Integrated Solutions for Volcanic Ash in View of Recent Alaskan Eruptions

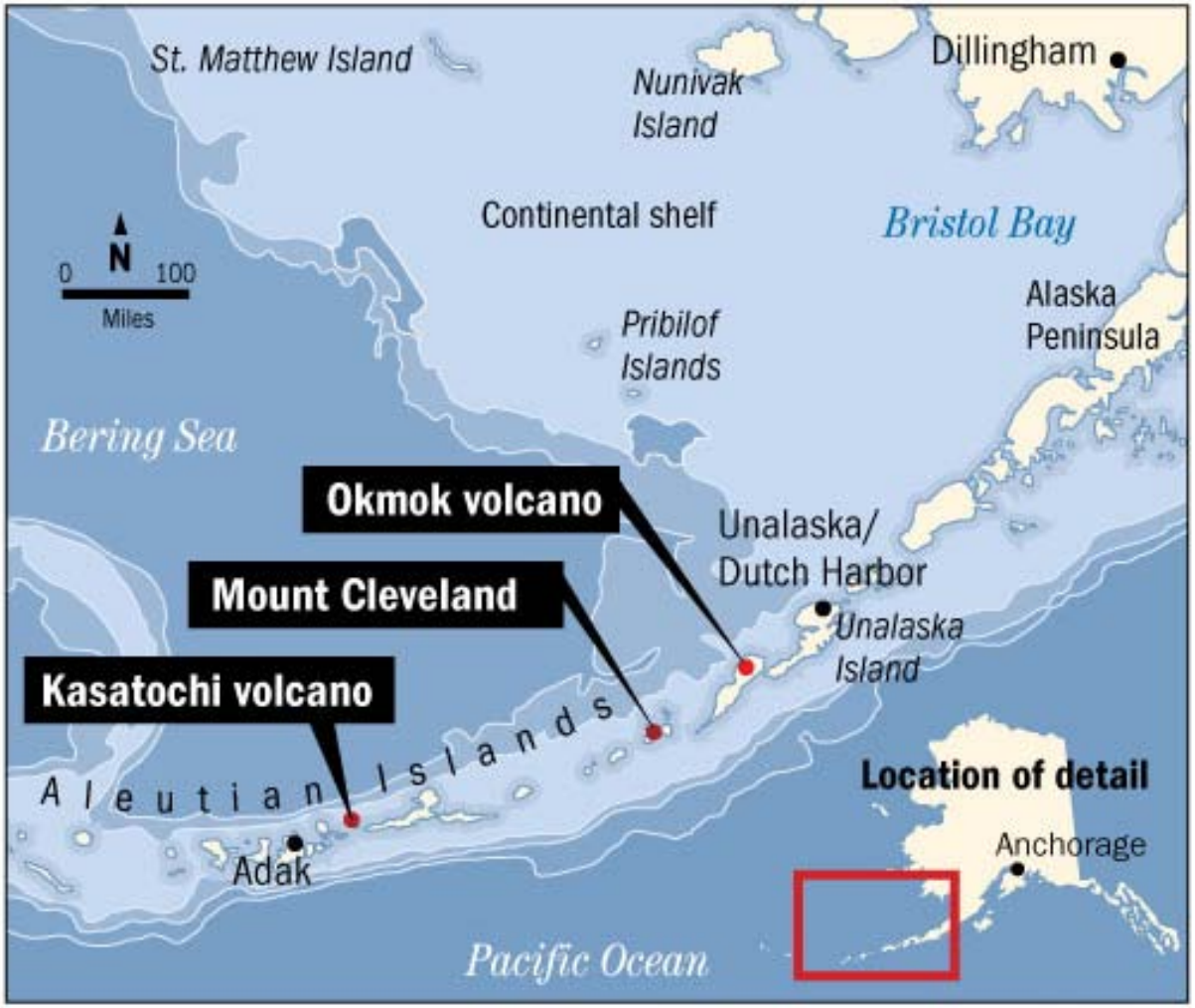
John J. Murray
NASA Langley Research Center

Image source: http://www.avo.alaska.edu/image.php?id=3595

1991 Pinatubo Eruption

- Lessons learned from the 1991 Pinatubo eruption
  - Largest eruption in the past 50 years
  - 20 ash encounters in flight, including a 747-400 jumbo jet (see figure)
  - Majority of ash encounters occurred when ash cloud at least 12 hours old and hundreds of miles from its source
  - The aging of volcanic ash reduces threat to aircraft, as larger particles (>30 μm diameter) particles had already settled from the cloud

Okmok and Kasatochi



RON ENGSTROM / Anchorage Daily News

Image source: http://www.adn.com

Volcano Okmok

- Stratovolcano (viscous lava, steep slope)
- Eruption at 1143Z on 12 July 2008
- Volcanic explosivity index (VEI) of 4
- Ash plume reached 15 km above MSL
- Ash drifted to the south and east over the North Pacific Ocean

