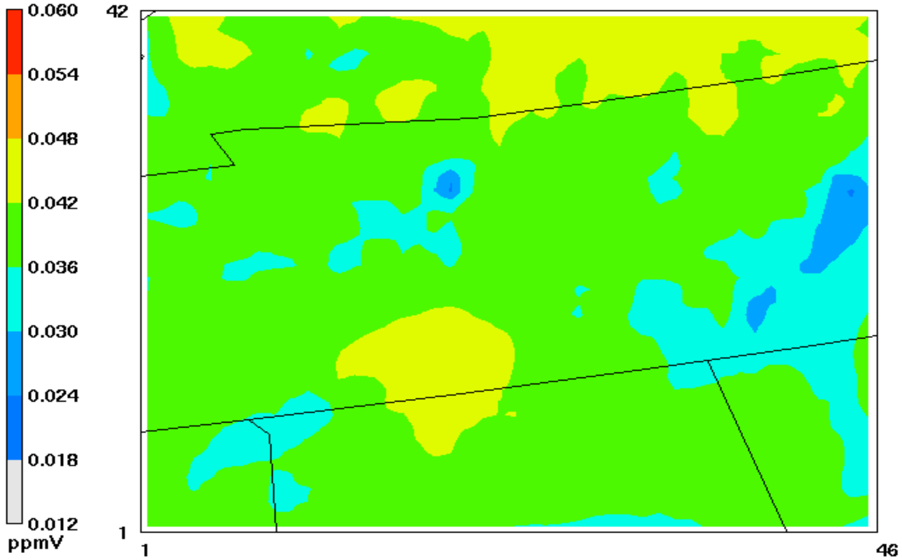
July 2,1999 15:00:00
Min=3978 at (41,25), Max=5499 at (2,30)

Total ozone column abundance (0.0 - 12.0 km)



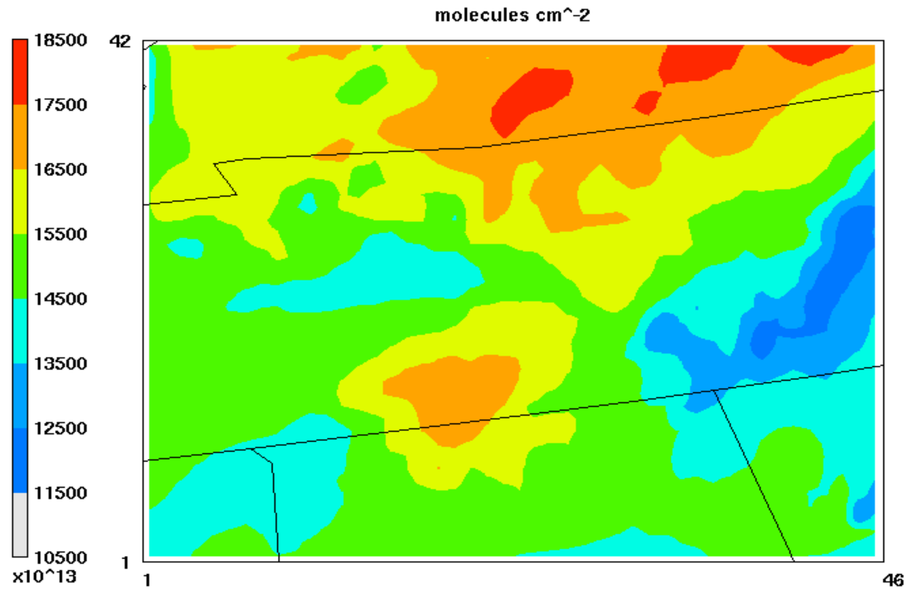
July 2,1999 15:00:00
Min=6471 at (40,24), Max=8520 at (20,37)

Hourly Surface Ozone Concentrations (ppmv)



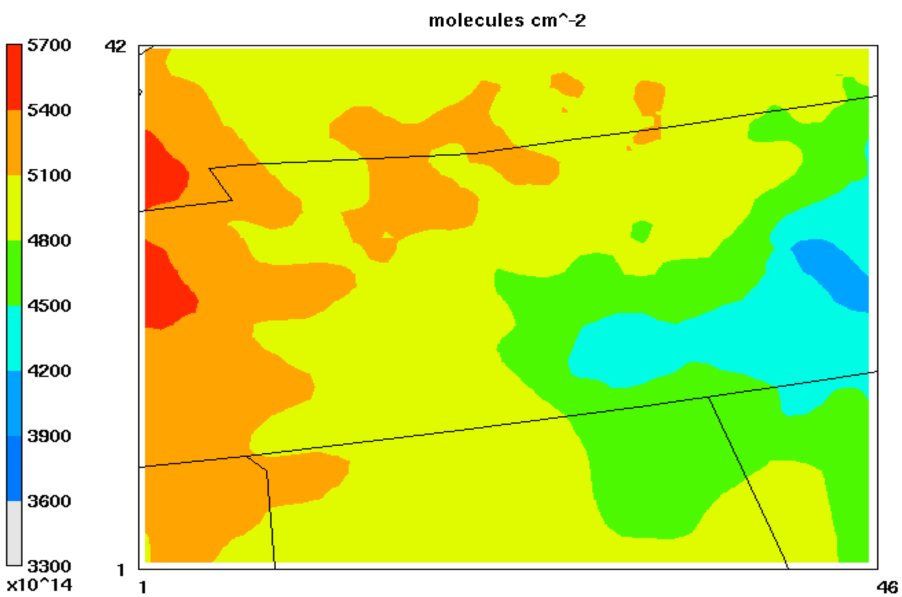
July 2,1999 16:00:00
Min=0.023 at (20,28), Max=0.047 at (37,41)

Ozone column abundance in PBL (0.0 - 1.5 km)



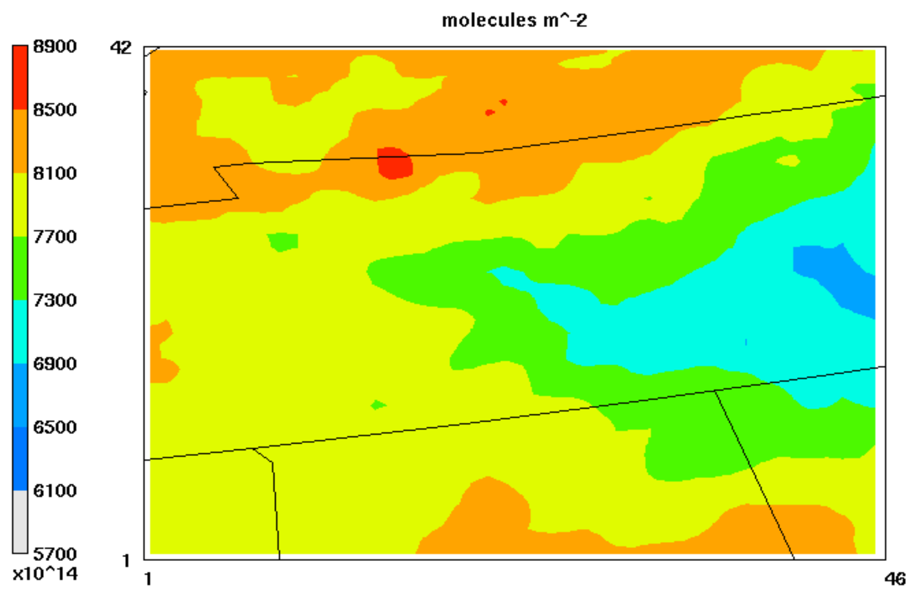
July 2,1999 16:00:00
Min=11592 at (45,28), Max=18042 at (25,38)

Ozone column abundance in free troposphere (1.5 - 8.0 km)

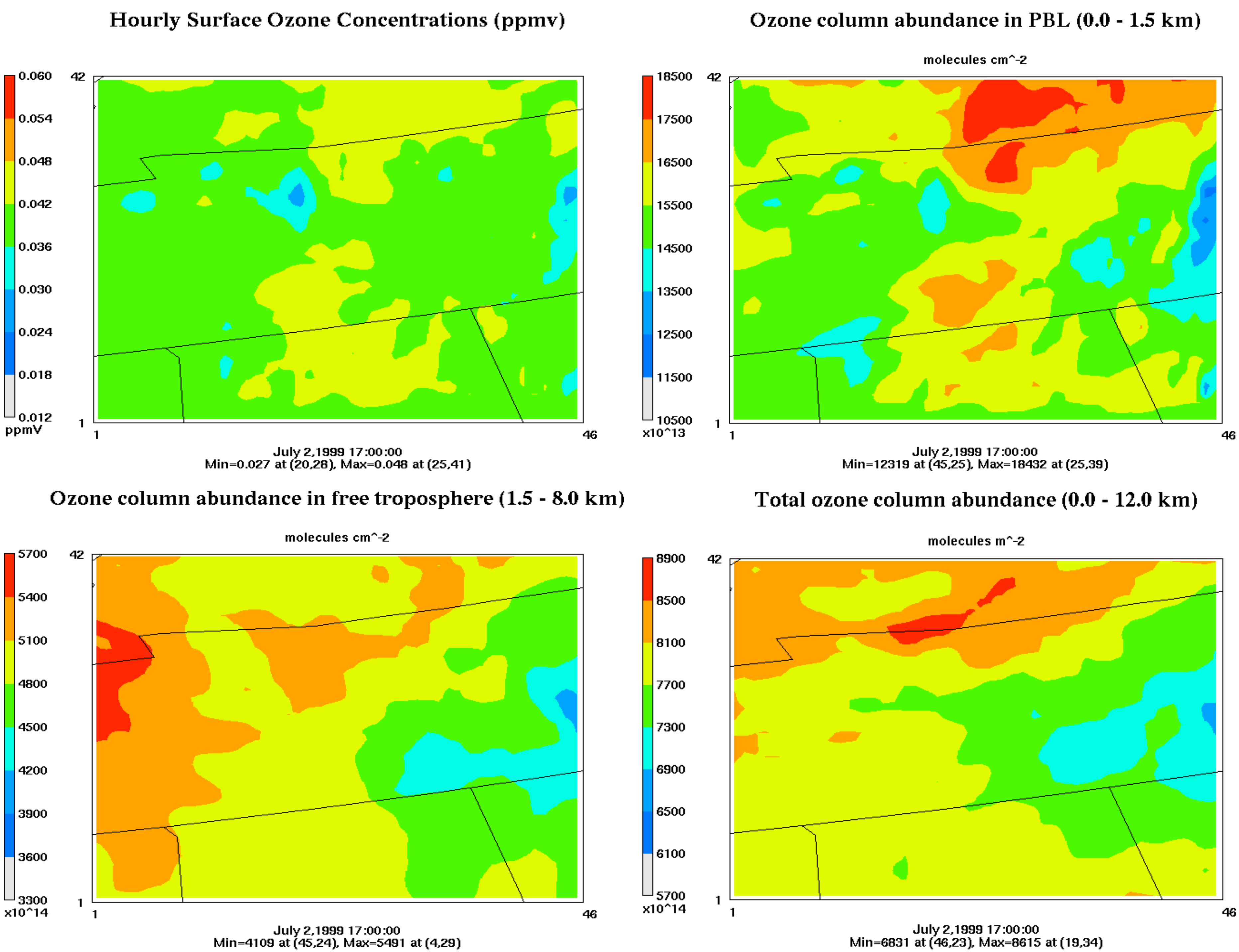


July 2,1999 16:00:00
Min=4078 at (44,24), Max=5496 at (2,31)

Total ozone column abundance (0.0 - 12.0 km)

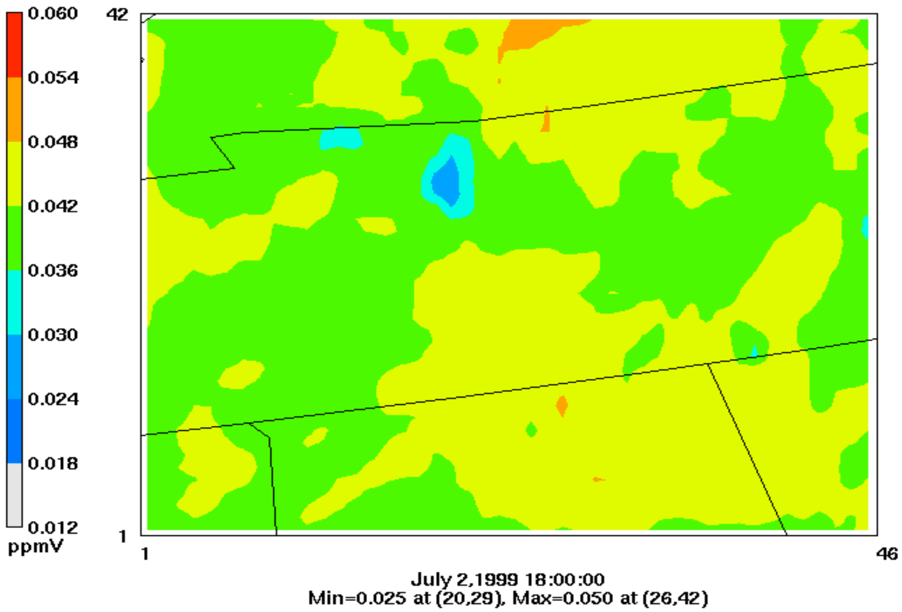


July 2,1999 16:00:00
Min=6797 at (46,22), Max=8603 at (16,32)

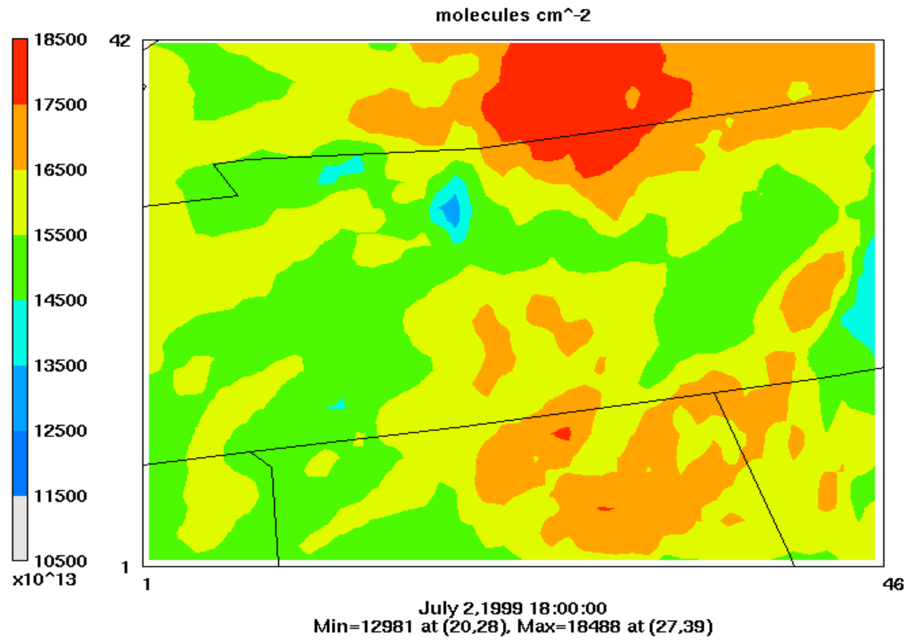


Hourly Surface Ozone Concentrations (ppmv)
0.060
0.054
0.048
0.042
0.036
0.030
0.024
0.018
0.012
ppmV
42
1
1
46
July 2,1999 17:00:00
Min=0.027 at (20,28), Max=0.048 at (25,41)
Ozone column abundance in PBL (0.0 - 1.5 km)
molecules cm^-2
18500
17500
16500
15500
14500
13500
12500
11500
10500
x10^13
42
1
1
46
July 2,1999 17:00:00
Min=12319 at (45,25), Max=18432 at (25,39)
Ozone column abundance in free troposphere (1.5 - 8.0 km)
molecules cm^-2
5700
5400
5100
4800
4500
4200
3900
3600
3300
x10^14
42
1
1
46
July 2,1999 17:00:00
Min=4109 at (45,24), Max=5491 at (4,29)
Total ozone column abundance (0.0 - 12.0 km)
molecules m^-2
8900
8500
8100
7700
7300
6900
6500
6100
5700
x10^14
42
1
1
46
July 2,1999 17:00:00
Min=6831 at (46,23), Max=8615 at (19,34)