Image source: http://geology.com

Okmok Eruption

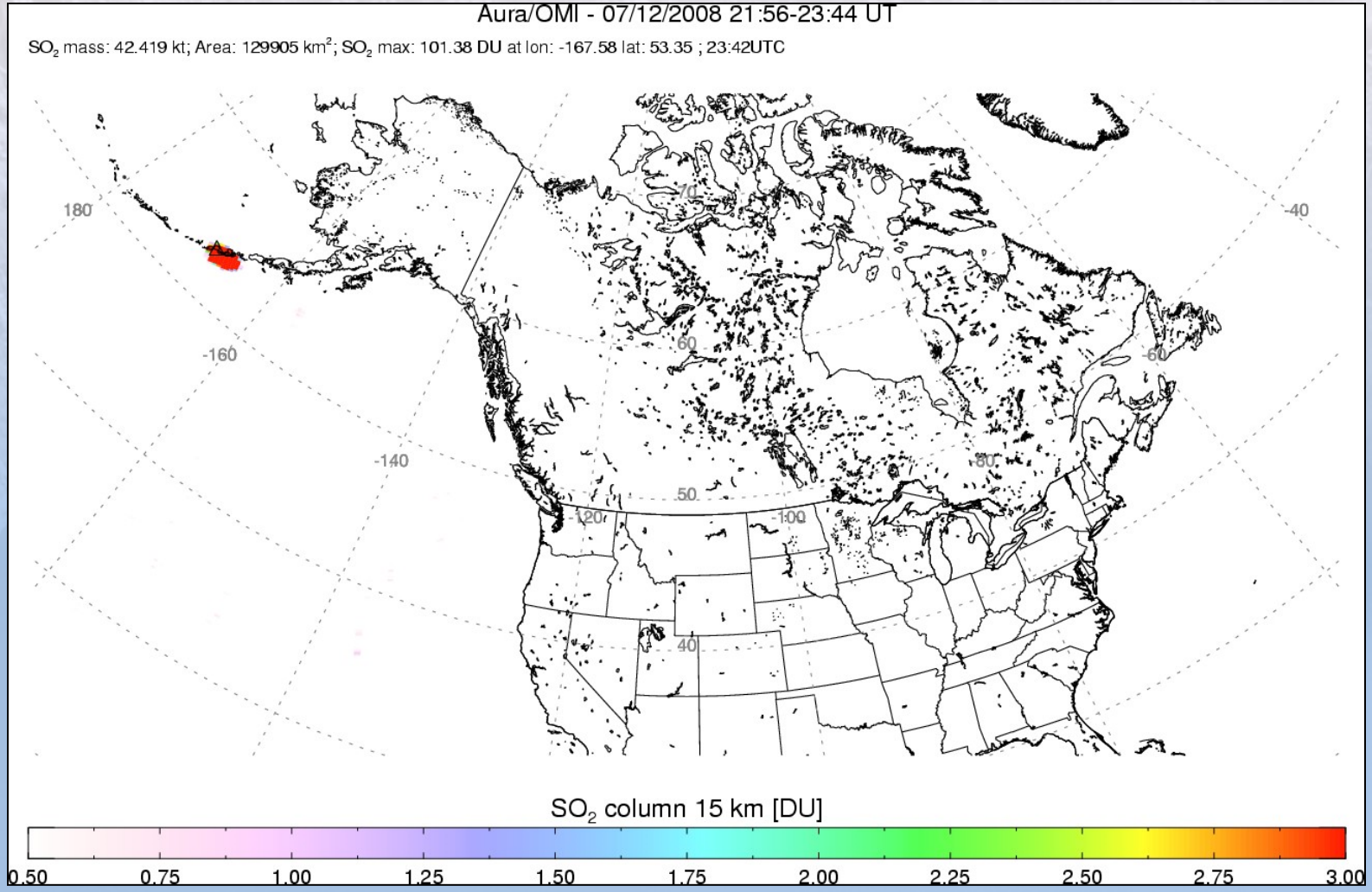


Image source: http://so2.umbc.edu/omi

Okmok Eruption

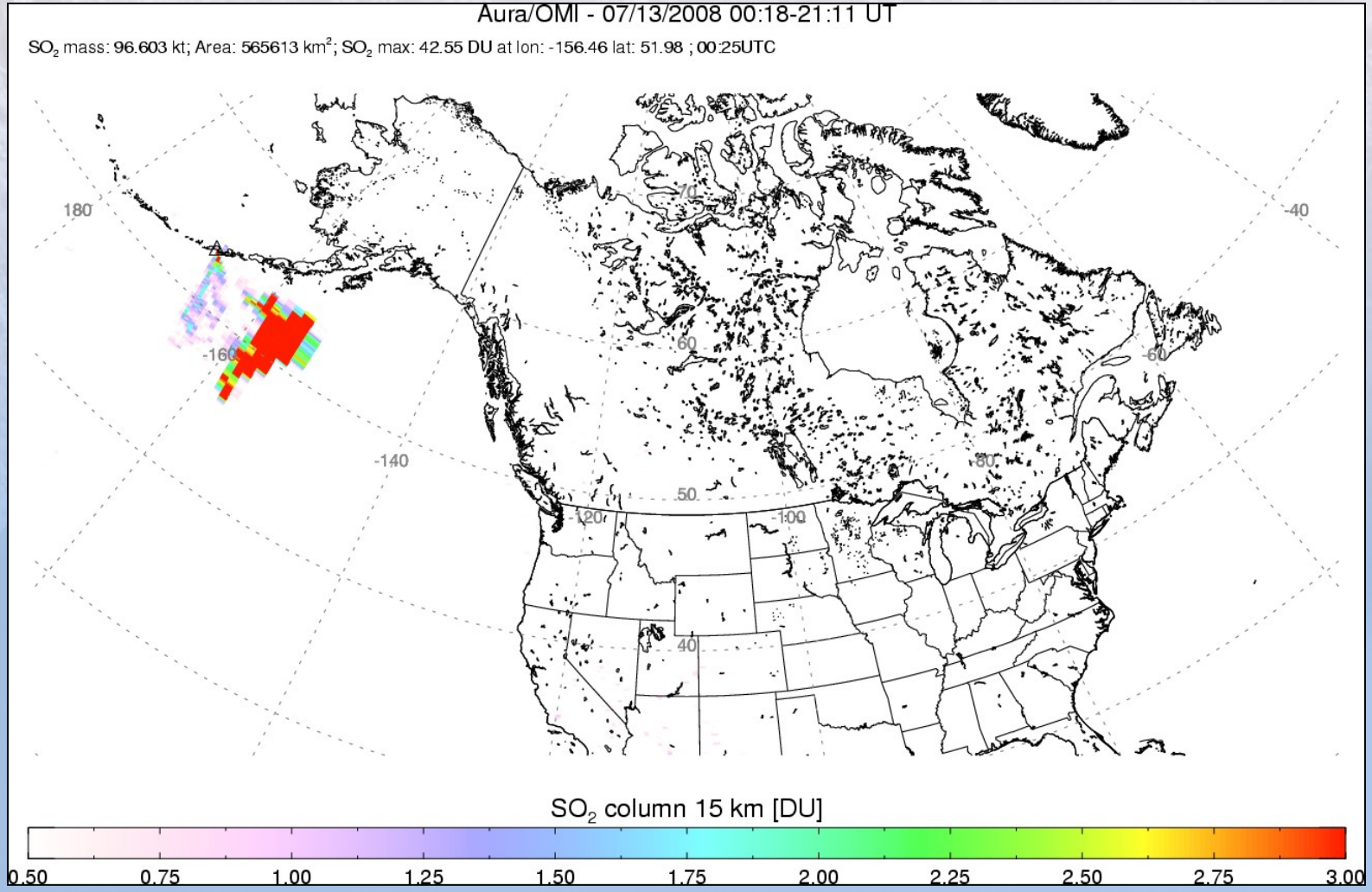


Image source: http://so2.umbc.edu/omi

Okmok Eruption

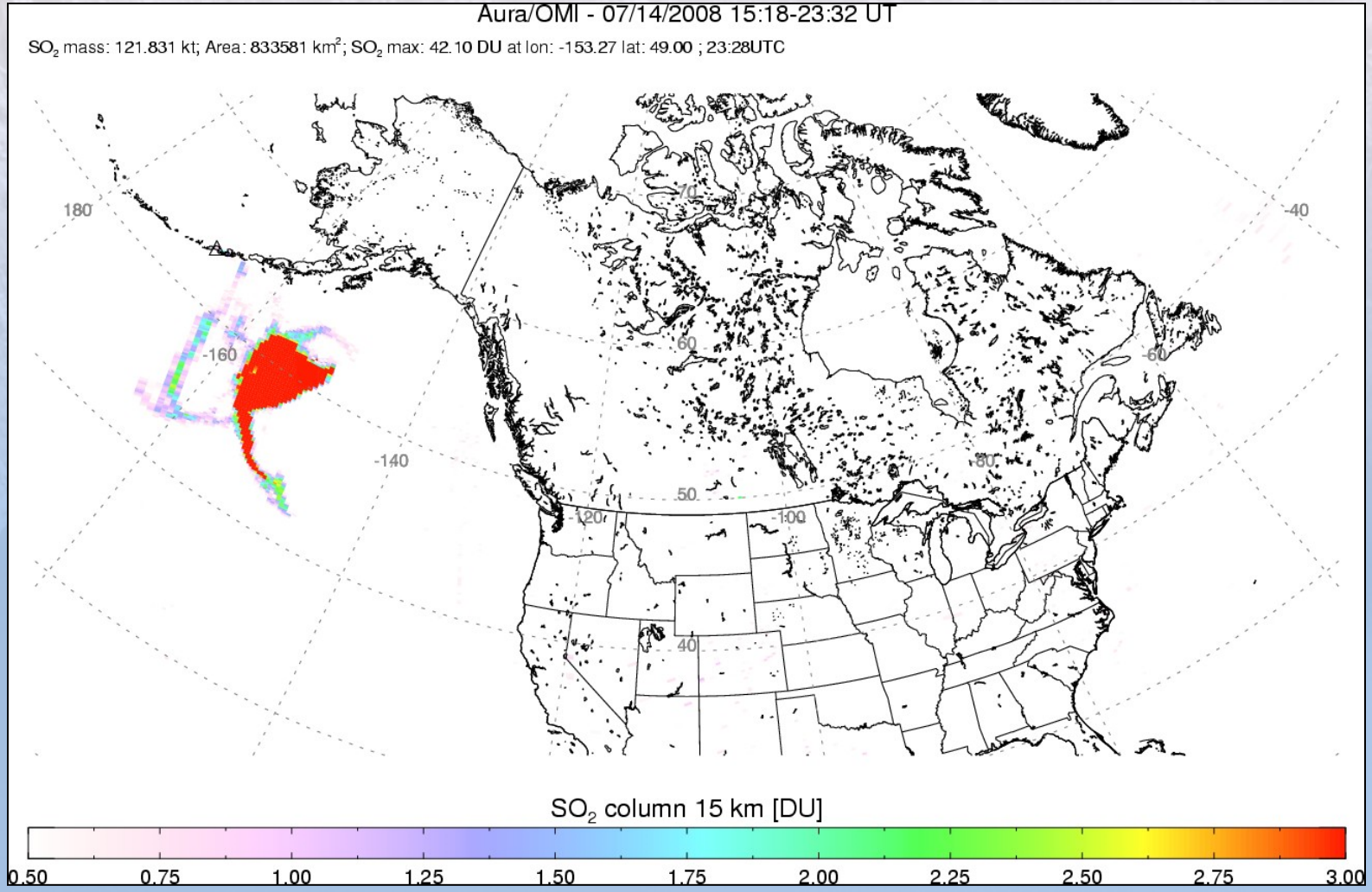


Image source: http://so2.umbc.edu/omi

Okmok Eruption

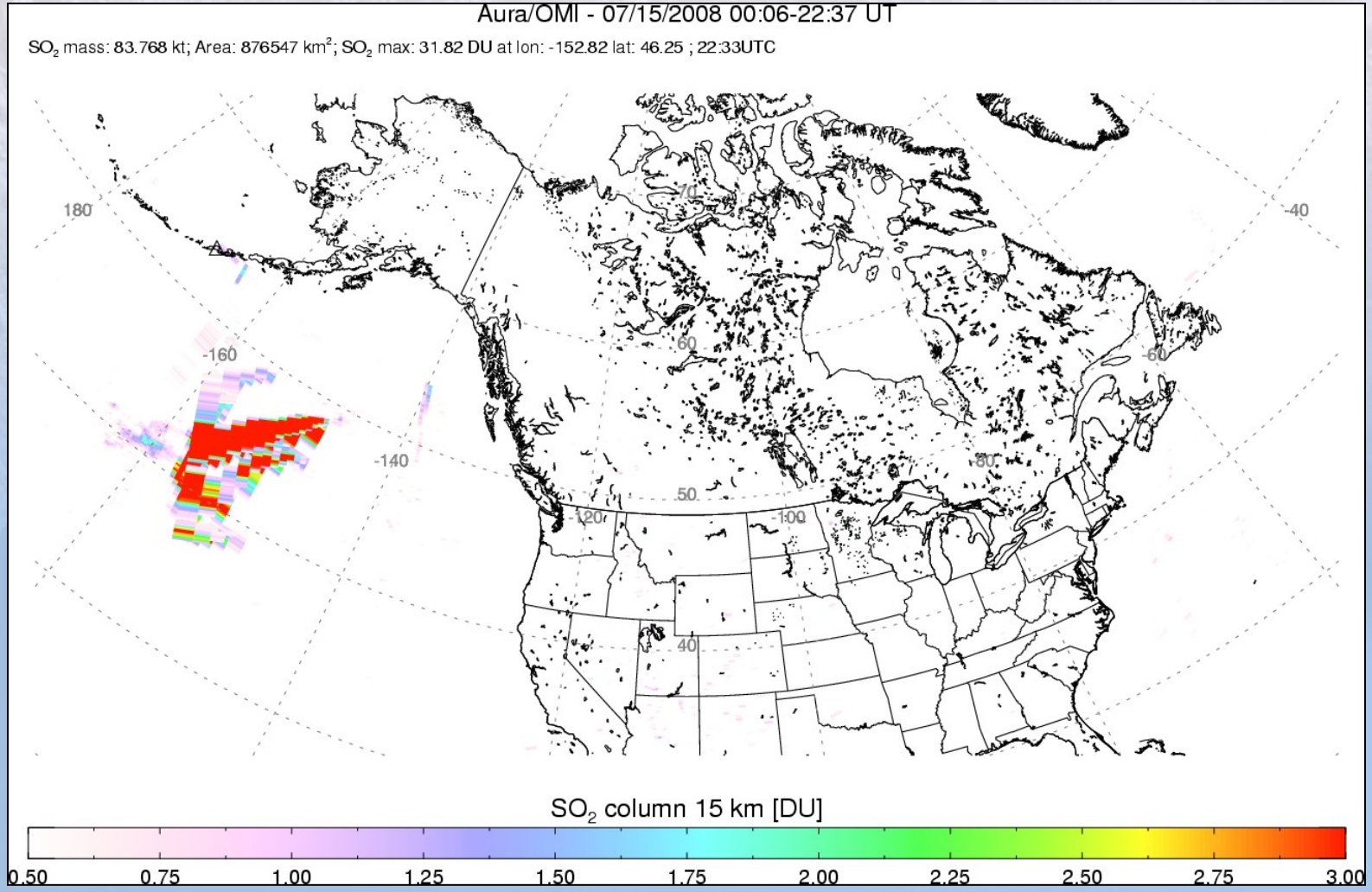


Image source: http://so2.umbc.edu/omi

Okmok Eruption

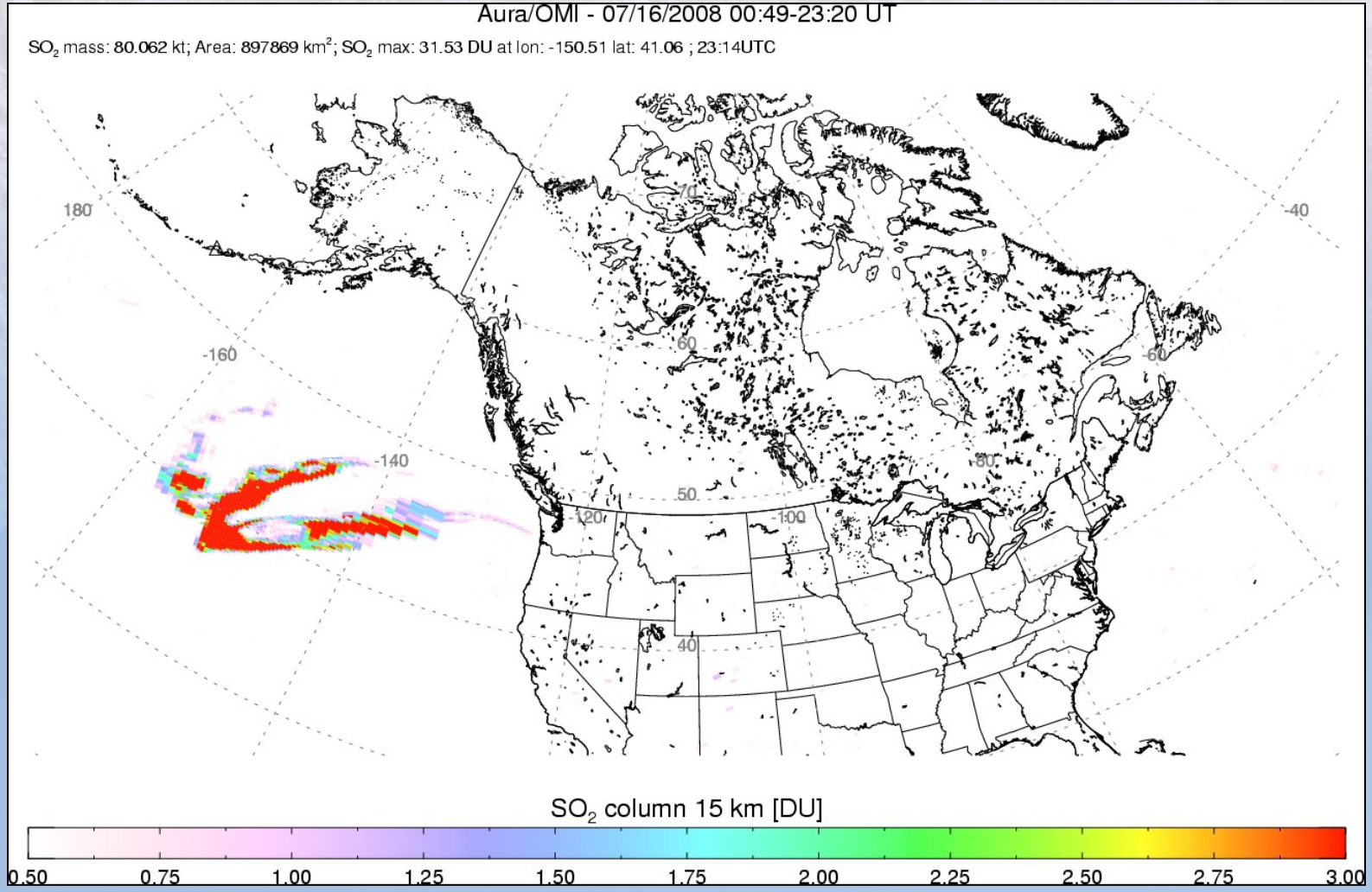


Image source: http://so2.umbc.edu/omi

Okmok Eruption

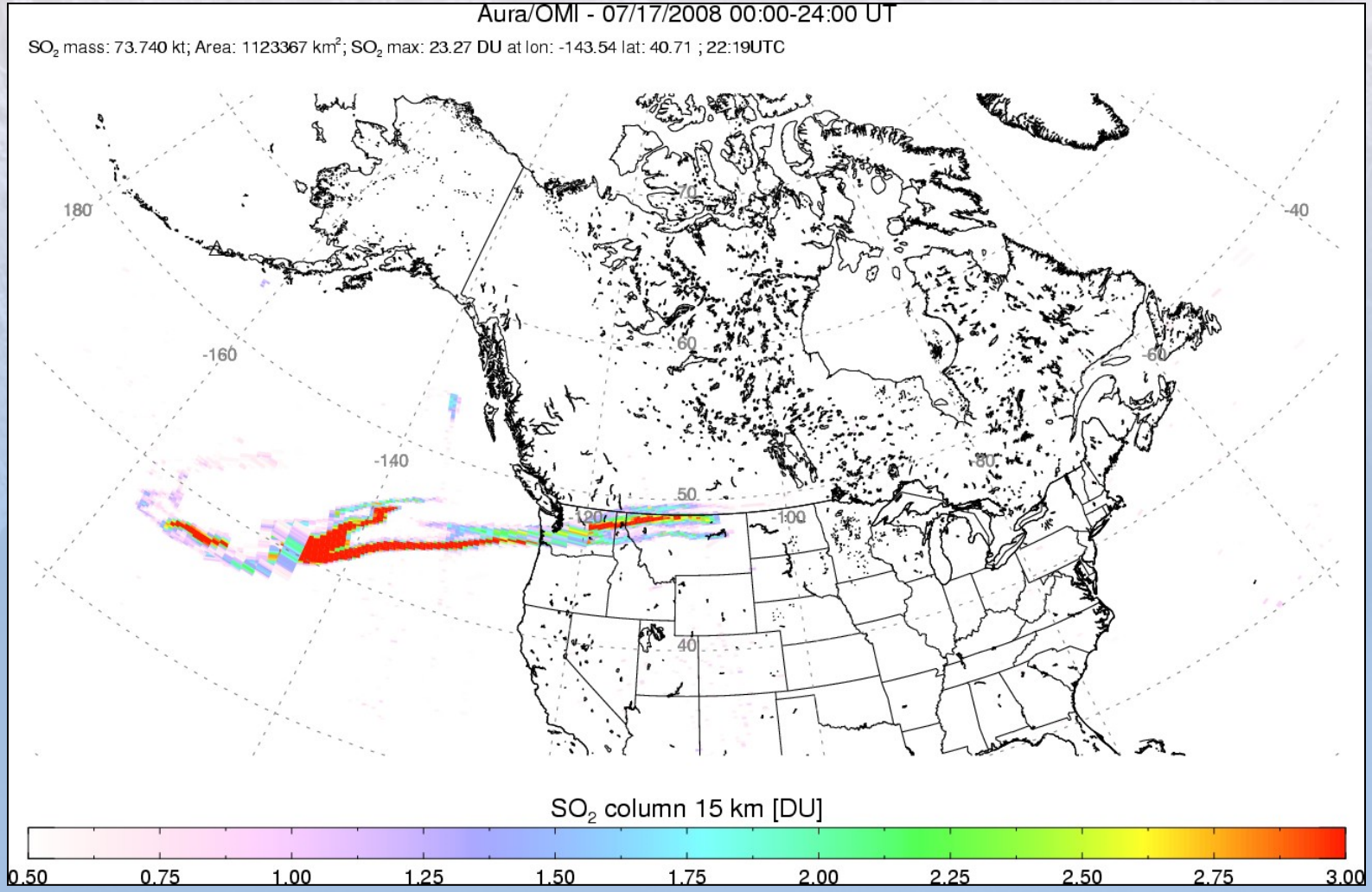


Image source: http://so2.umbc.edu/omi

Okmok Eruption

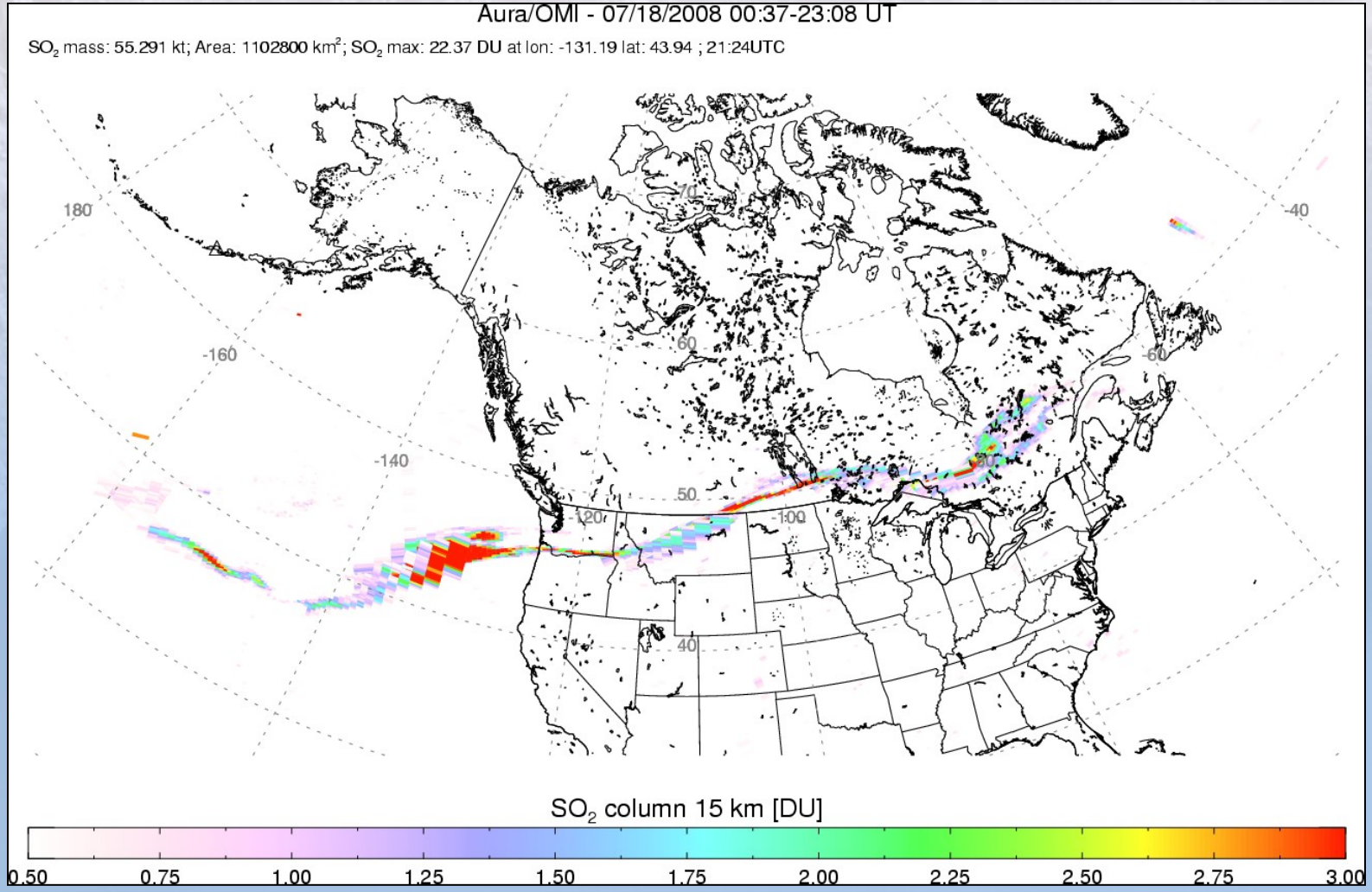


Image source: http://so2.umbc.edu/omi

Okmok Eruption

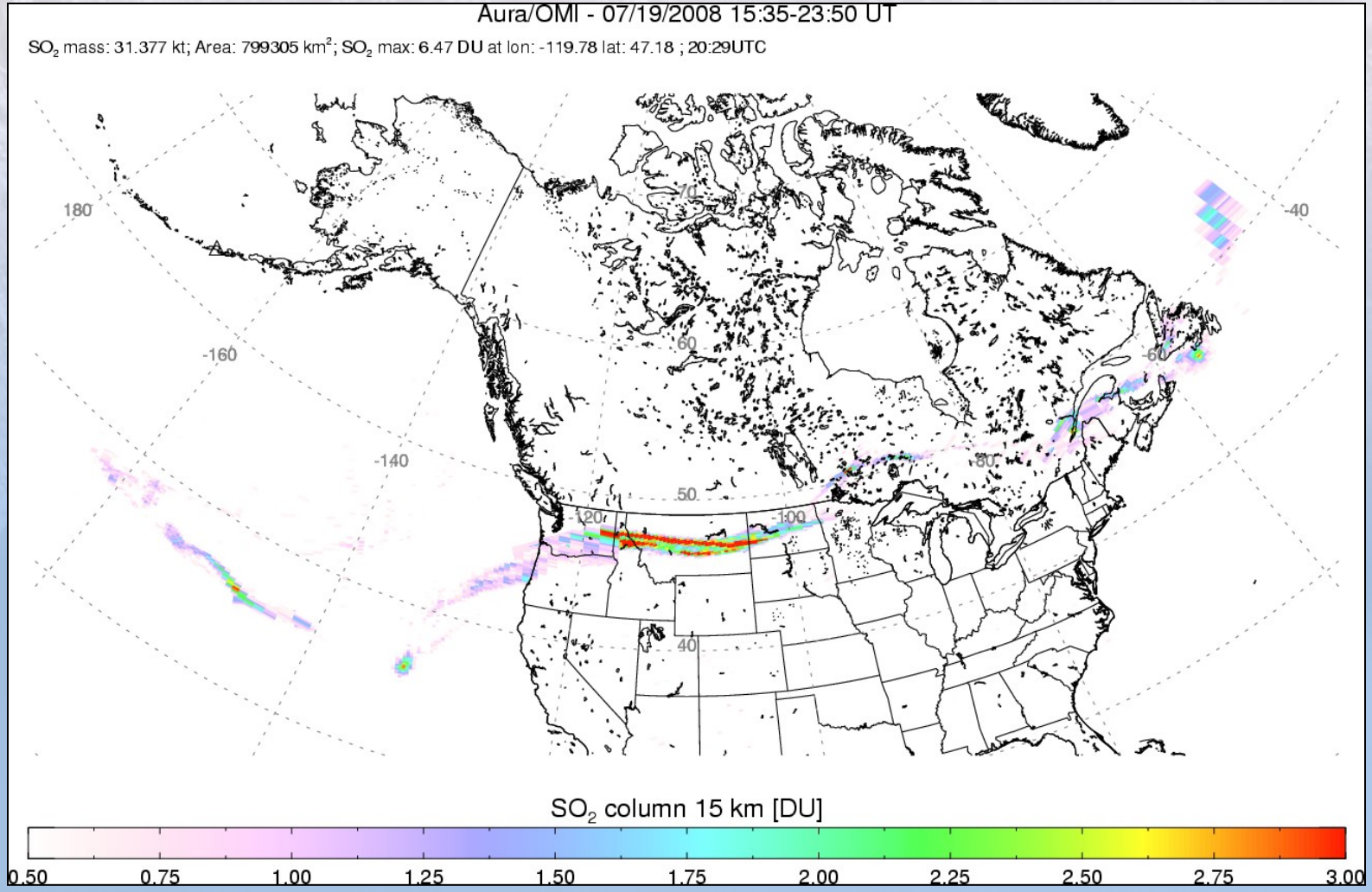


Image source: http://so2.umbc.edu/omi

Okmok Eruption

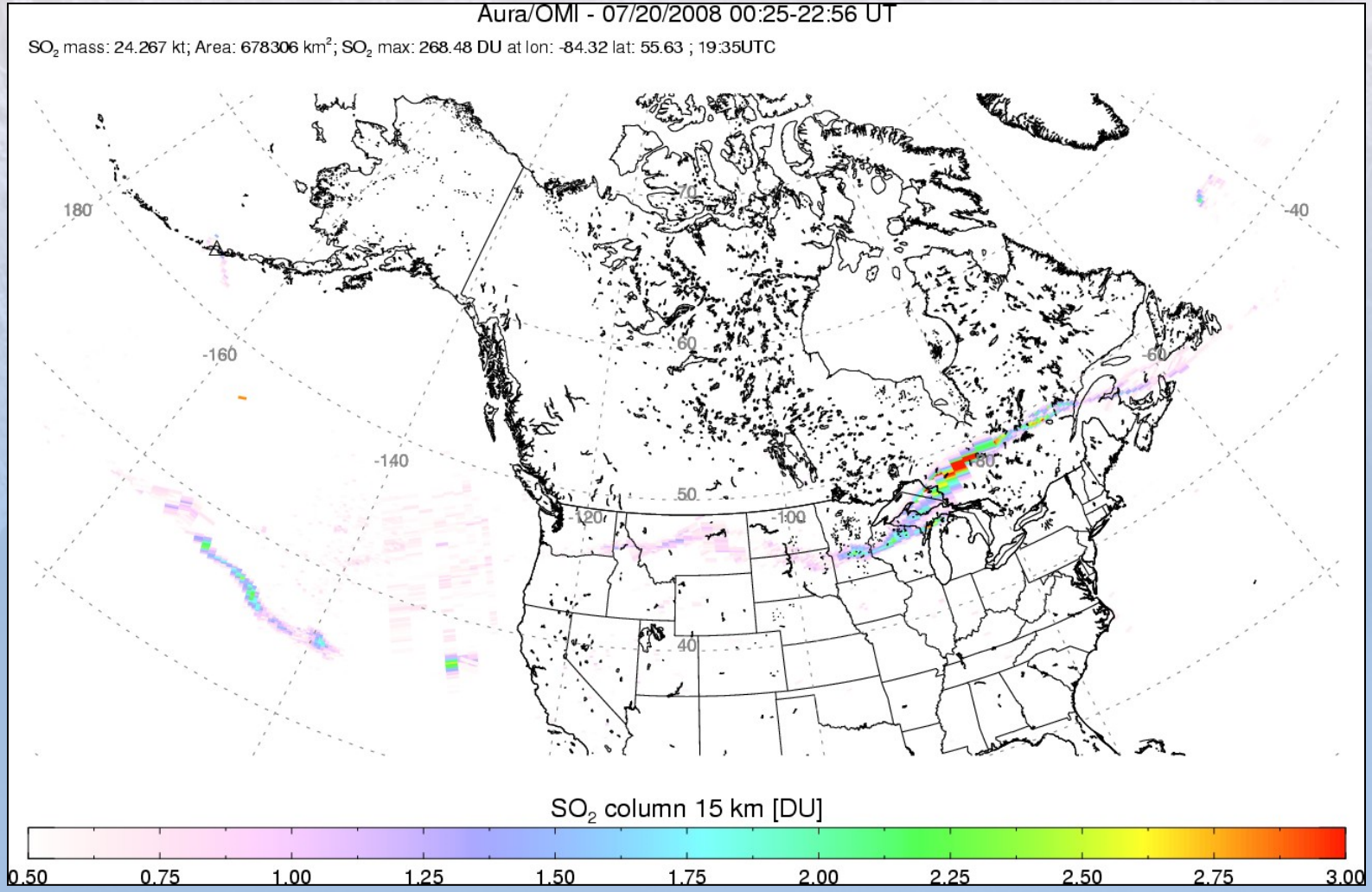
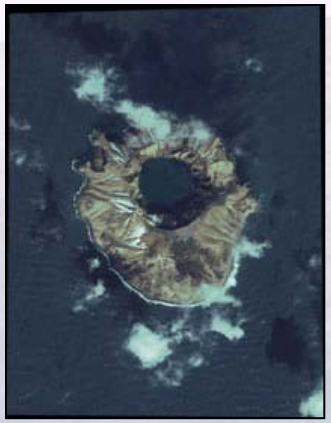


Image source: http://so2.umbc.edu/omi

Volcano Kasatochi



- Shield volcano (fluid lava, gentle slope)
- Eruption at 2230Z on 7 August 2008
- Volcanic explosivity index (VEI) of 4
- Ash plume reached 10.7 km above MSL
- Ash drifted to the south