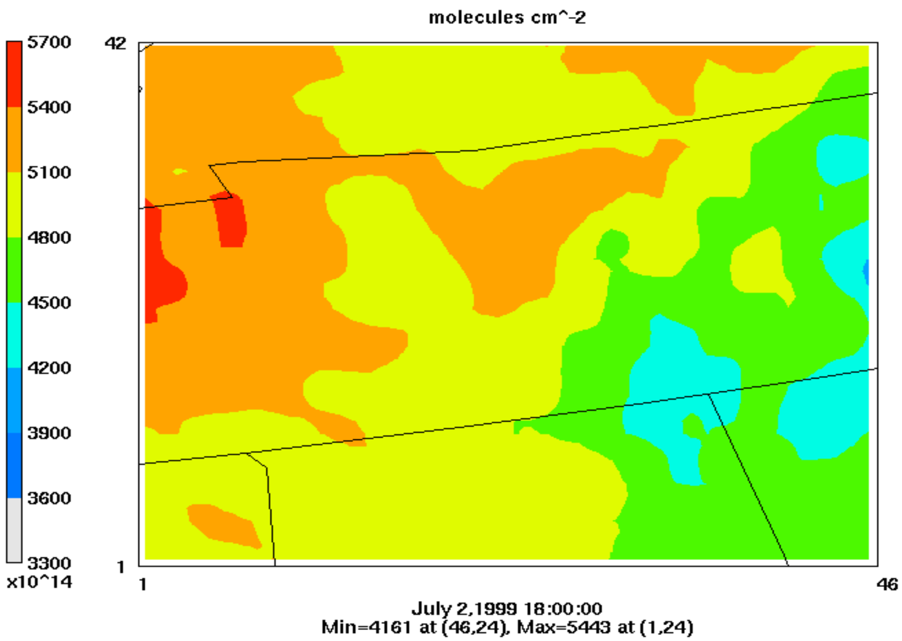
Hourly Surface Ozone Concentrations (ppmv)



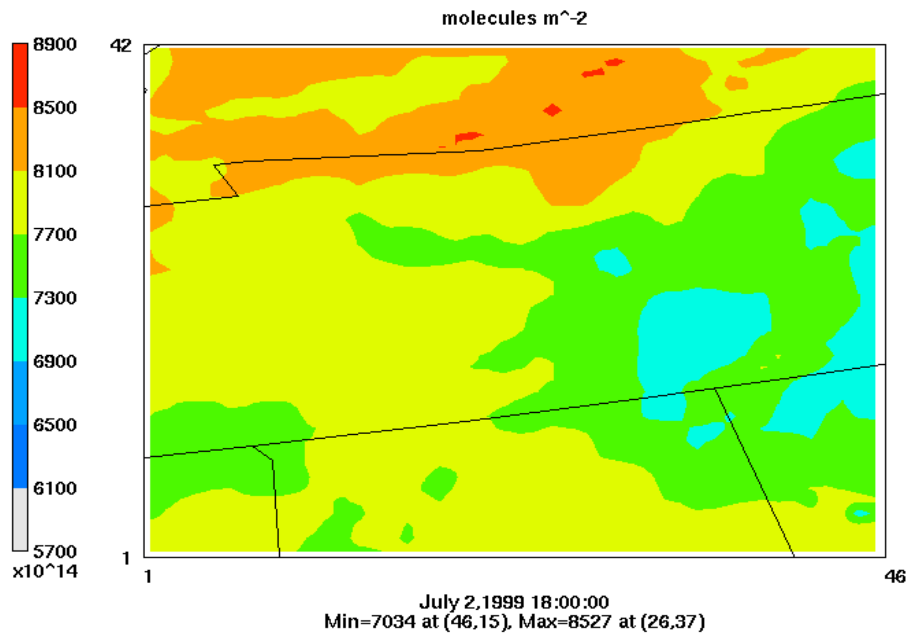
Ozone column abundance in PBL (0.0 - 1.5 km)



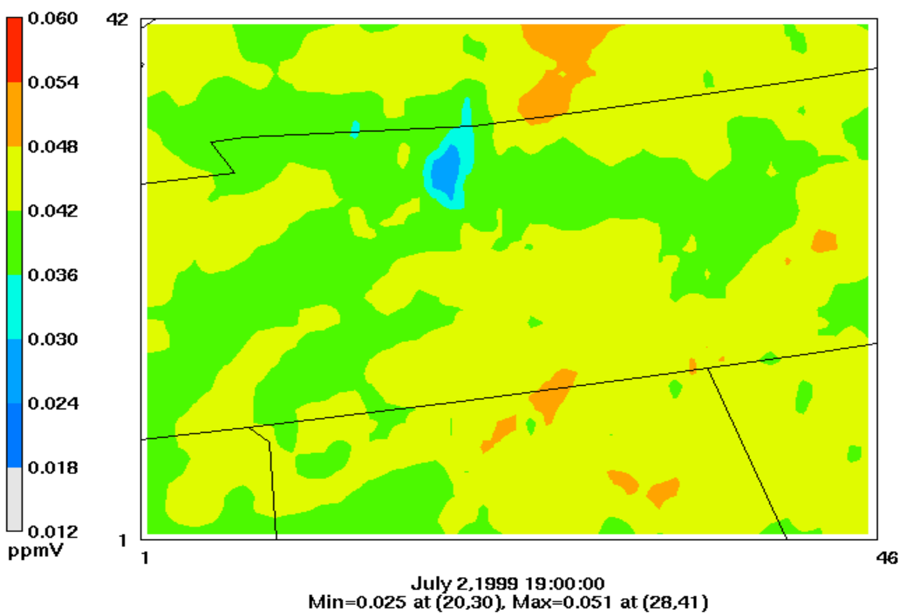
Ozone column abundance in free troposphere (1.5 - 8.0 km)



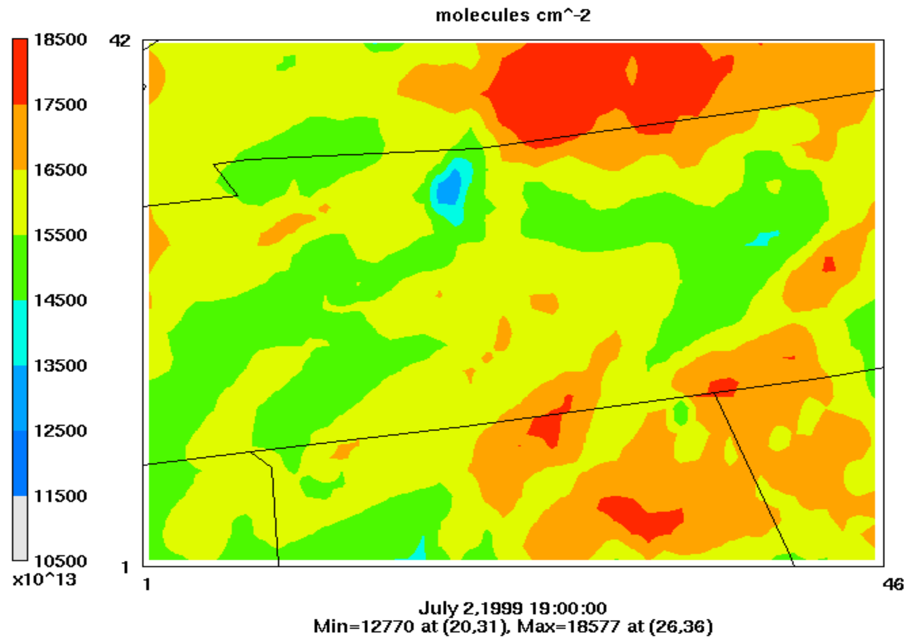
Total ozone column abundance (0.0 - 12.0 km)