Image source: http://alaskareport.com

Kasatochi Eruption

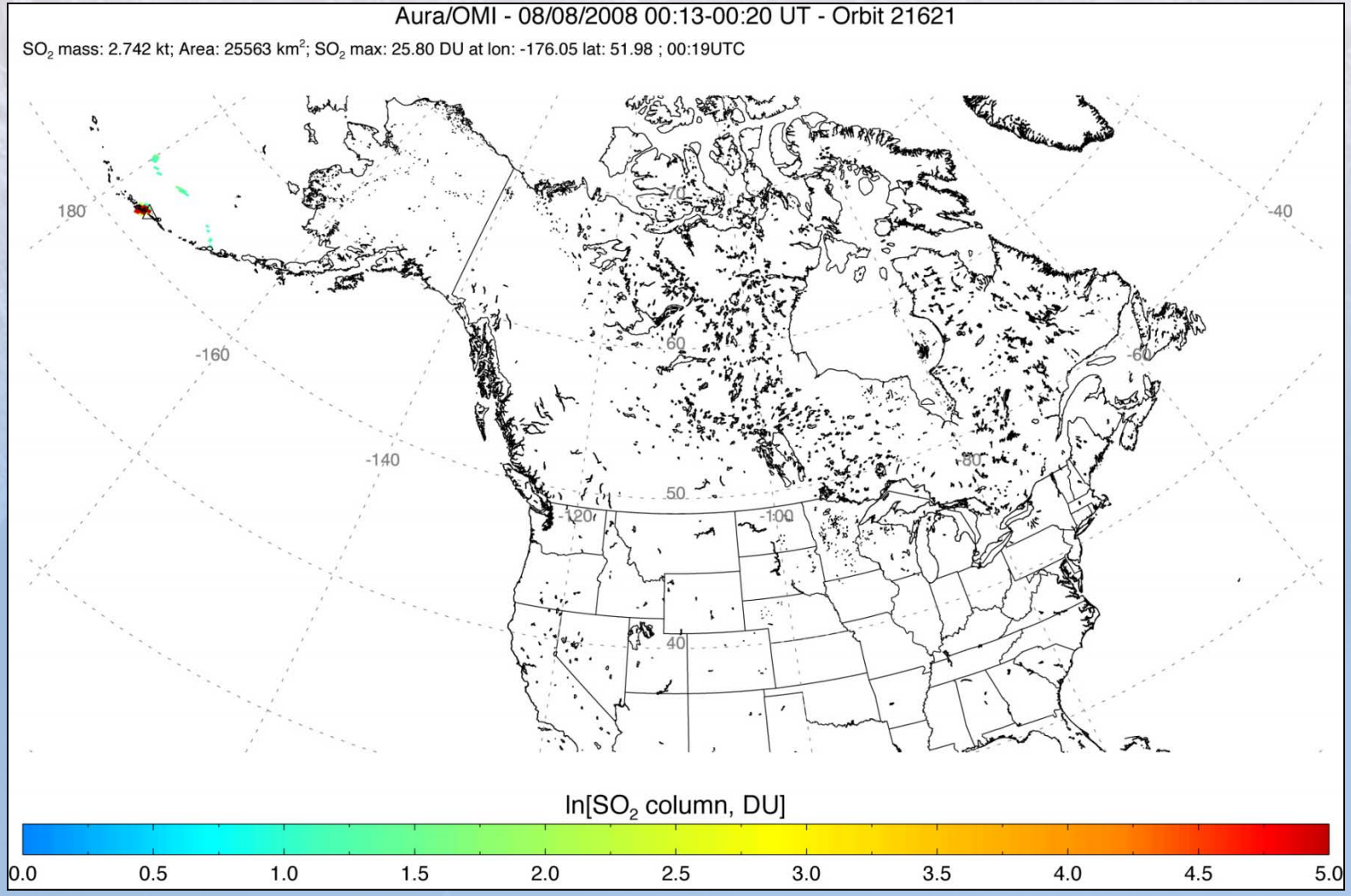


Image source: http://so2.umbc.edu/omi

Kasatochi Eruption

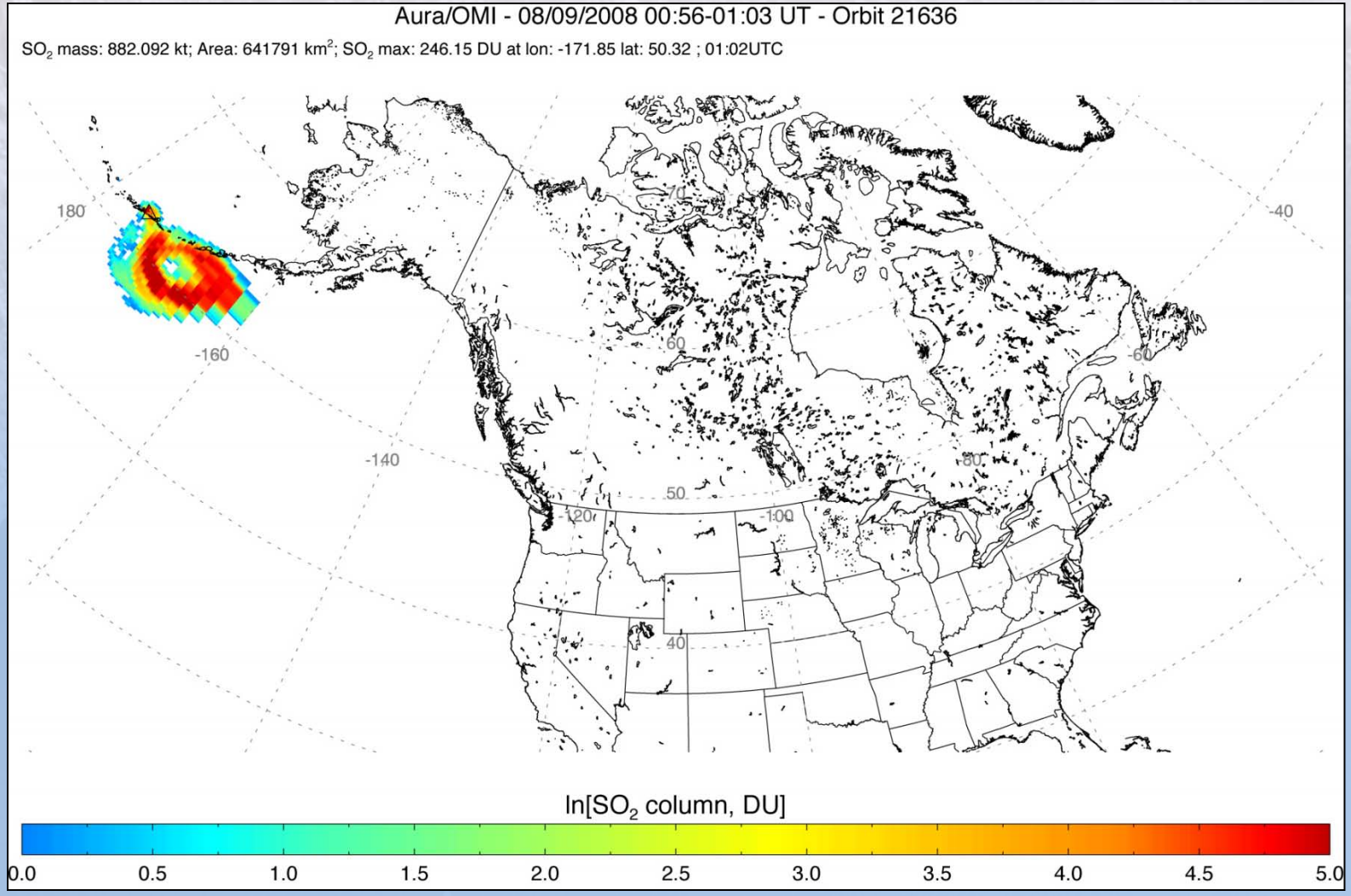


Image source: http://so2.umbc.edu/omi

Kasatochi Eruption

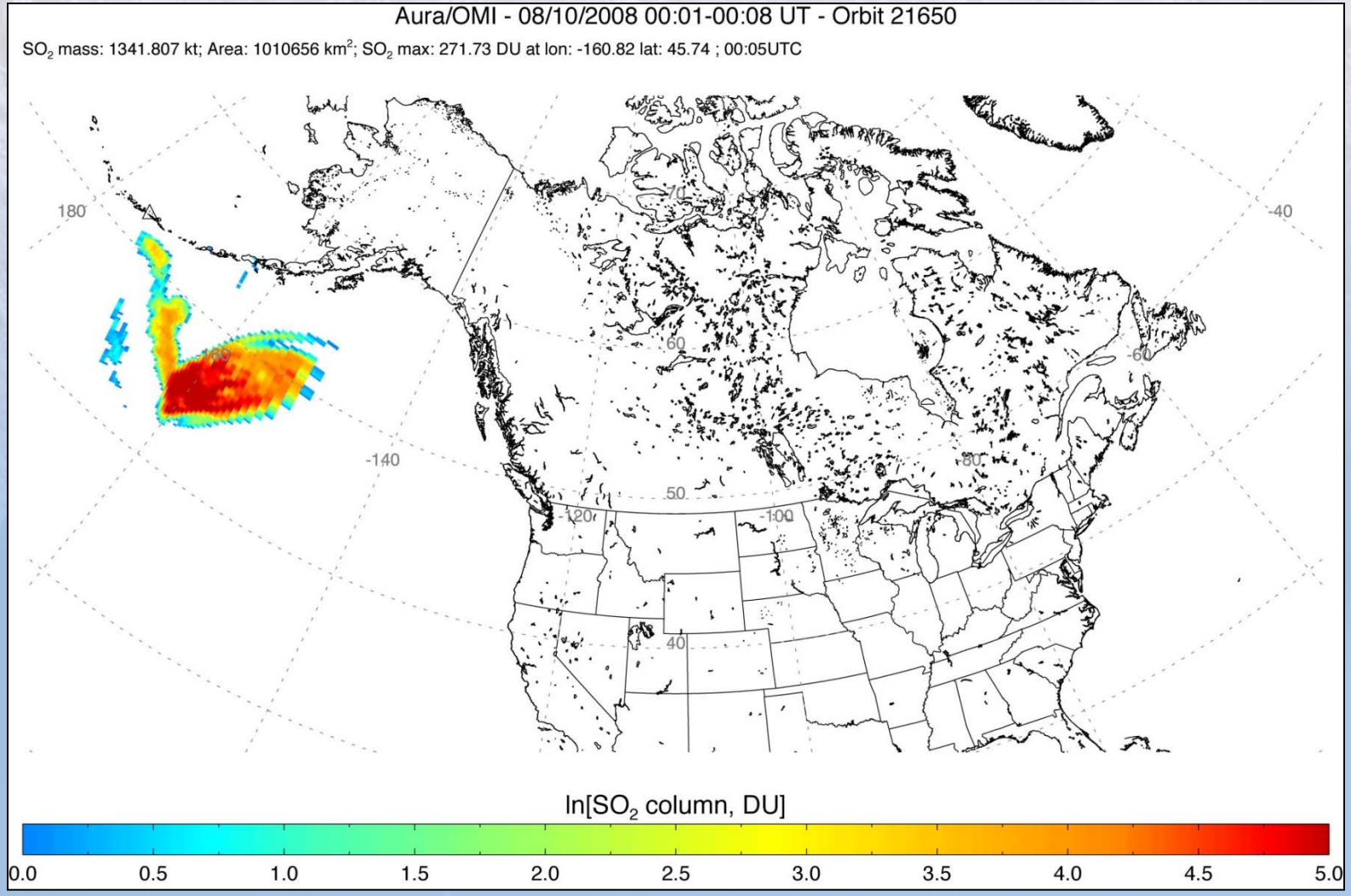


Image source: http://so2.umbc.edu/omi

Kasatochi Eruption

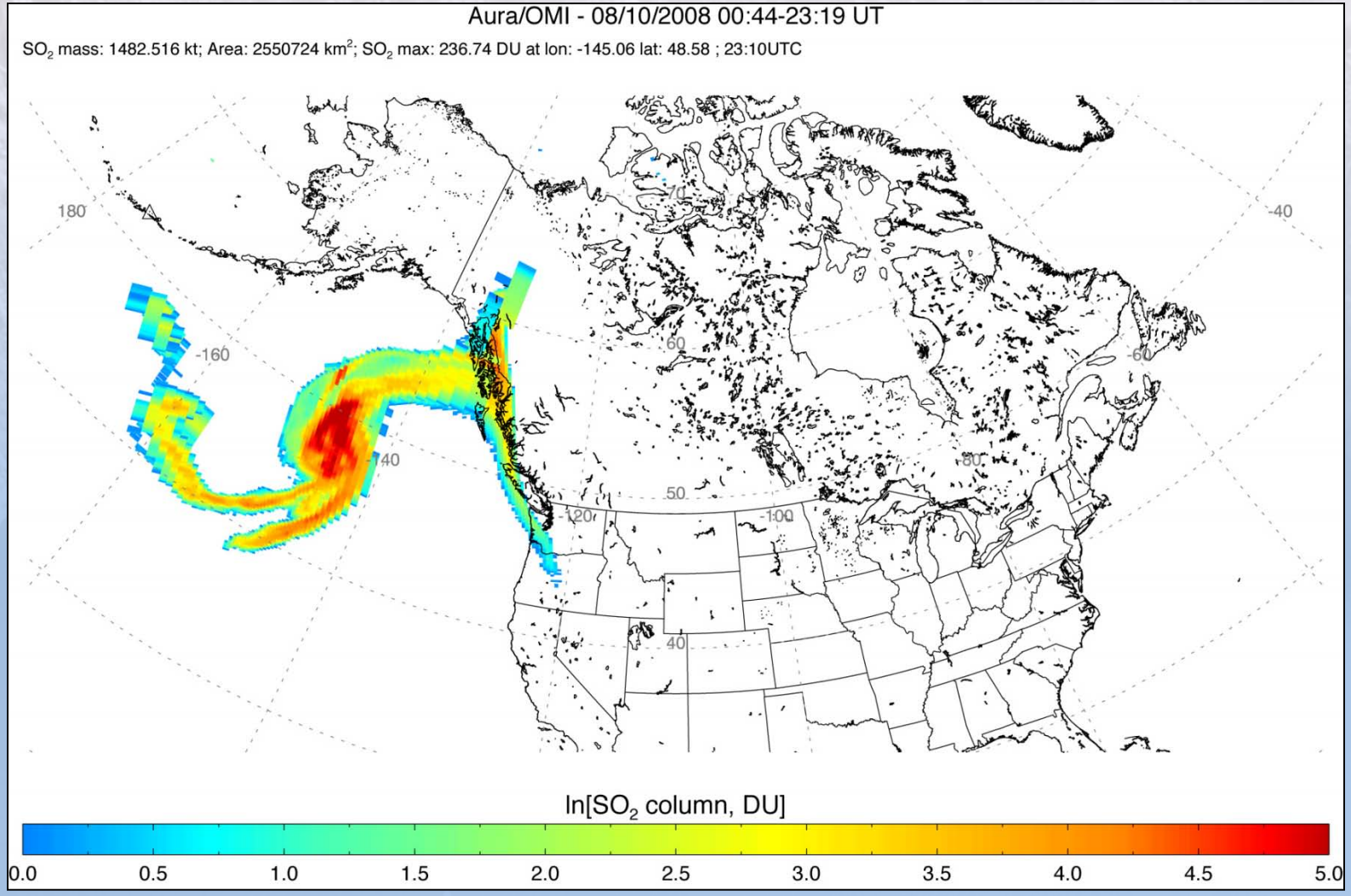


Image source: http://so2.umbc.edu/omi

Kasatochi Eruption

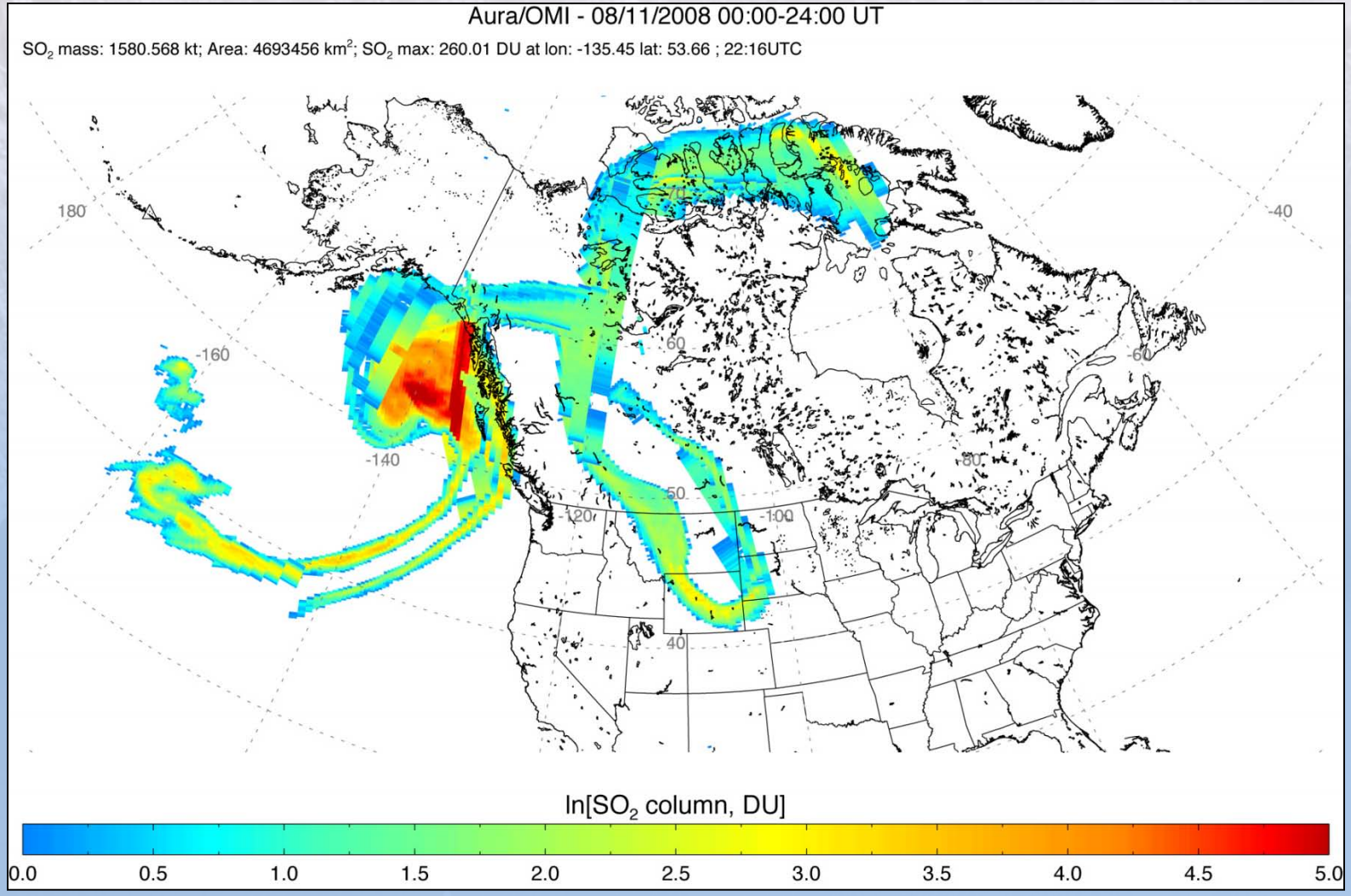


Image source: http://so2.umbc.edu/omi

Kasatochi Eruption

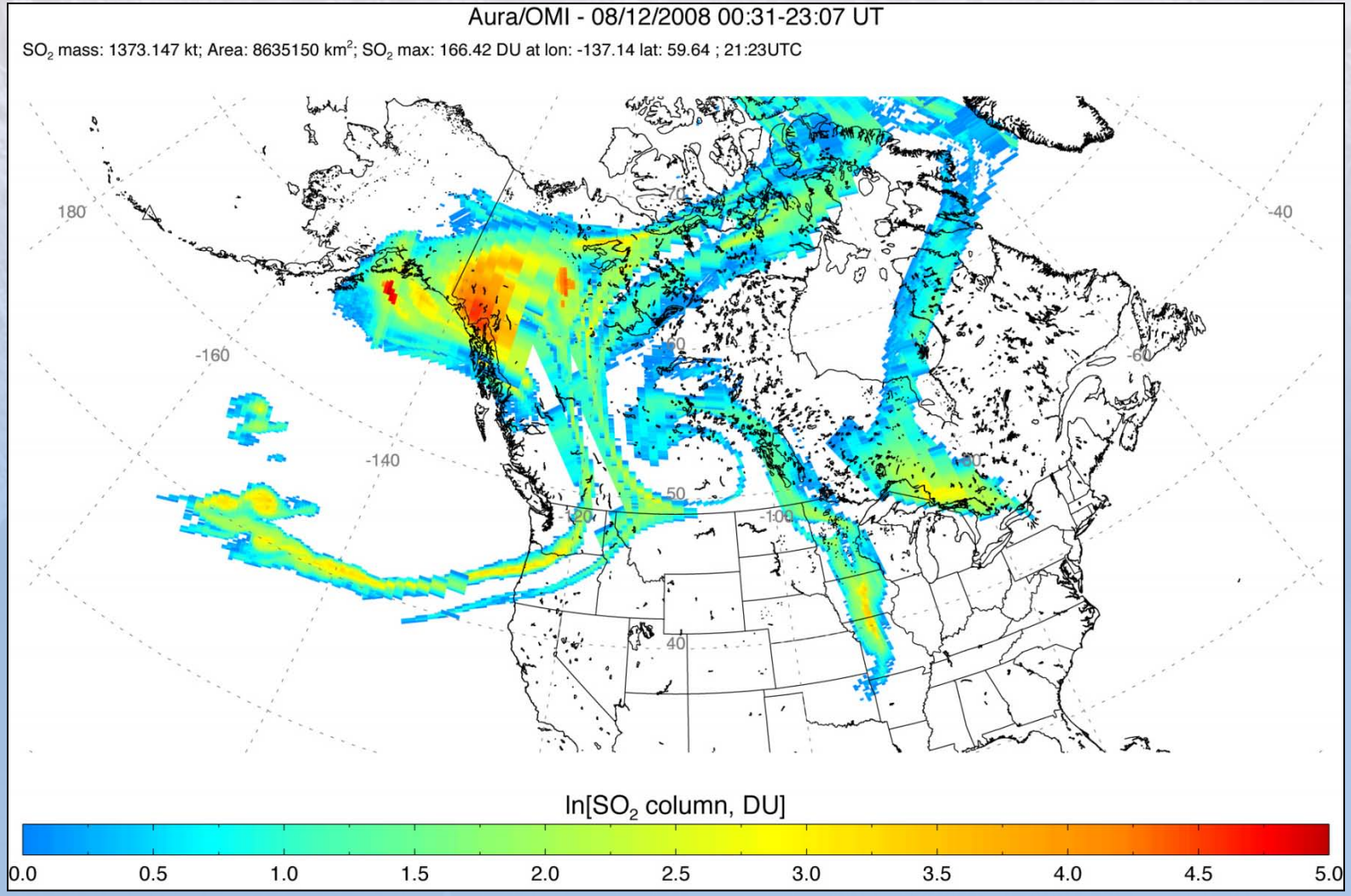


Image source: http://so2.umbc.edu/omi

Kasatochi Eruption

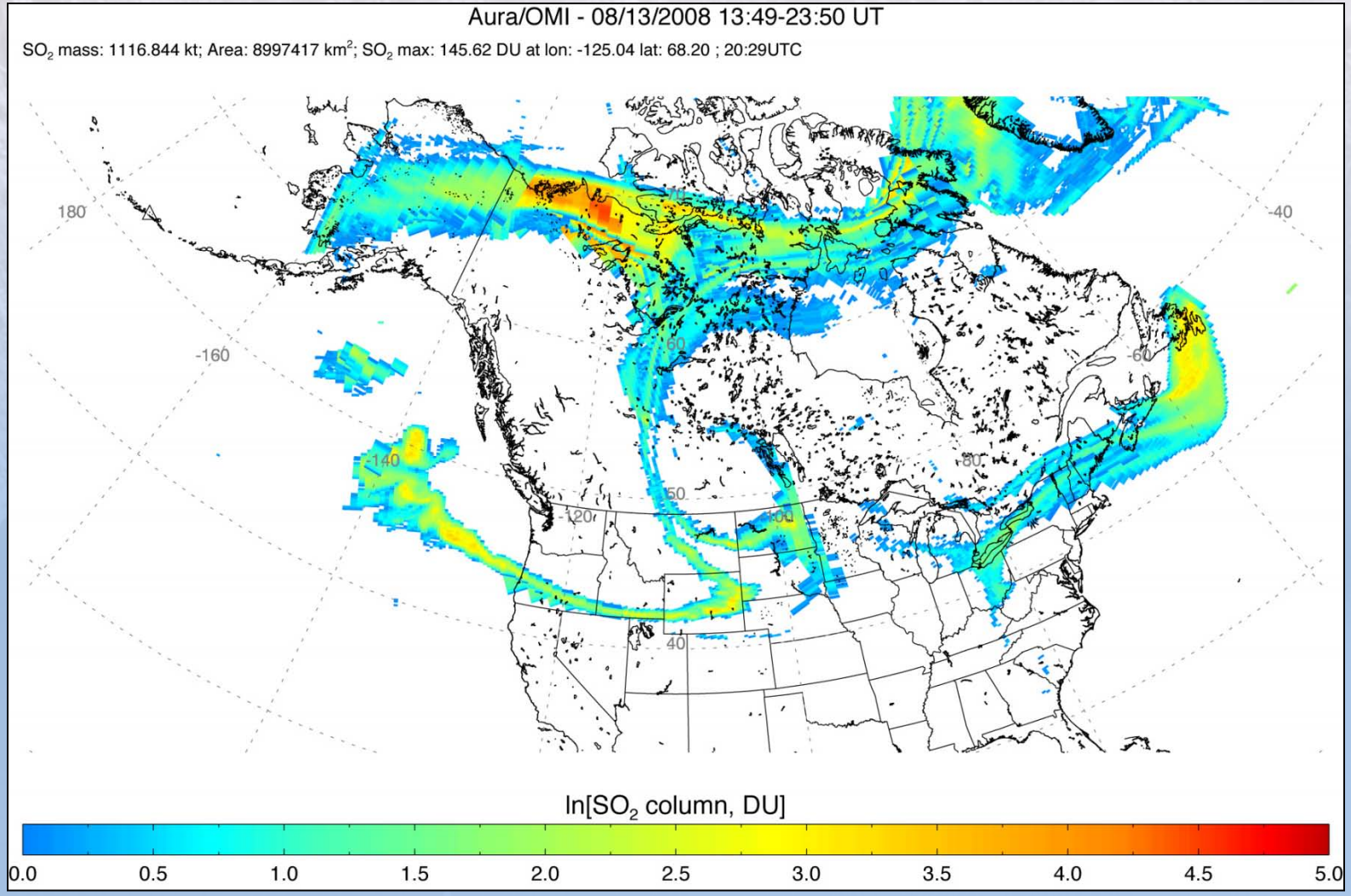
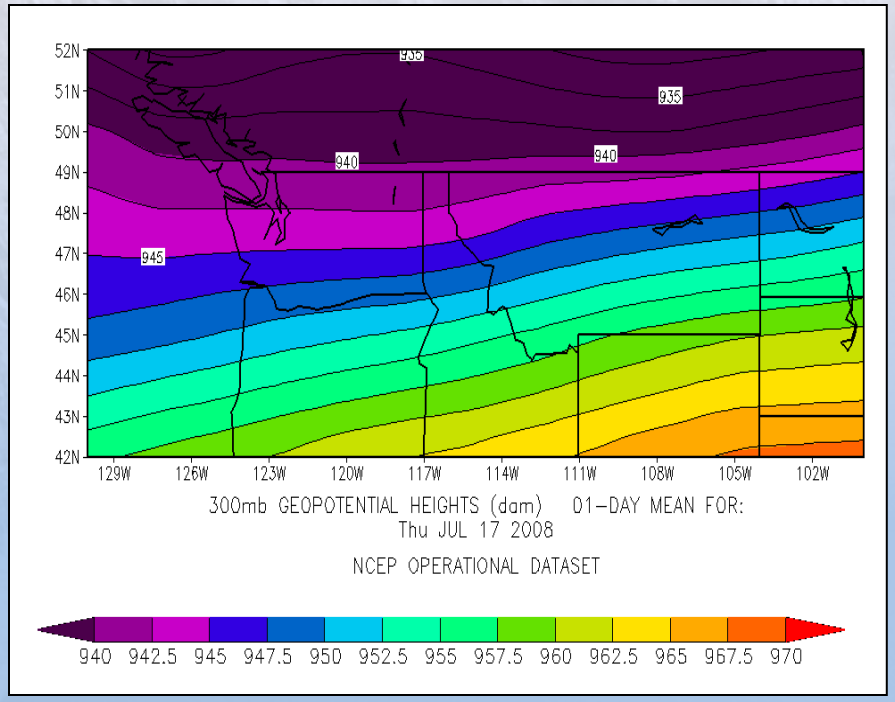