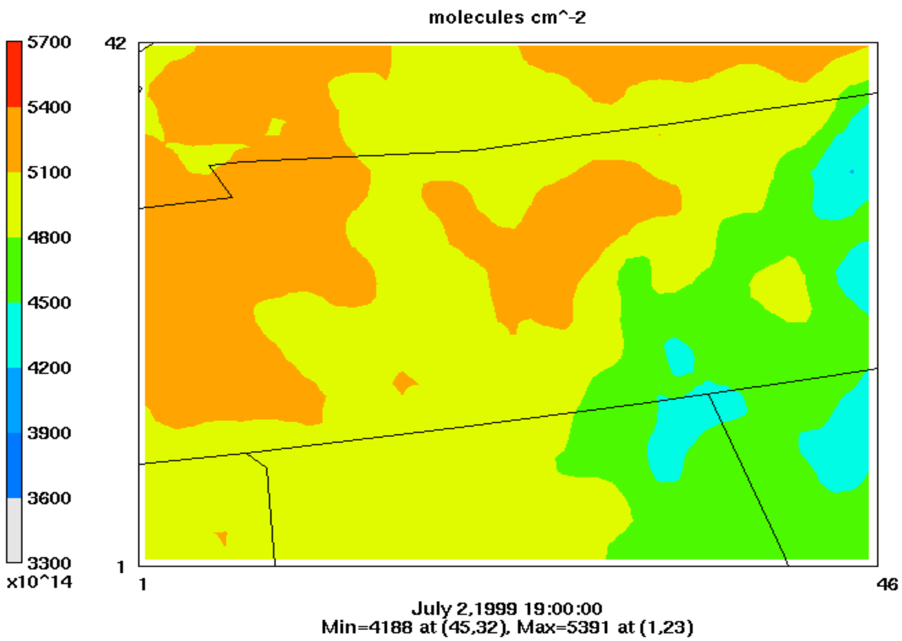
Hourly Surface Ozone Concentrations (ppmv)



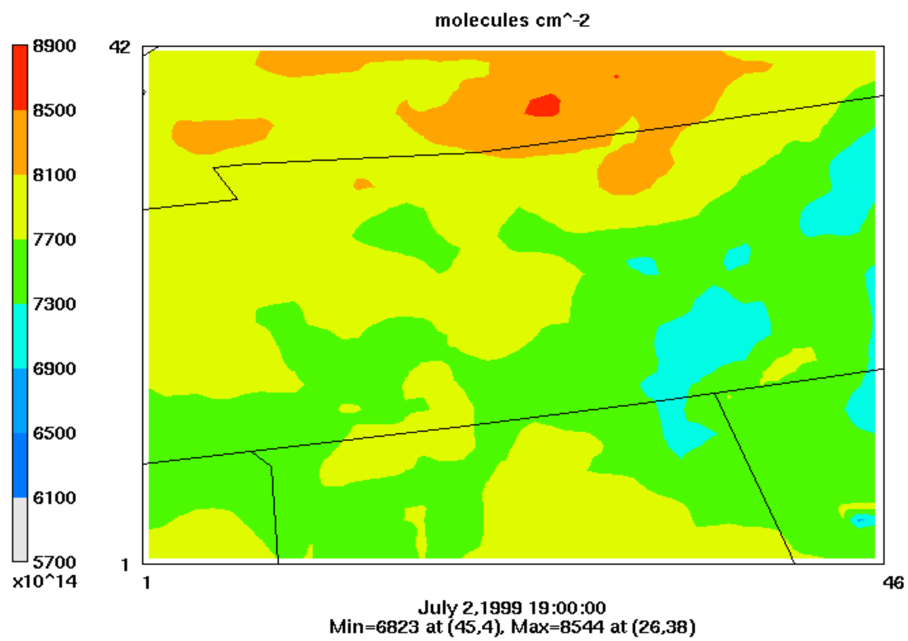
Ozone column abundance in PBL (0.0 - 1.5 km)



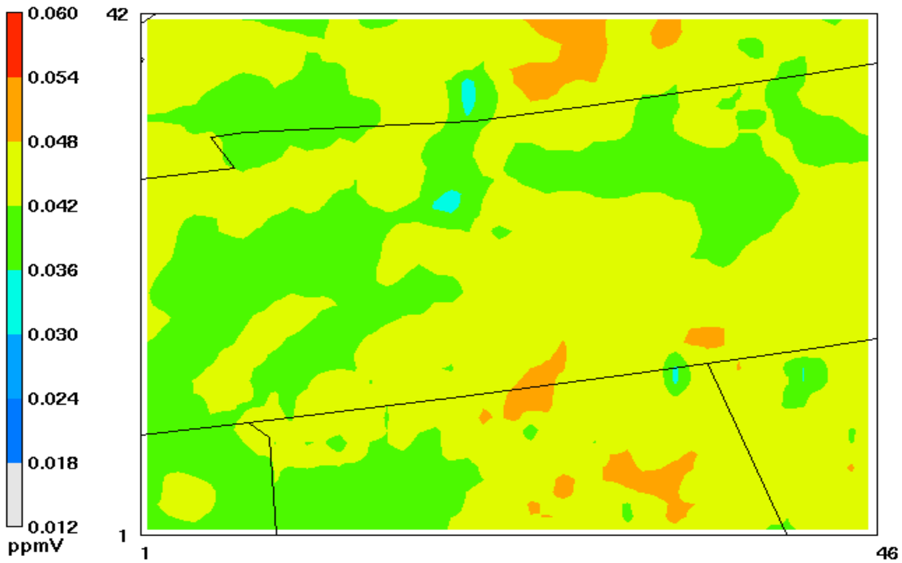
Ozone column abundance in free troposphere (1.5 - 8.0 km)



Total ozone column abundance (0.0 - 12.0 km)



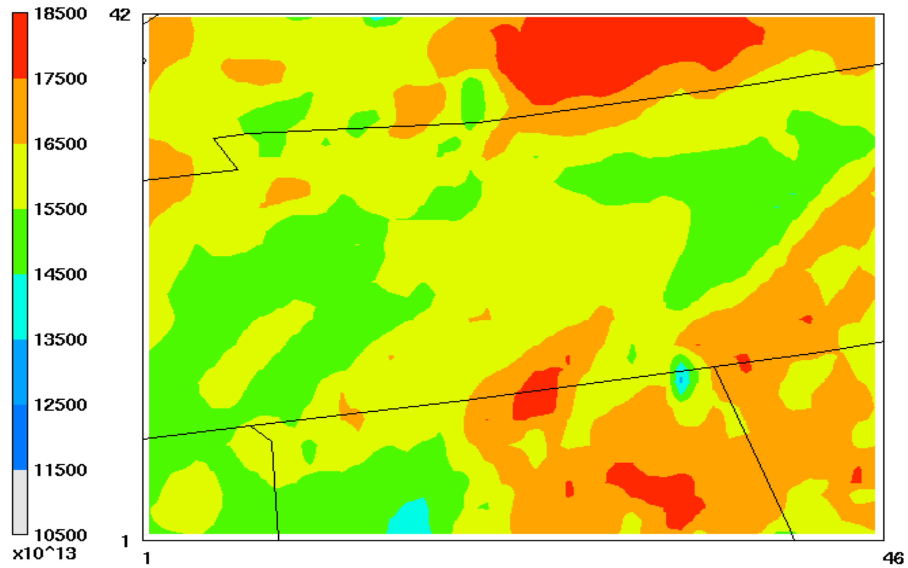
Hourly Surface Ozone Concentrations (ppmv)



July 2,1999 20:00:00
Min=0.033 at (21,36), Max=0.050 at (25,37)

Ozone column abundance in PBL (0.0 - 1.5 km)