Image source: http://so2.umbc.edu/omi

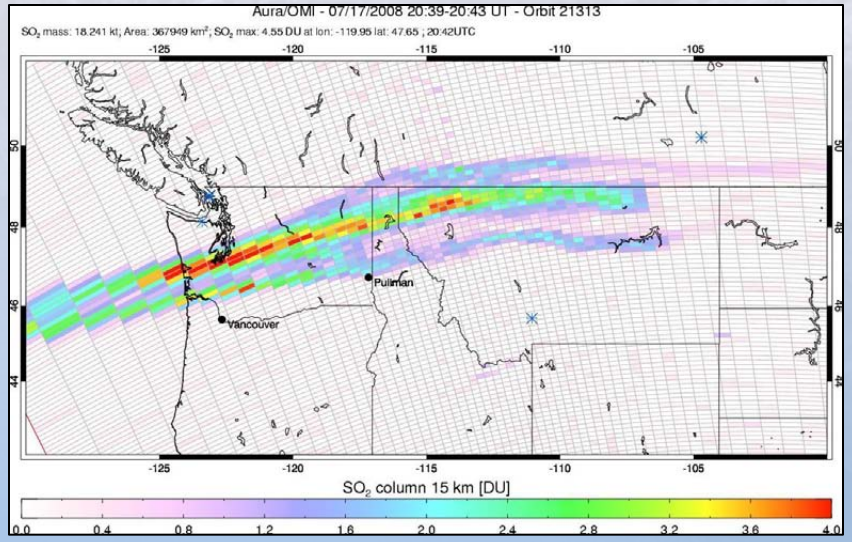
Synoptic Pattern: Okmok

300mb Geopotential Heights*



Source: http://www.cdc.noaa.gov

SO_2 Column Measurements

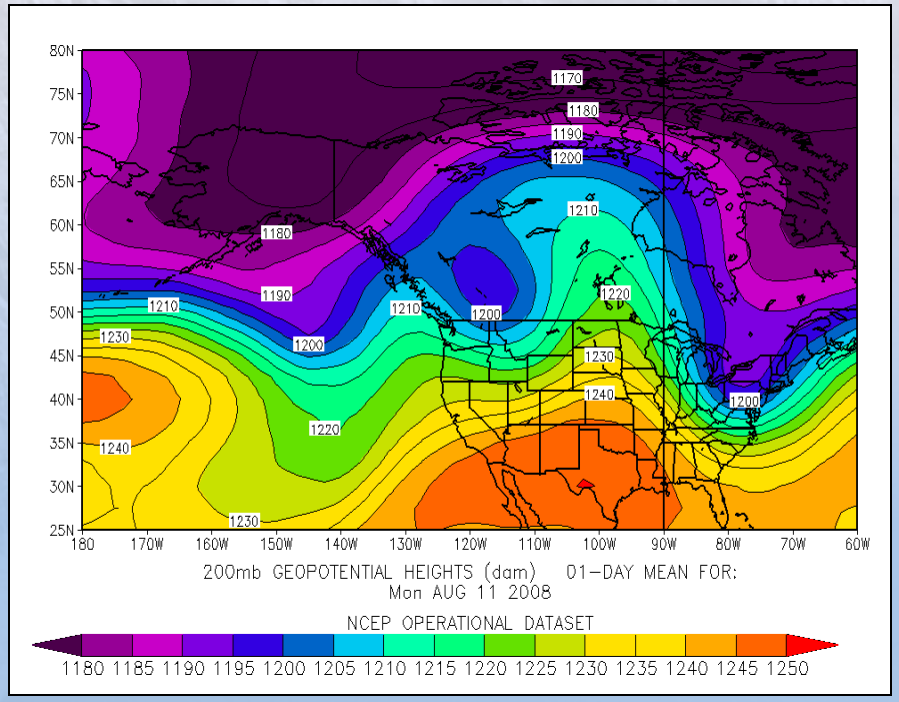


Source: http://so2.umbc.edu/omi/

*300mb is approximately 30,000 ft (FL300)

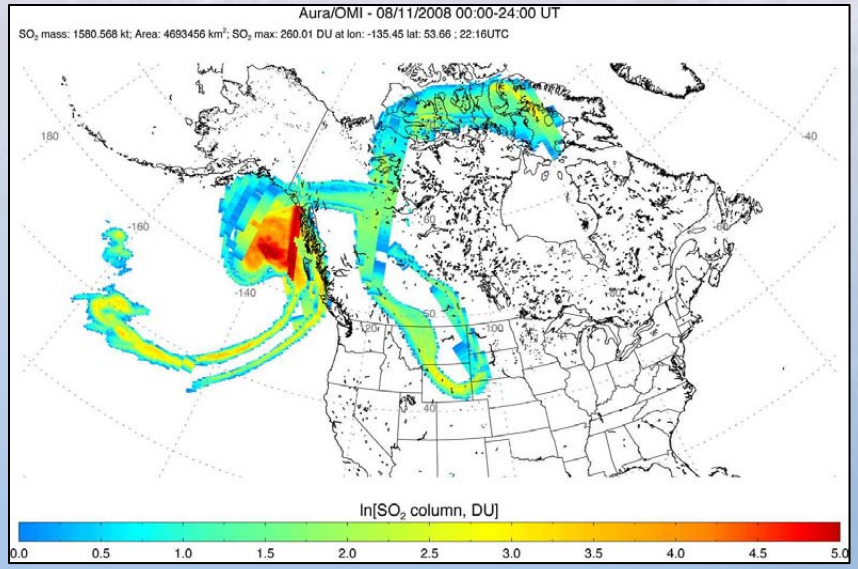
Synoptic Pattern: Kasatochi

200mb Geopotential Heights*



Source: http://www.cdc.noaa.gov

SO_2 Column Measurements

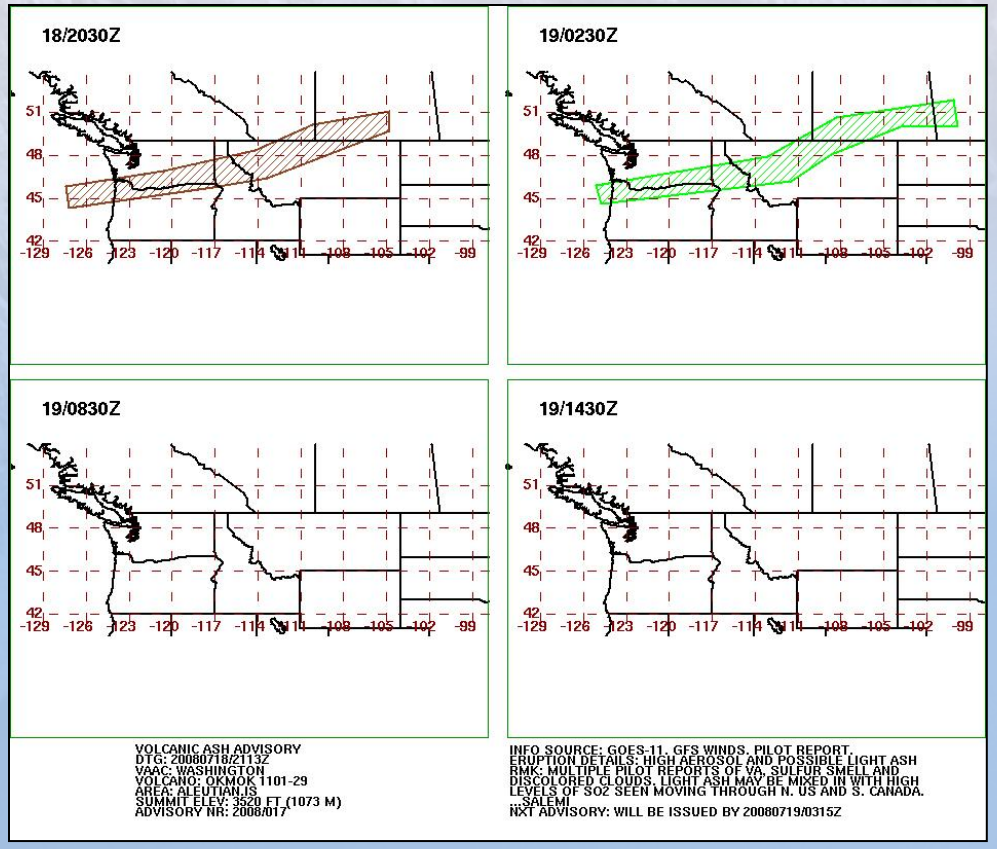


Source: http://so2.umbc.edu/omi/

*200mb is approximately 40,000 ft (FL400)

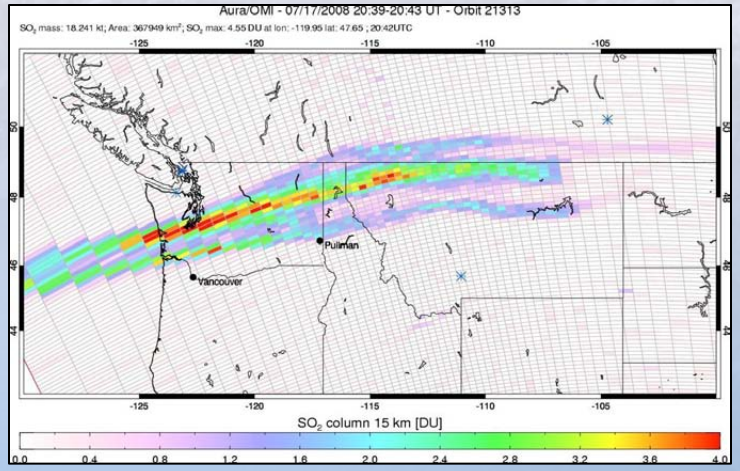
Ash Advisories: Okmok

Volcanic Ash Advisory



Source: http://www.ssd.noaa.gov/VAAC/ARCH08/archive.html

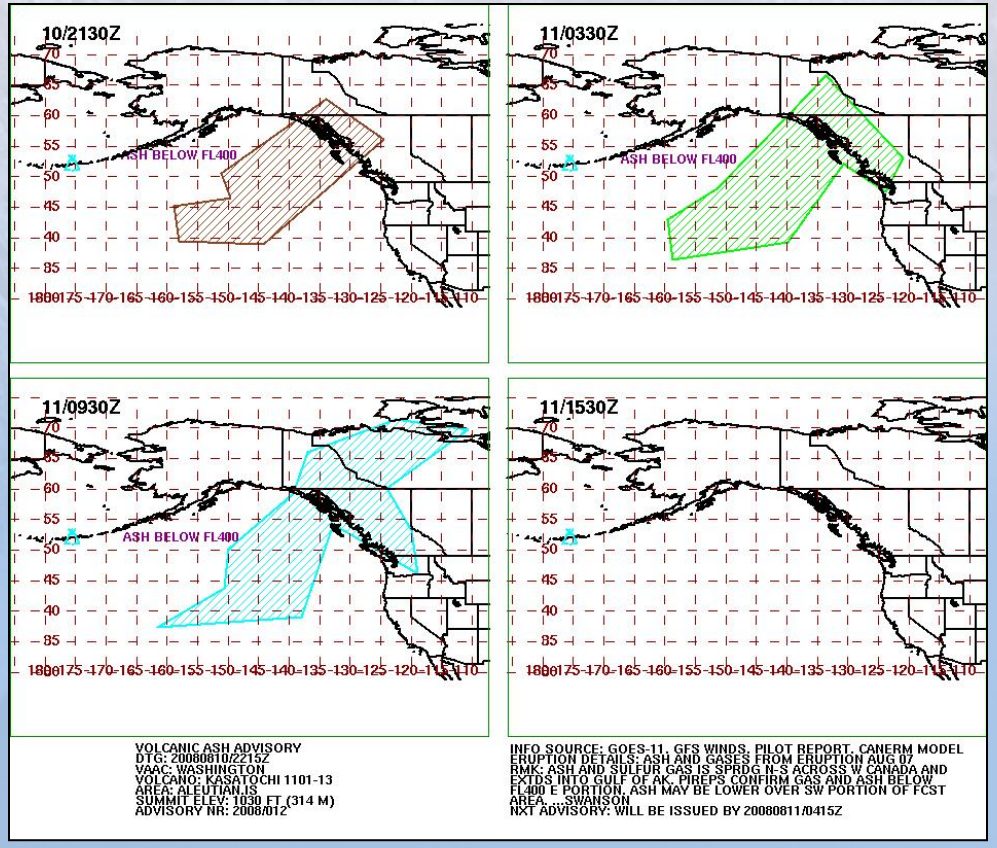
SO_2 Column Measurements



Source: http://so2.umbc.edu/omi/

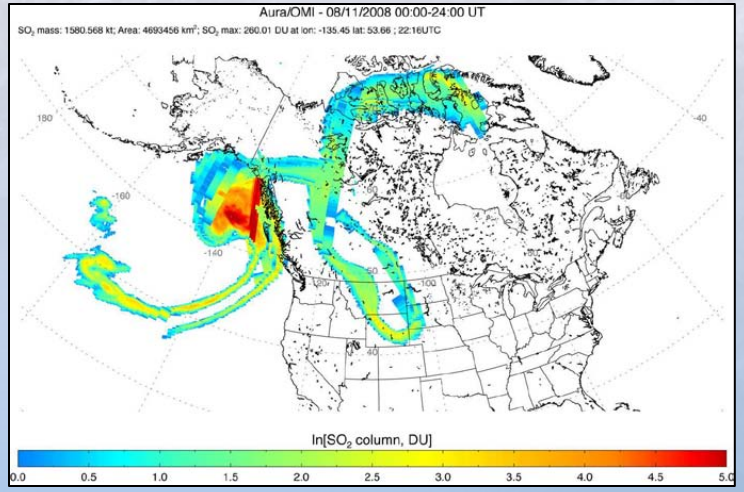
Ash Advisories: Kasatochi

Volcanic Ash Advisory



Source: http://www.ssd.noaa.gov/VAAC/ARCH08/archive.html

SO_2 Column Measurements



Source: http://so2.umbc.edu/omi/

3. Investigating reported impacts on aviation

- Examined past studies of reported impacts on aviation
- Examined pilot reports from the Aviation Safety Reporting System (ASRS) database and the United States Geological Survey (USGS)

Reported Impacts

- **Okmok:** On 15 July 2008 a non-damaging aircraft encounter occurred near Kodiak Island due to volcanic ash from Okmok.

- **Kasatochi:** On 11 August 2008 a 757 aircraft encountered an ash cloud over the Yukon from the Kasatochi eruption.
  - On 10 August 2008 flights were cancelled in several cities and over 6000 passengers were stranded

Conclusion

- The airline industry is exposed to a considerable threat from volcanic eruptions
  - Fine-grained ash can linger in the atmosphere for several days after an eruption and disperse over hundreds of kilometers
  - Since the issue of ash avoidance is primarily an issue of economic implications, an investment in preparing for volcanic encounters would yield high returns for the airline industry over the long term.

How did the 2009 Mt. Redoubt eruptions impact the aviation industry?

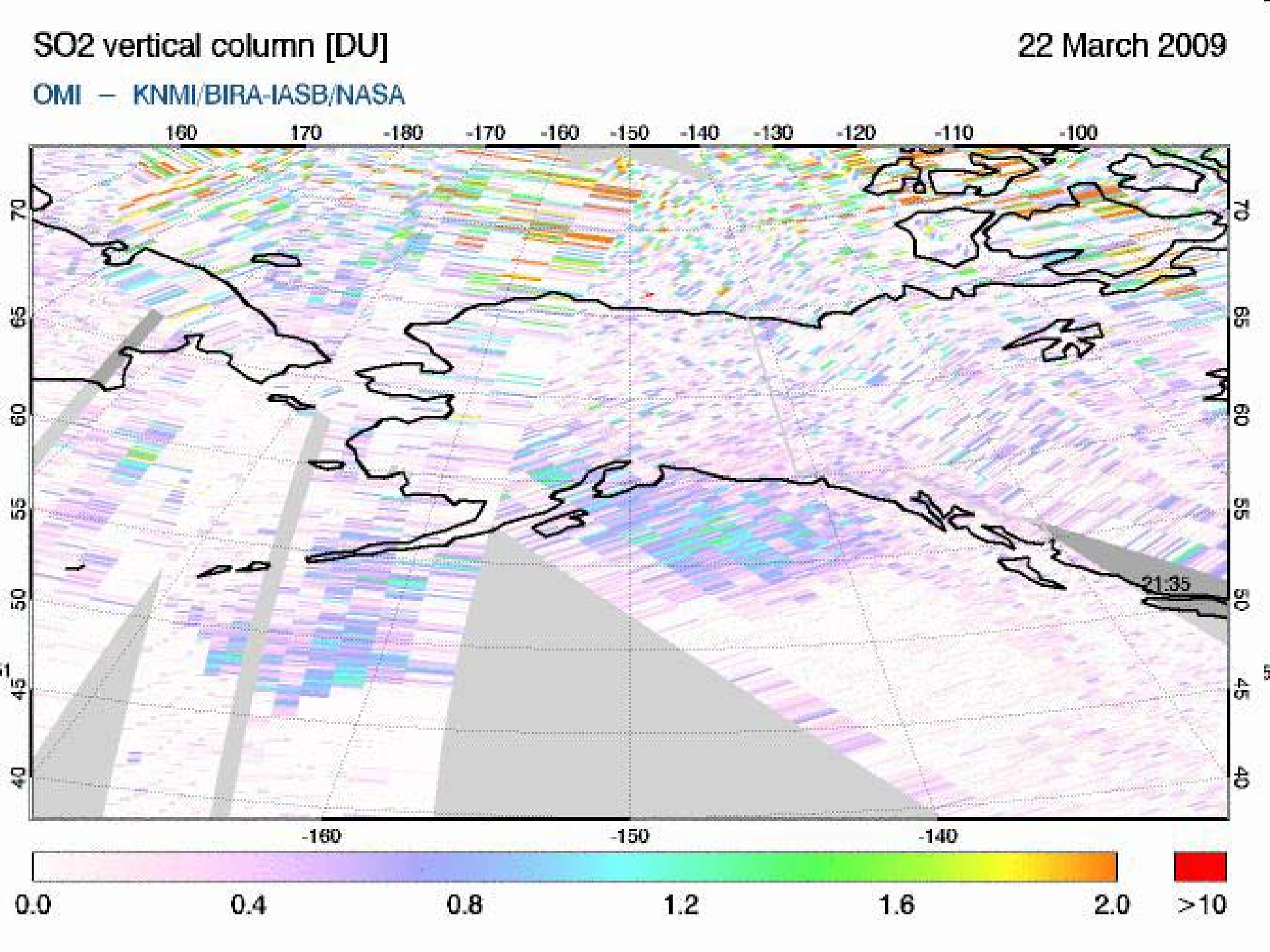
Image source: http://www.boston.com/bigpicture

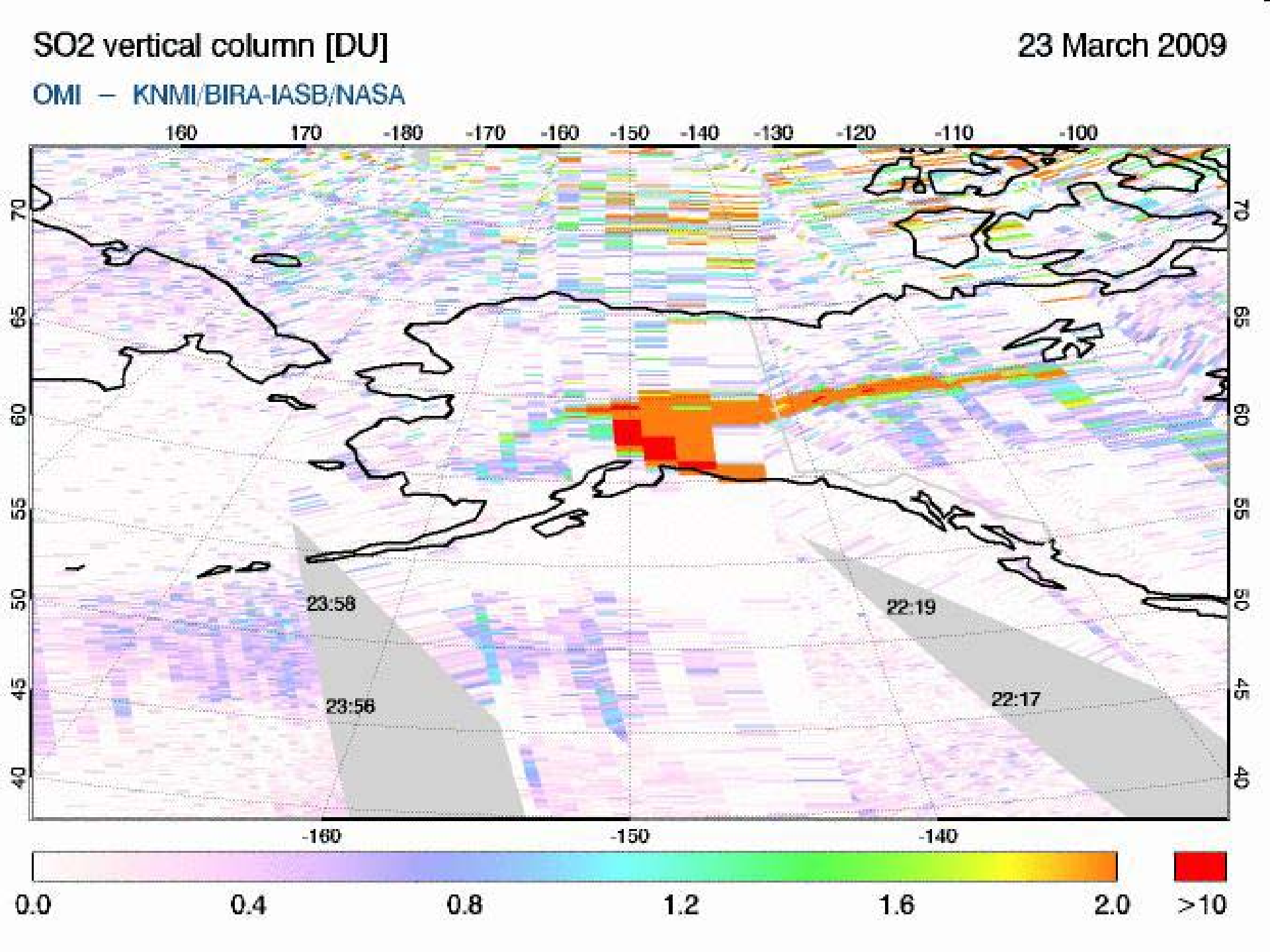
Engine Damage

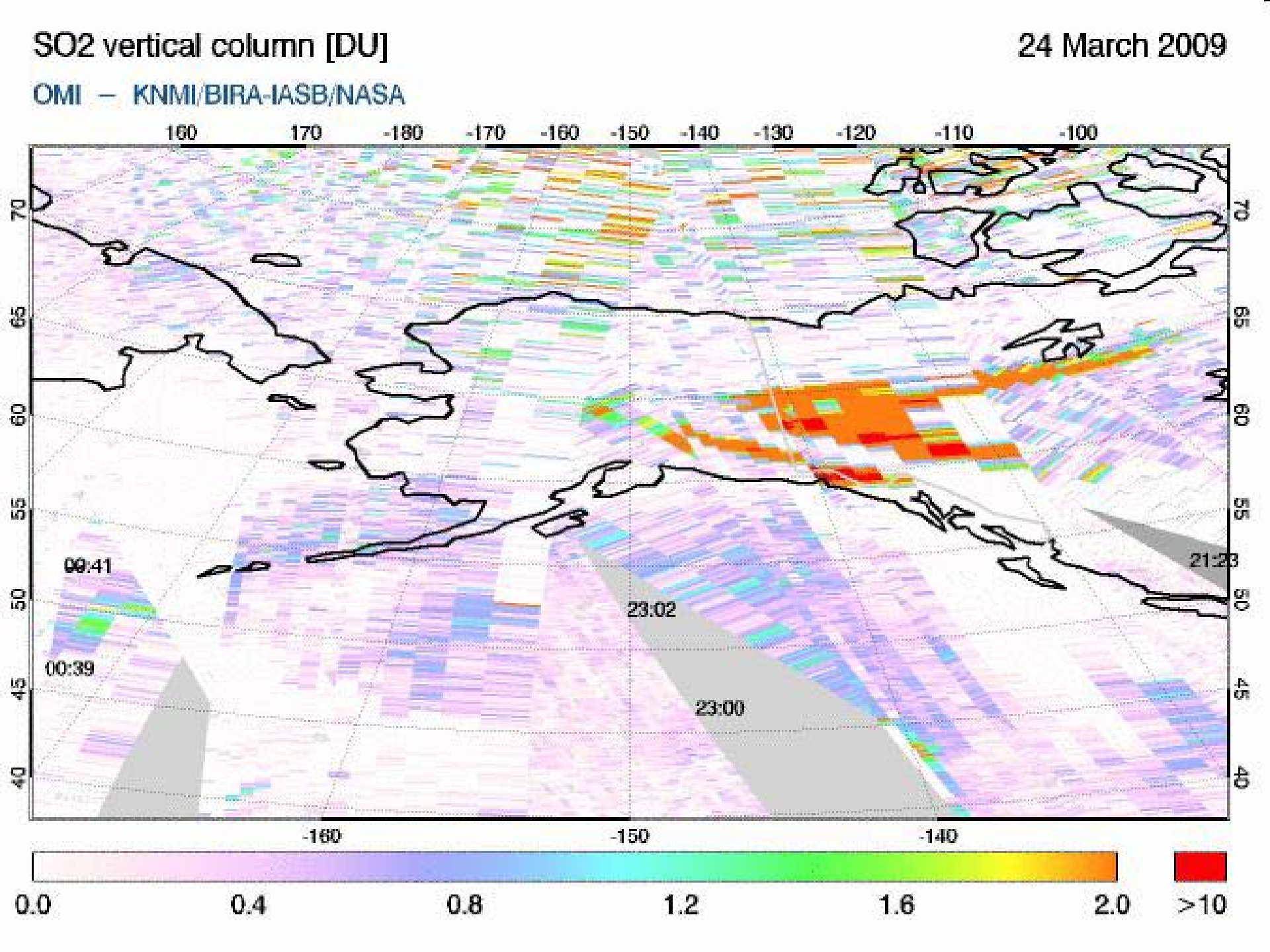
- Commercial aircraft
  - Engines operate at 1400°C
  - Volcanic ash melts at 1100°C
- Damages
  - Loss in engine thrust
  - Clogging of fuel nozzles (flameout)

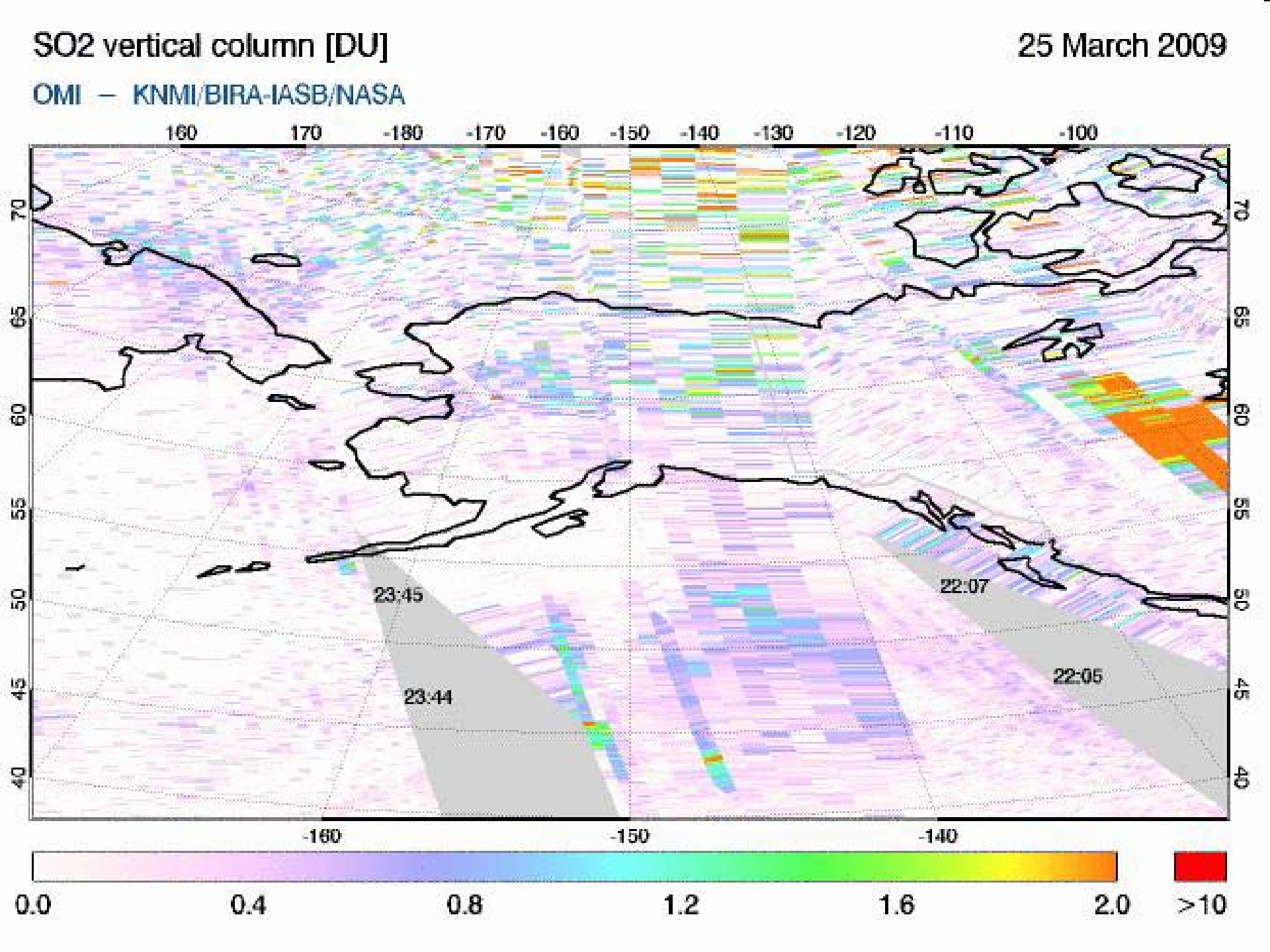
2009 Redoubt Eruptions

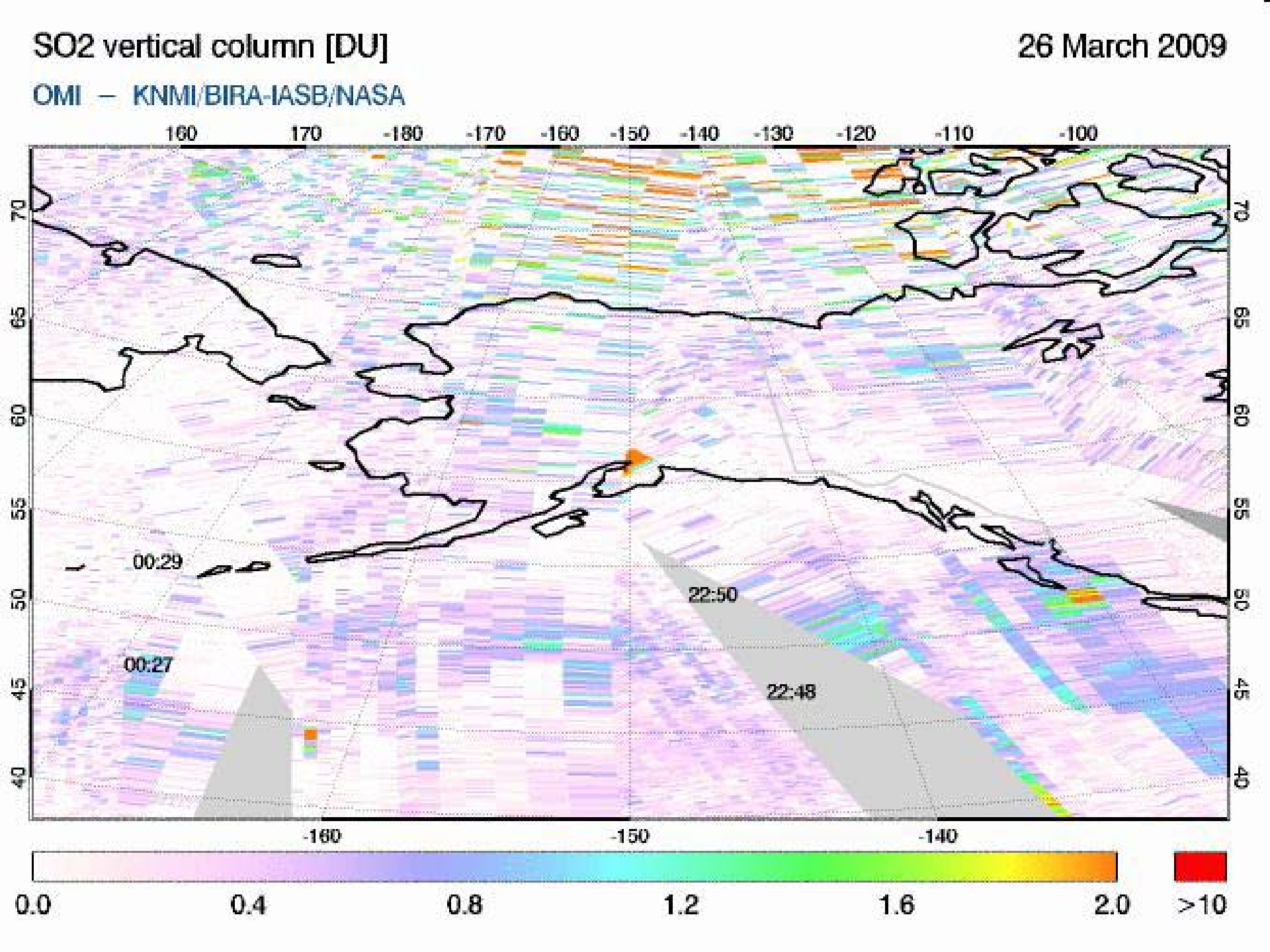
- 23 eruptions
- 23 March 2009 – 4 April 2009
- Maximum ash plume reached 18.3 km (60,000 ft)
- VEI 4 – 5 (E.g. Pinatubo VEI 6, greater mass+energy)