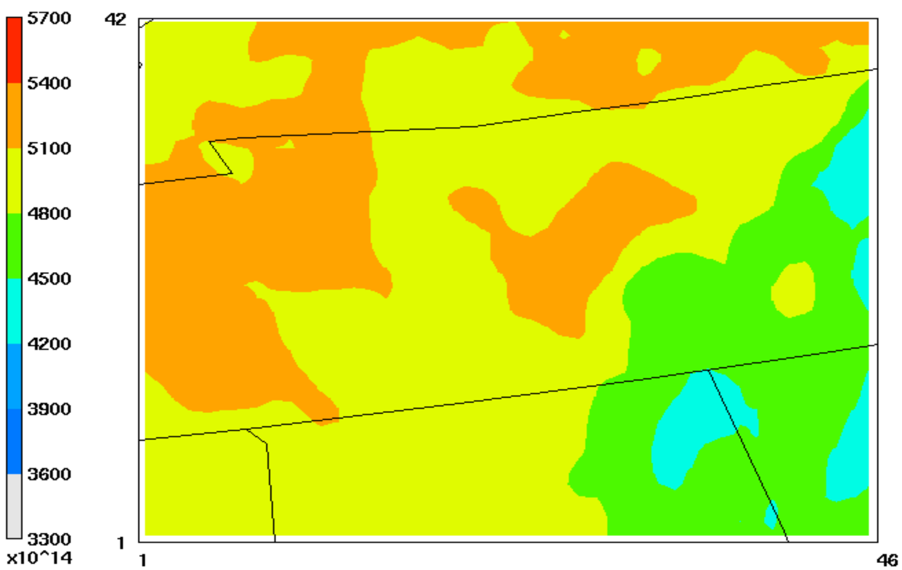
molecules cm^-2



July 2,1999 20:00:00
Min=13368 at (34,13), Max=18766 at (25,38)

Ozone column abundance in free troposphere (1.5 - 8.0 km)

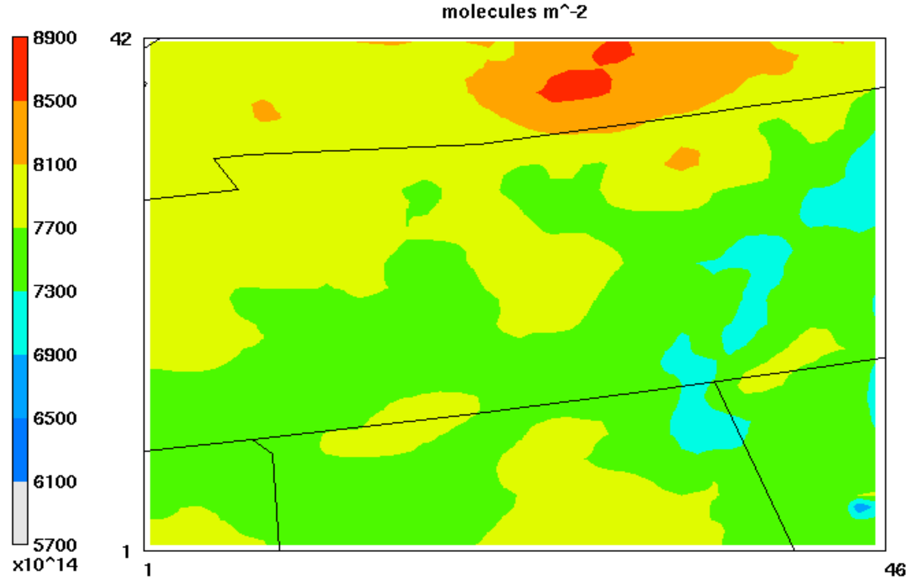
molecules cm^-2



July 2,1999 20:00:00
Min=4257 at (45,32), Max=5356 at (4,28)

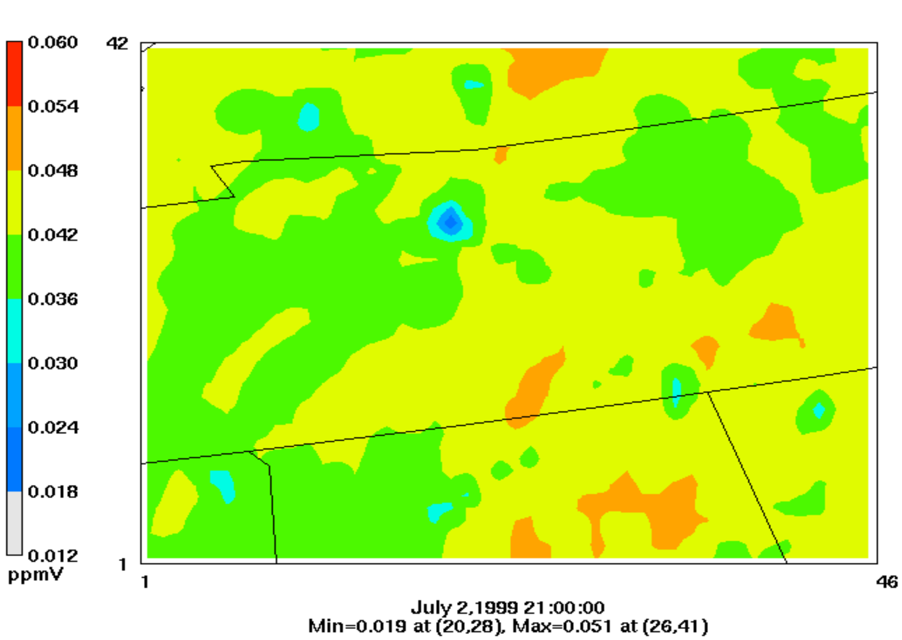
Total ozone column abundance (0.0 - 12.0 km)

molecules m^-2

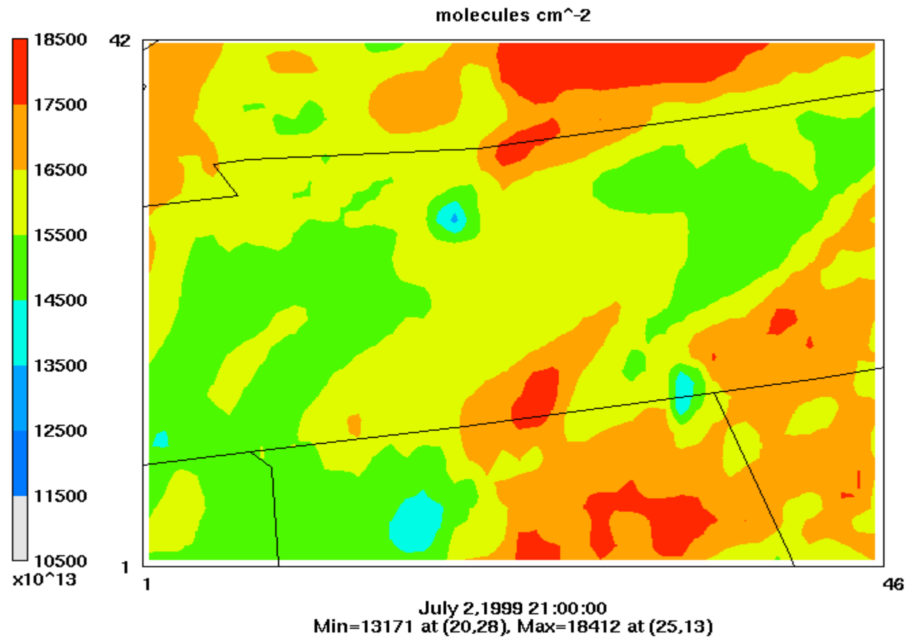


July 2,1999 20:00:00
Min=6563 at (45,4), Max=8567 at (27,39)

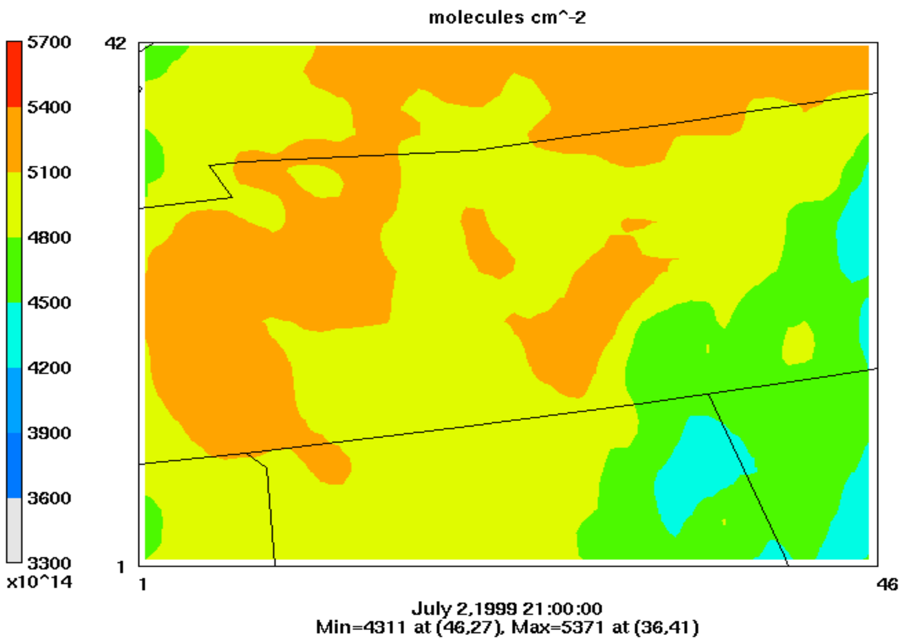
Hourly Surface Ozone Concentrations (ppmv)



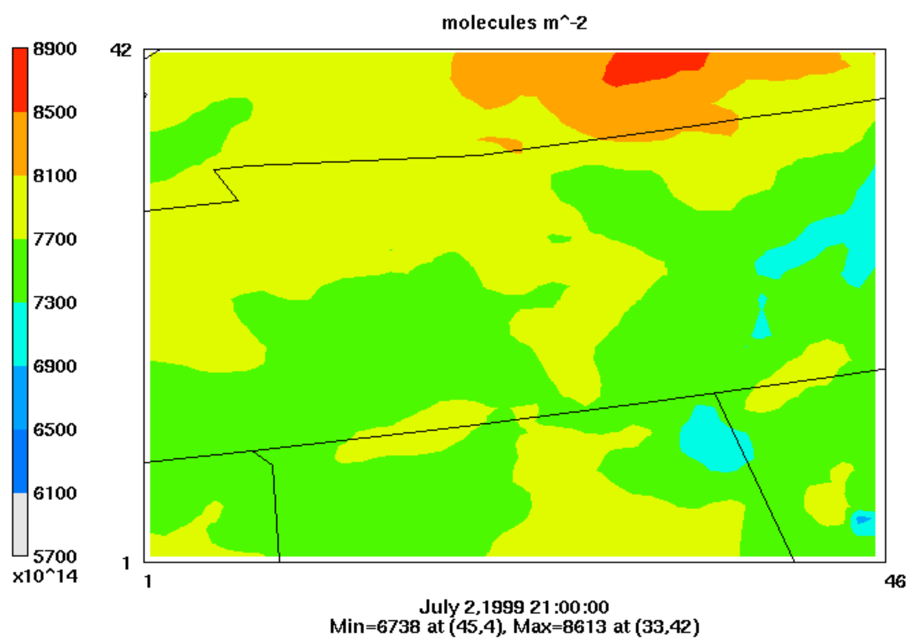
Ozone column abundance in PBL (0.0 - 1.5 km)



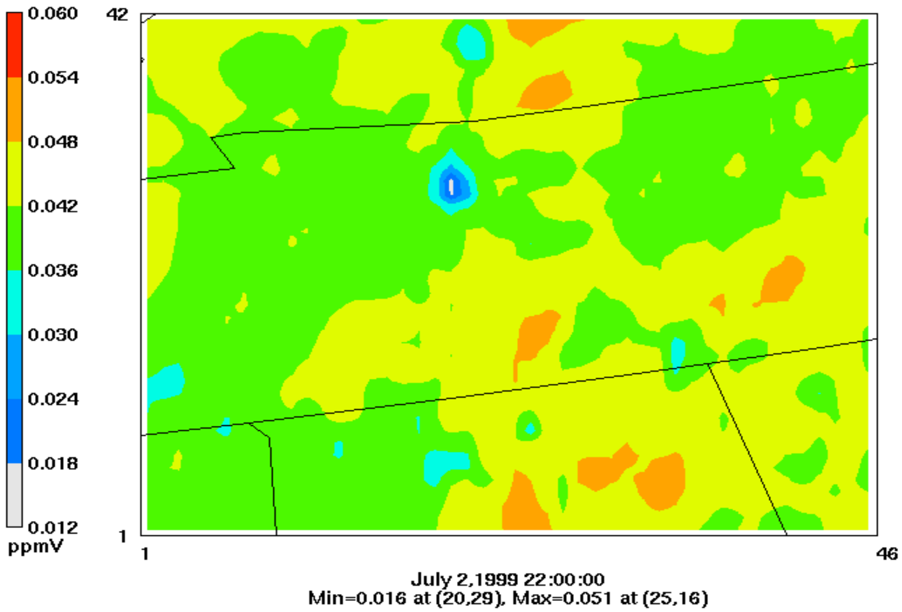
Ozone column abundance in free troposphere (1.5 - 8.0 km)



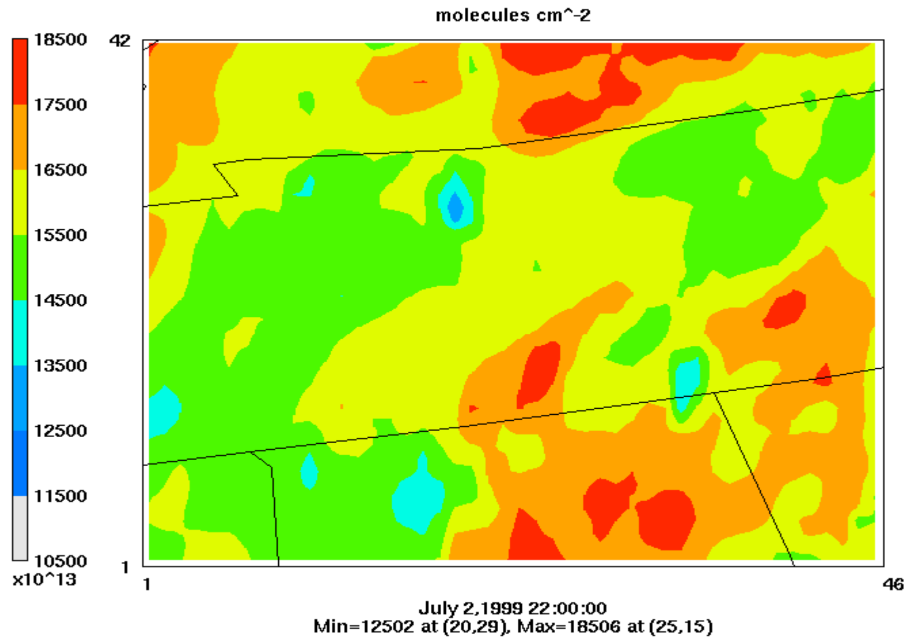
Total ozone column abundance (0.0 - 12.0 km)



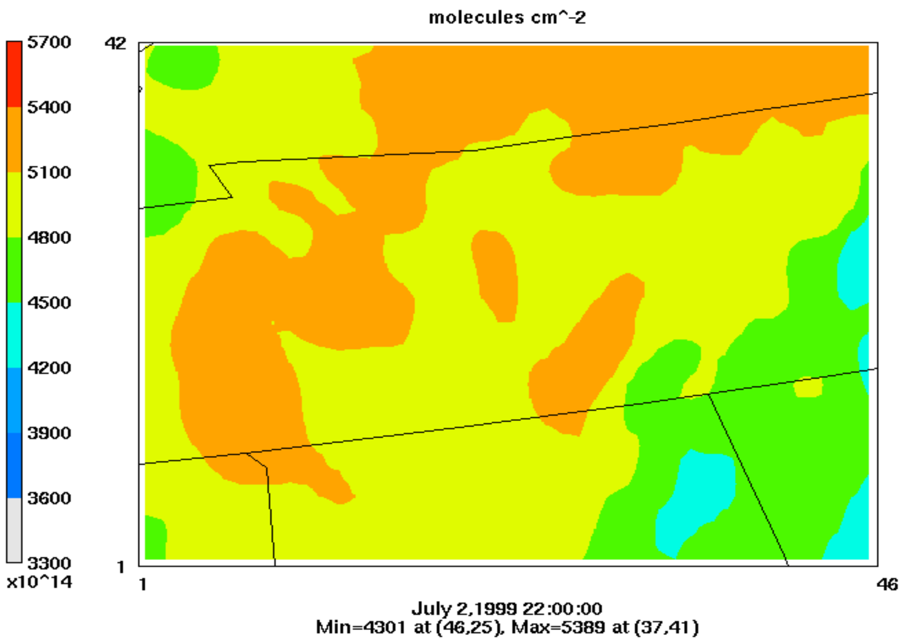
Hourly Surface Ozone Concentrations (ppmv)