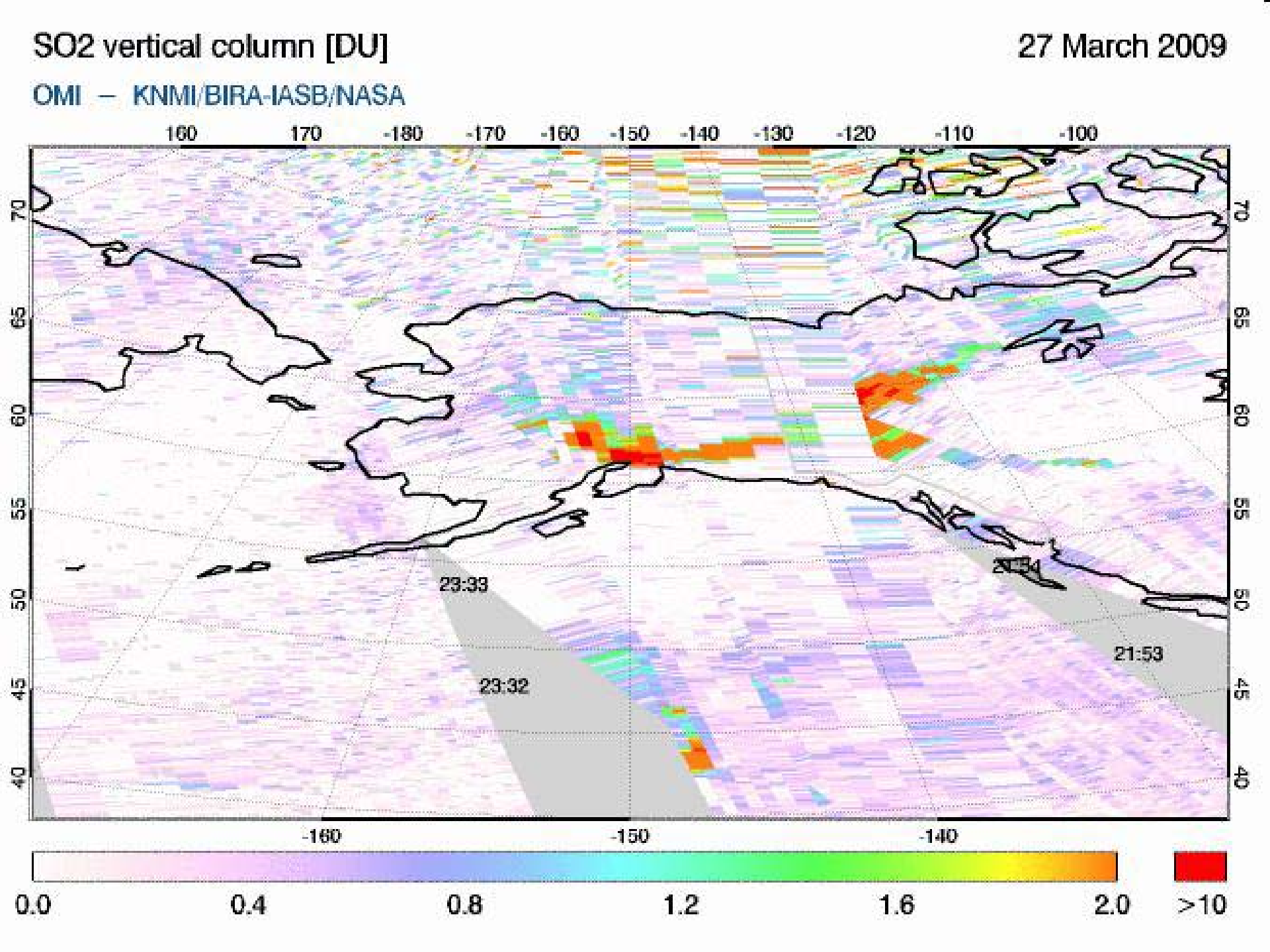

SO2 vertical column [DU]
22 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
21:35
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

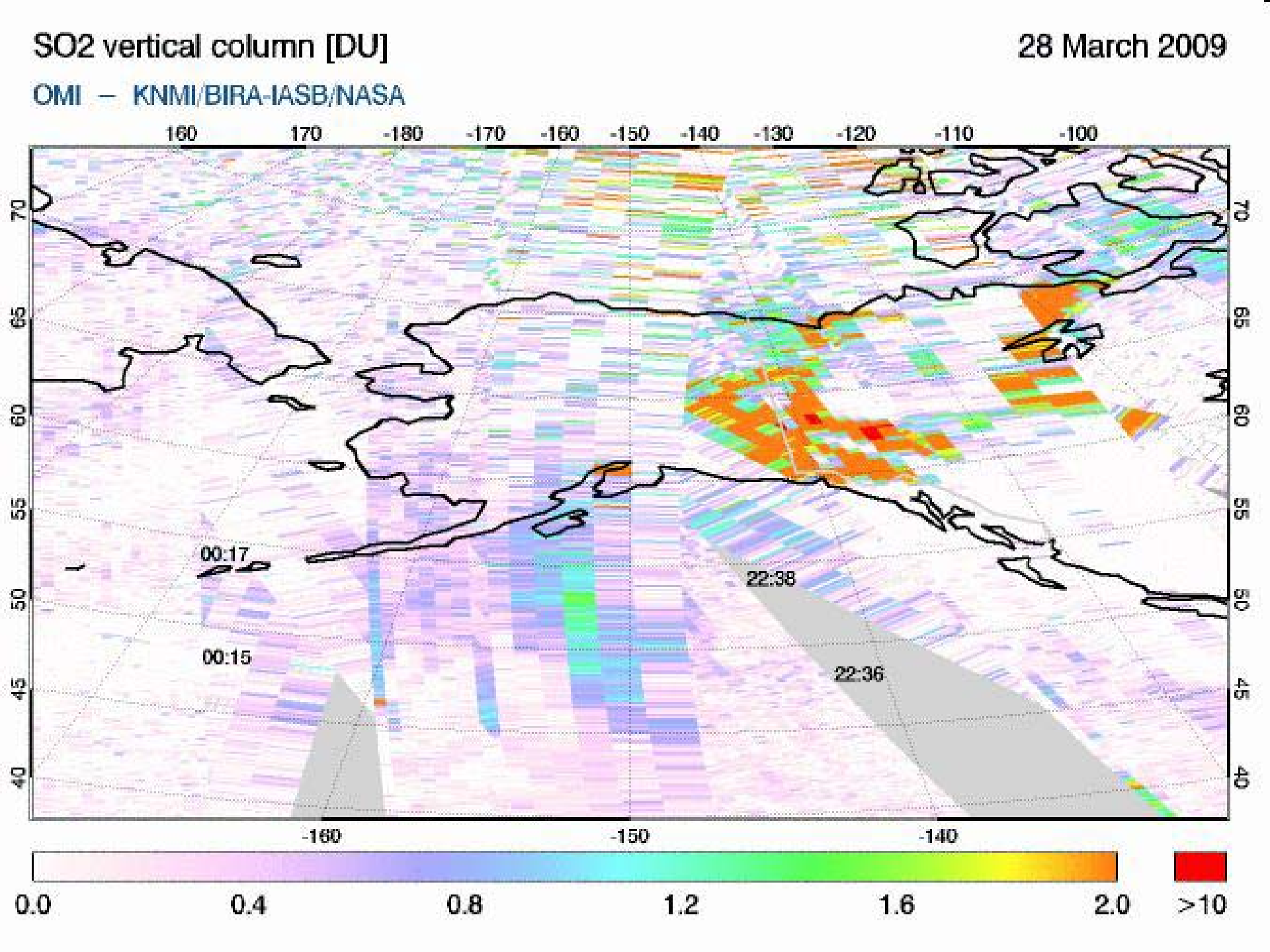

SO2 vertical column [DU]
23 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
23:58
23:56
22:19
22:17
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

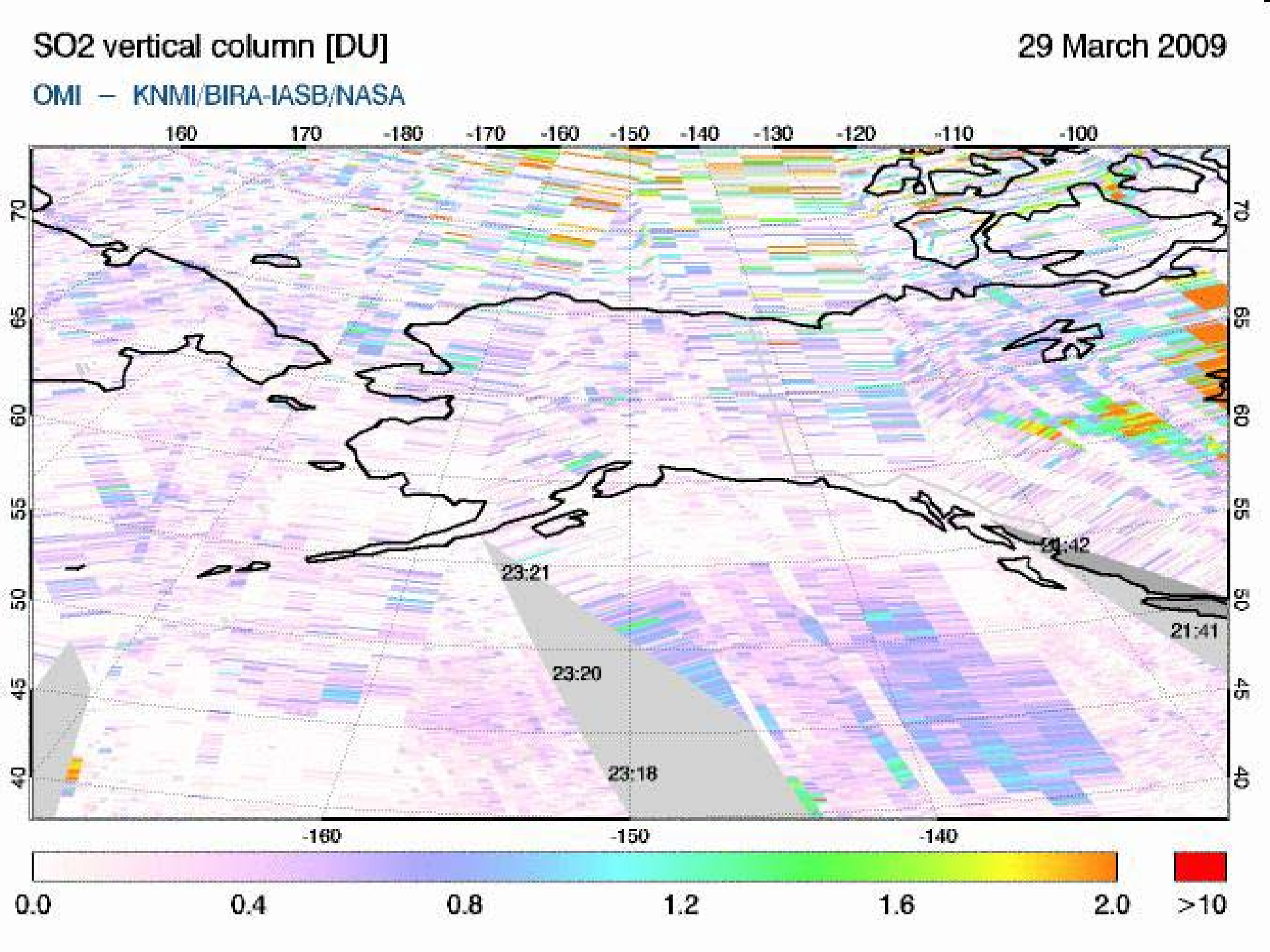

SO2 vertical column [DU]
24 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
09:41
00:39
23:02
23:00
21:23
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

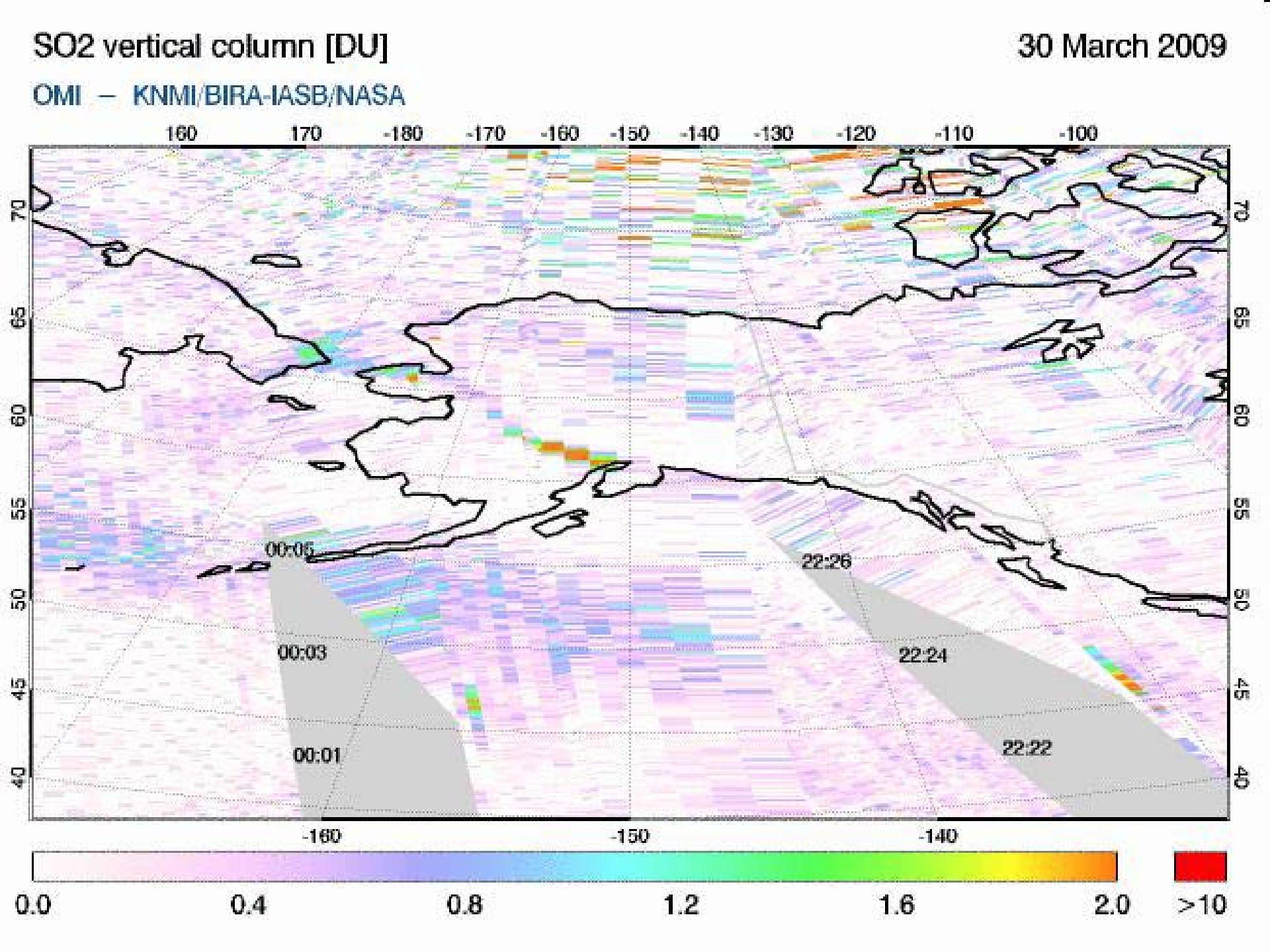

SO2 vertical column [DU]
25 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
23:45
23:44
22:07
22:05
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

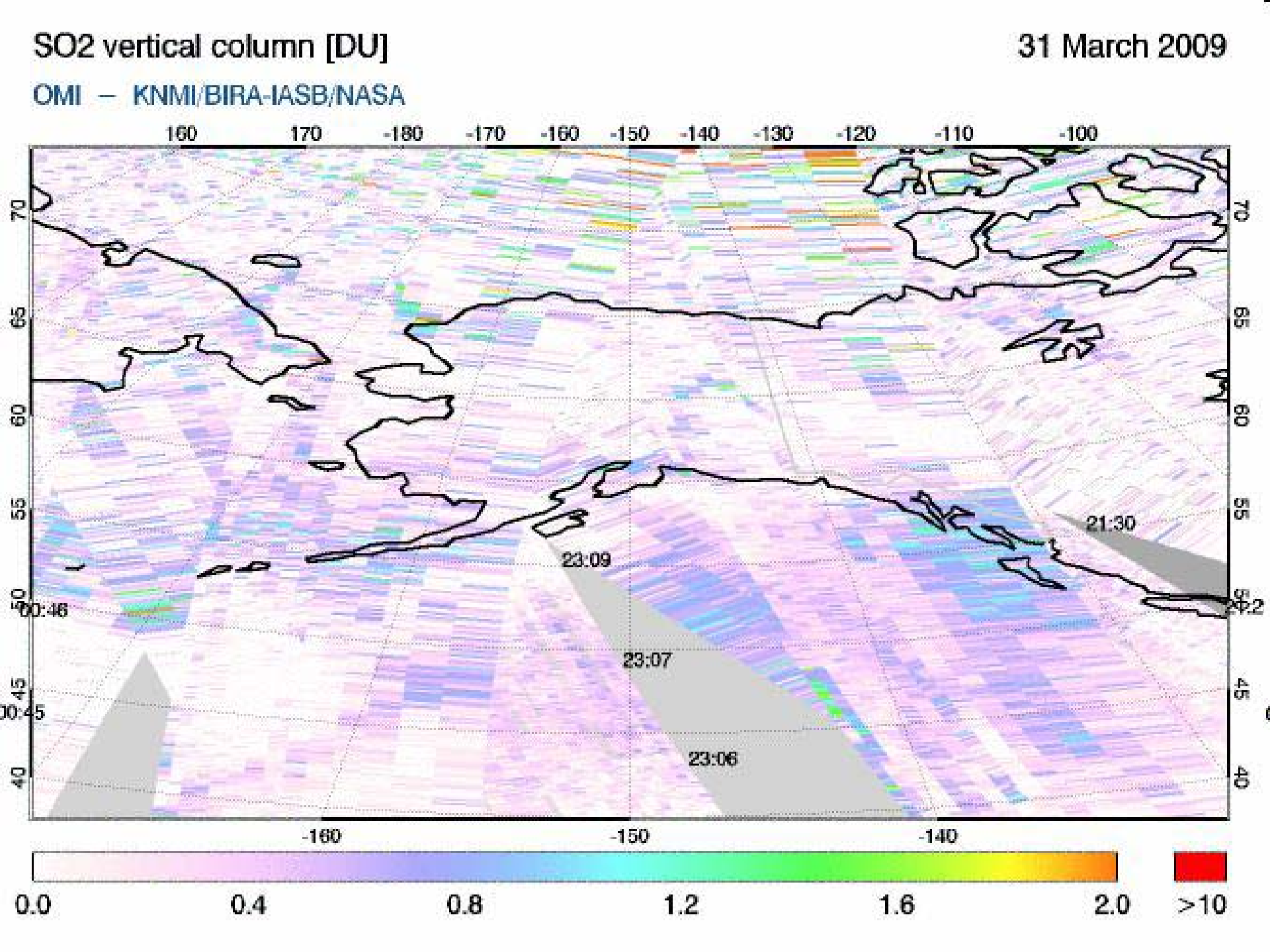

SO2 vertical column [DU]
26 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
00:29
00:27
22:50
22:48
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