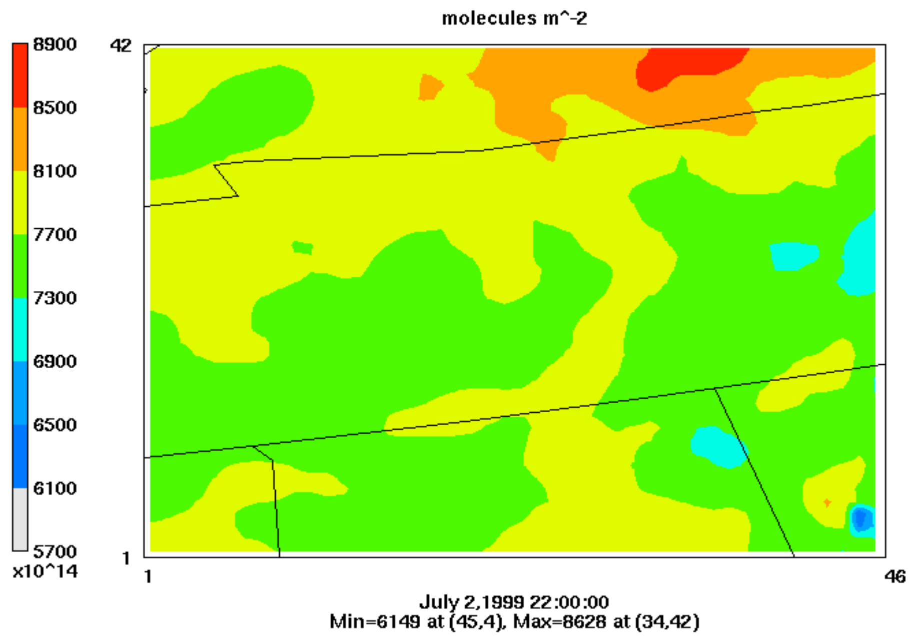
Ozone column abundance in PBL (0.0 - 1.5 km)



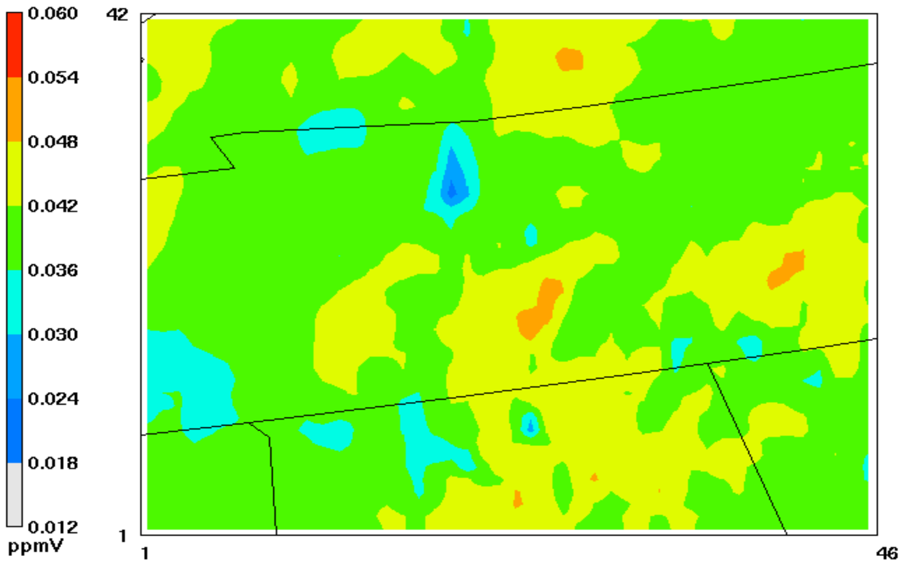
Ozone column abundance in free troposphere (1.5 - 8.0 km)



Total ozone column abundance (0.0 - 12.0 km)

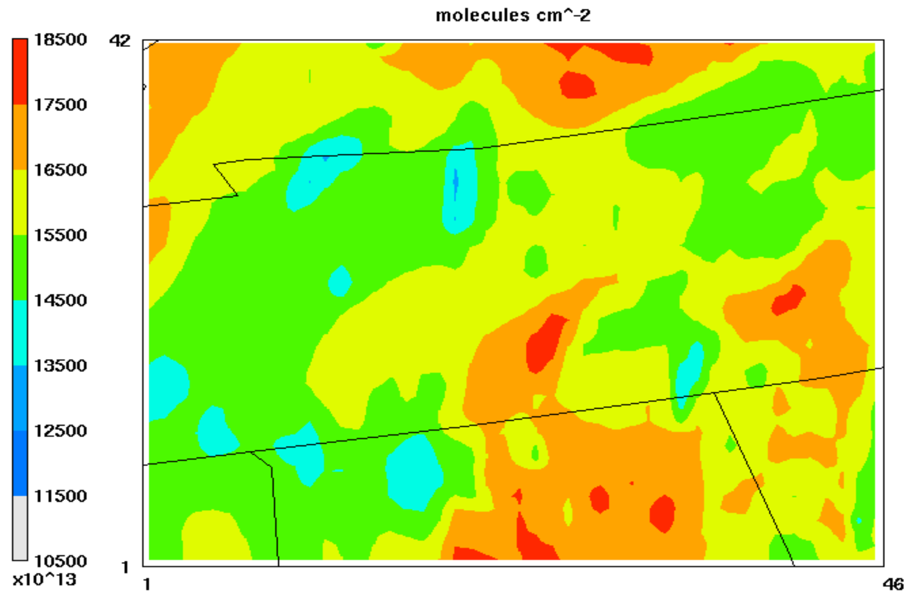


Hourly Surface Ozone Concentrations (ppmv)



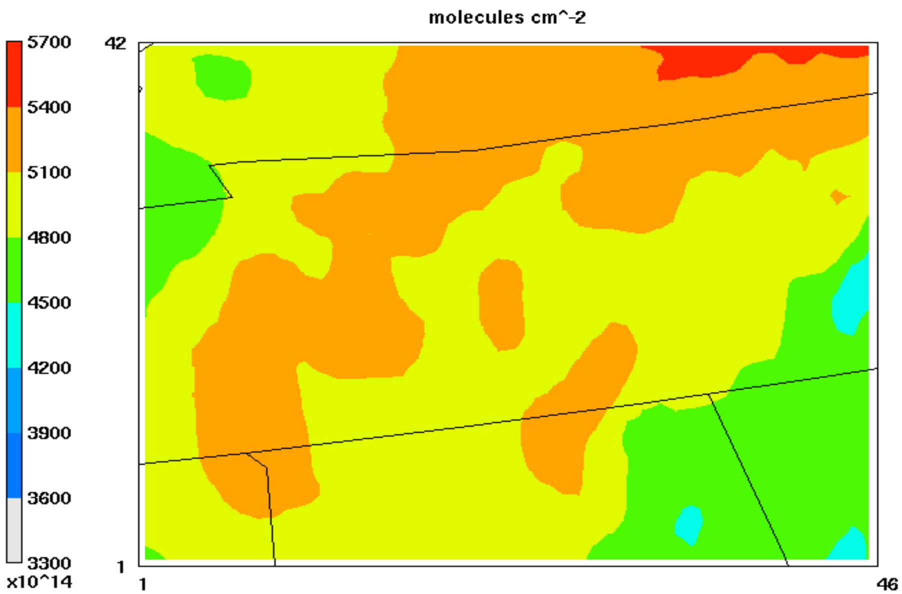
July 2,1999 23:00:00
Min=0.021 at (20,28), Max=0.051 at (25,17)

Ozone column abundance in PBL (0.0 - 1.5 km)



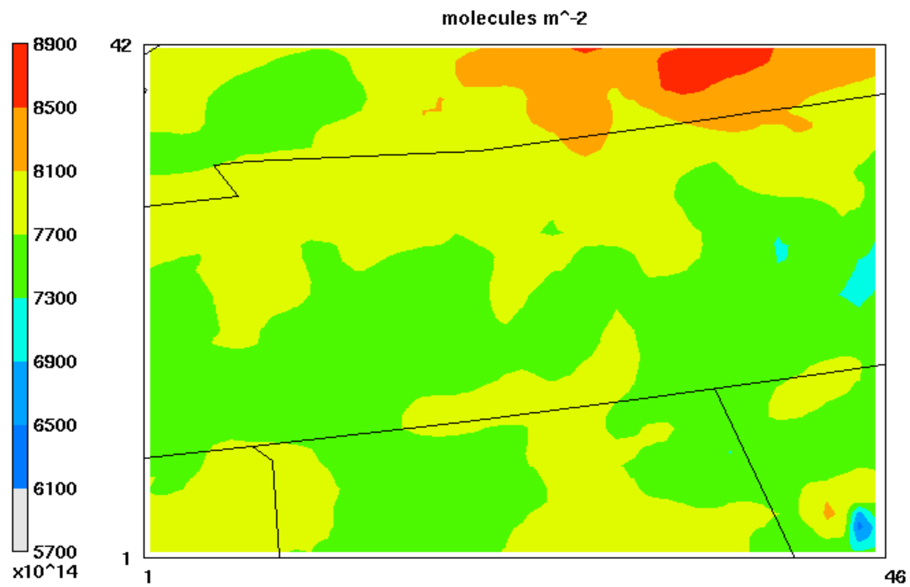
July 2,1999 23:00:00
Min=13330 at (20,31), Max=18140 at (25,17)

Ozone column abundance in free troposphere (1.5 - 8.0 km)



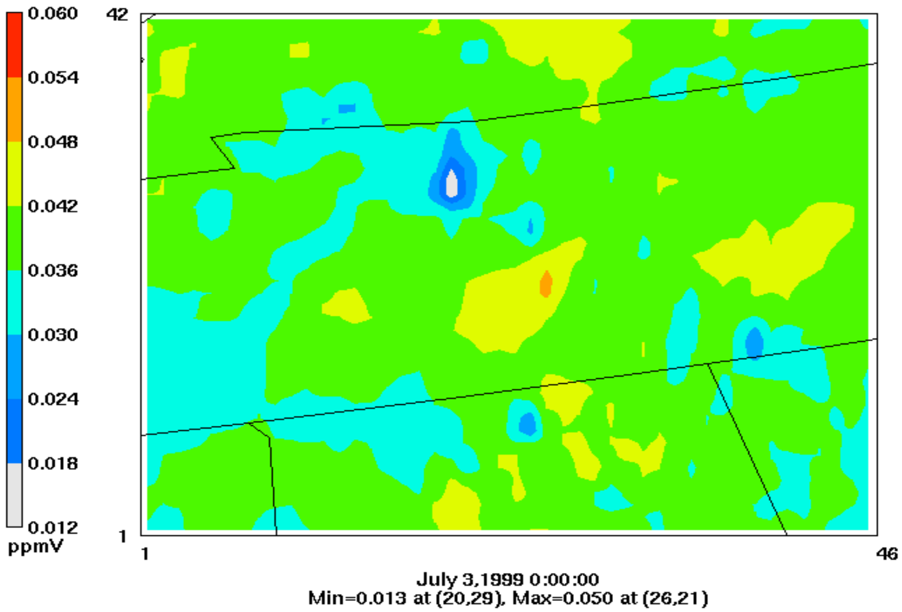
July 2,1999 23:00:00
Min=4371 at (45,22), Max=5442 at (37,42)

Total ozone column abundance (0.0 - 12.0 km)

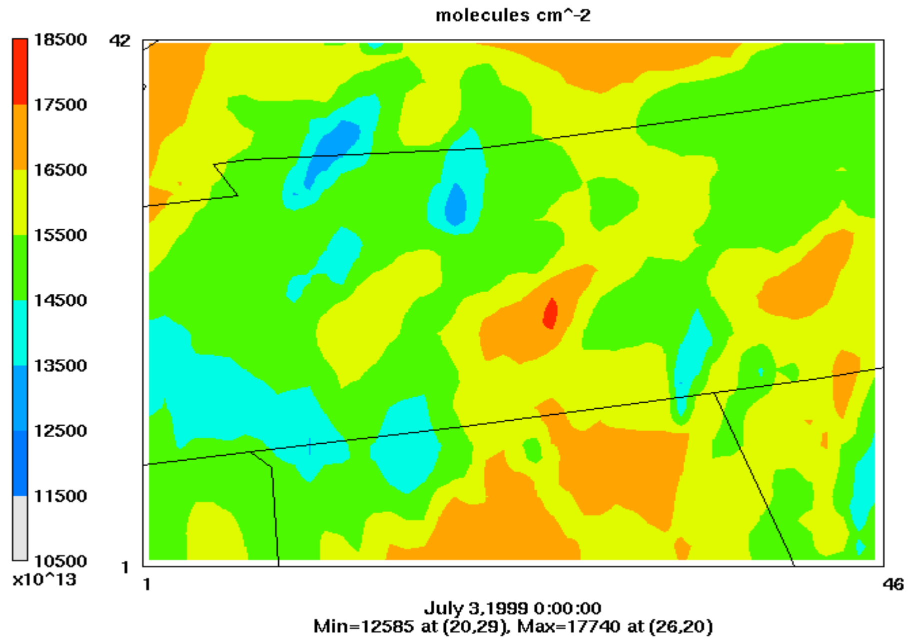


July 2,1999 23:00:00
Min=6366 at (45,3), Max=8619 at (38,42)

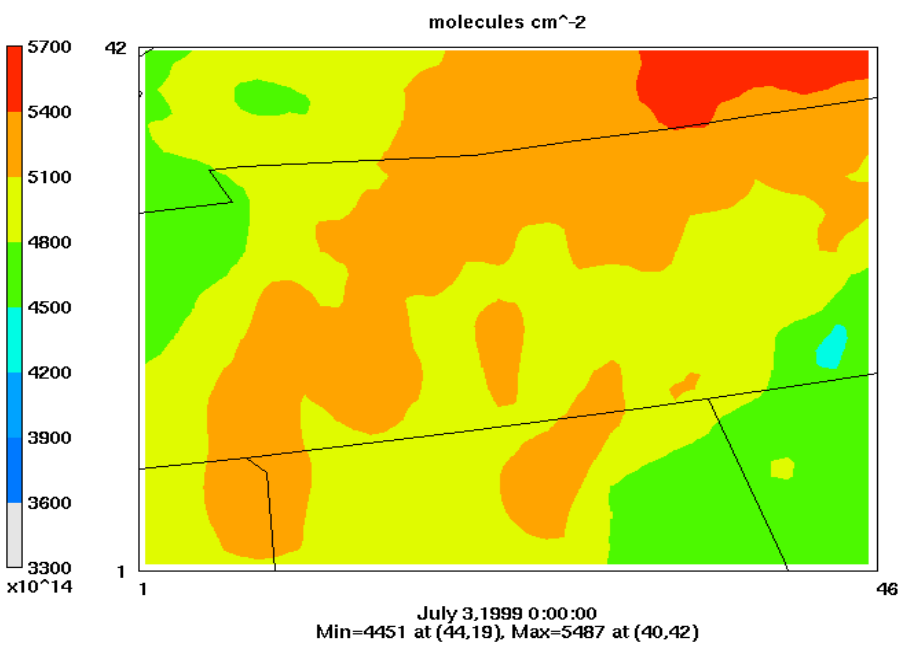
Hourly Surface Ozone Concentrations (ppmv)



Ozone column abundance in PBL (0.0 - 1.5 km)



Ozone column abundance in free troposphere (1.5 - 8.0 km)



Total ozone column abundance (0.0 - 12.0 km)