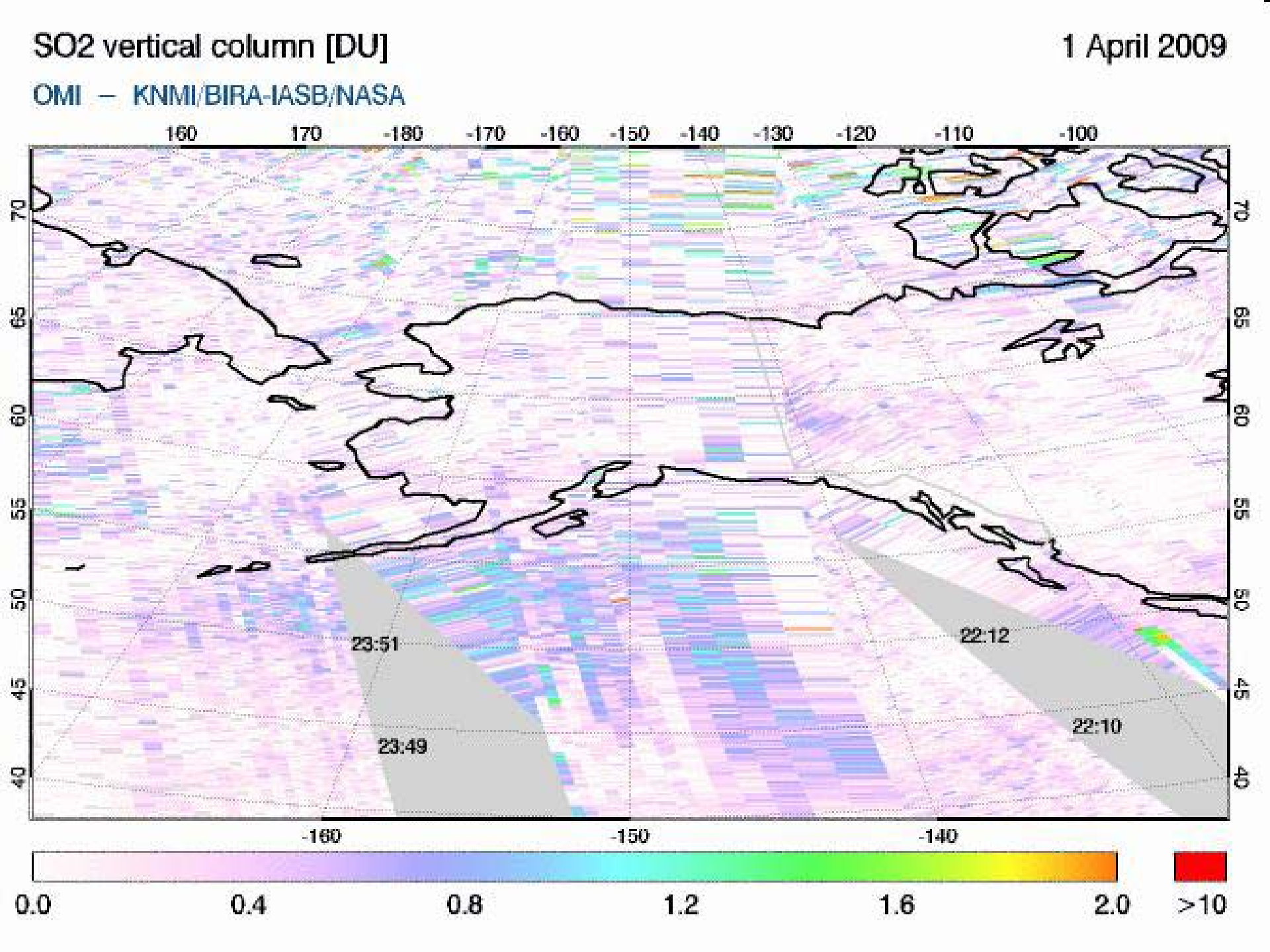

SO2 vertical column [DU]
27 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
23:33
23:32
21:54
21:53
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

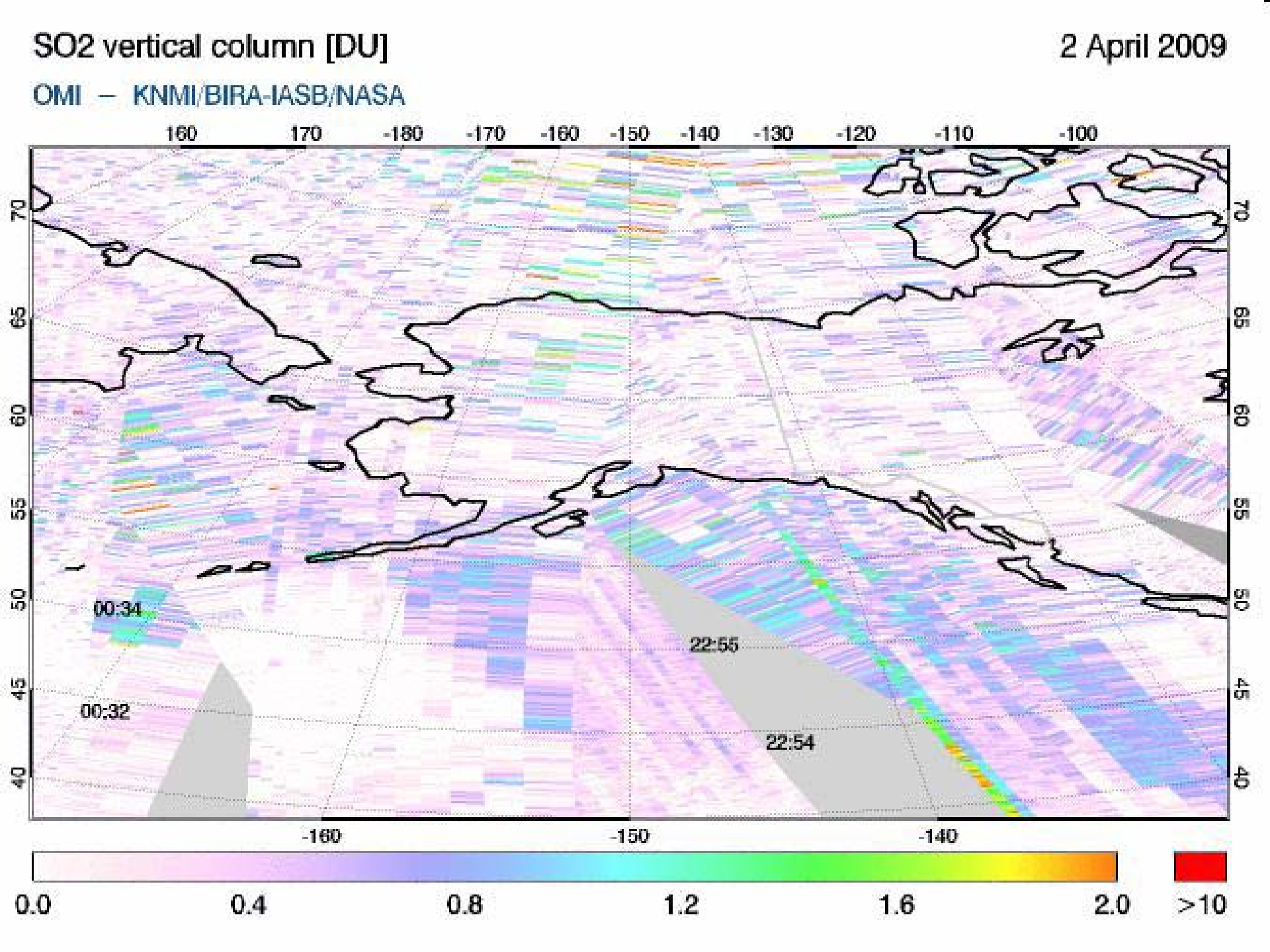

SO2 vertical column [DU]
28 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
00:17
00:15
22:38
22:36
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

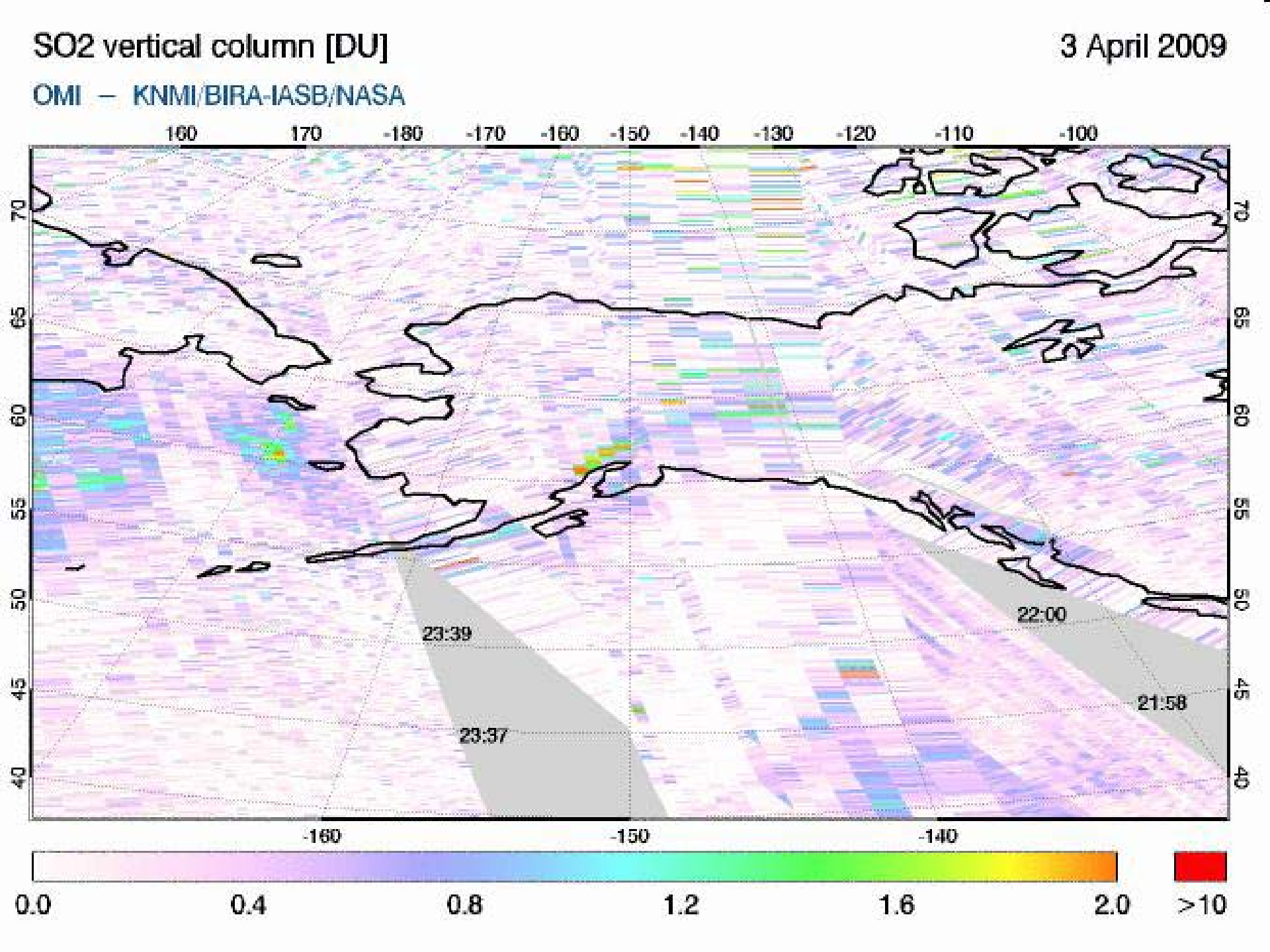

SO2 vertical column [DU]
29 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
23:21
23:20
23:18
21:42
21:41
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

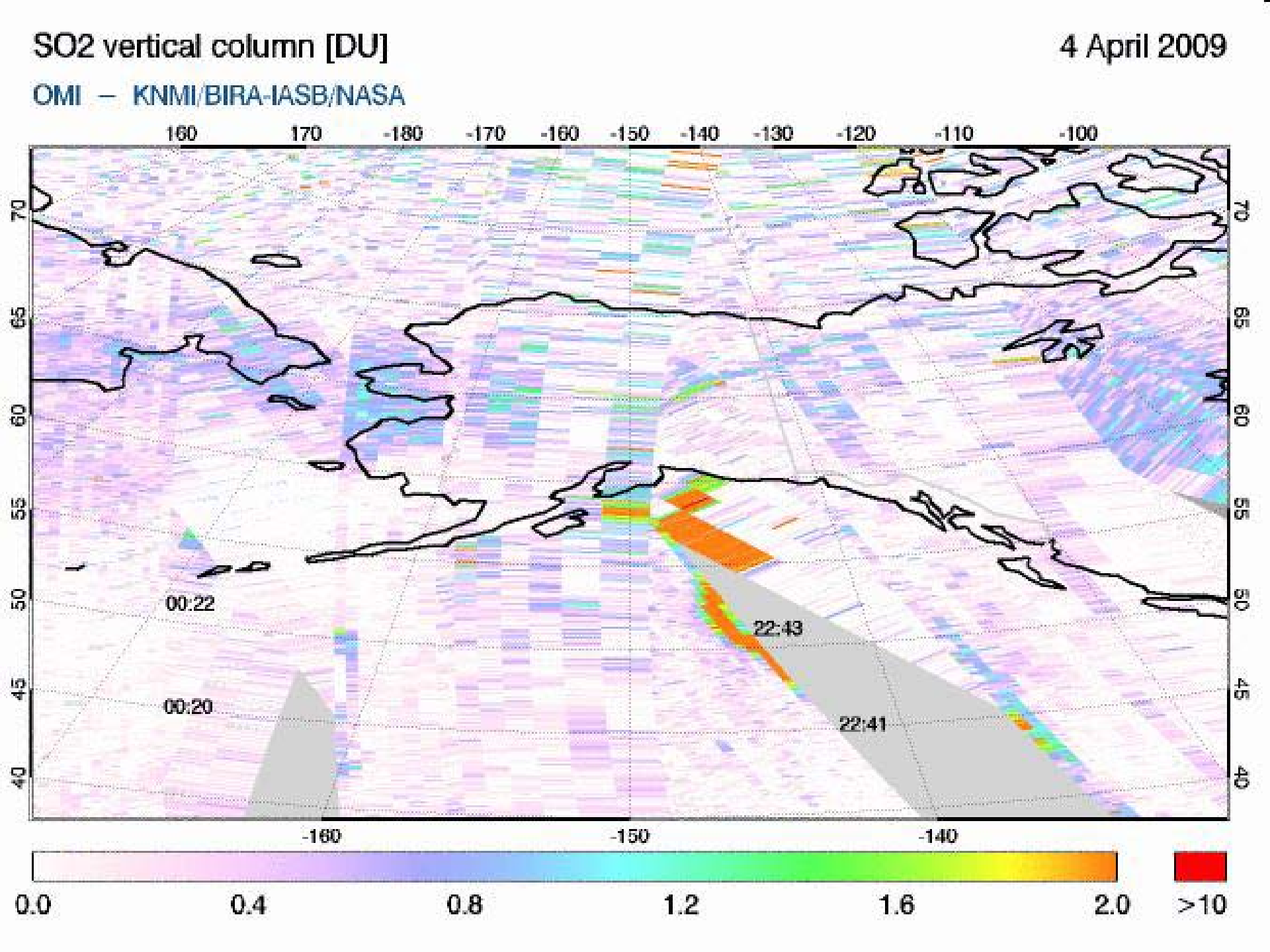

SO2 vertical column [DU]
30 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
00:05
00:03
00:01
22:26
22:24
22:22
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10


SO2 vertical column [DU]
31 March 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
00:46
00:45
23:09
23:07
23:06
21:30
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10


SO2 vertical column [DU]
1 April 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
23:51
23:49
22:12
22:10
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

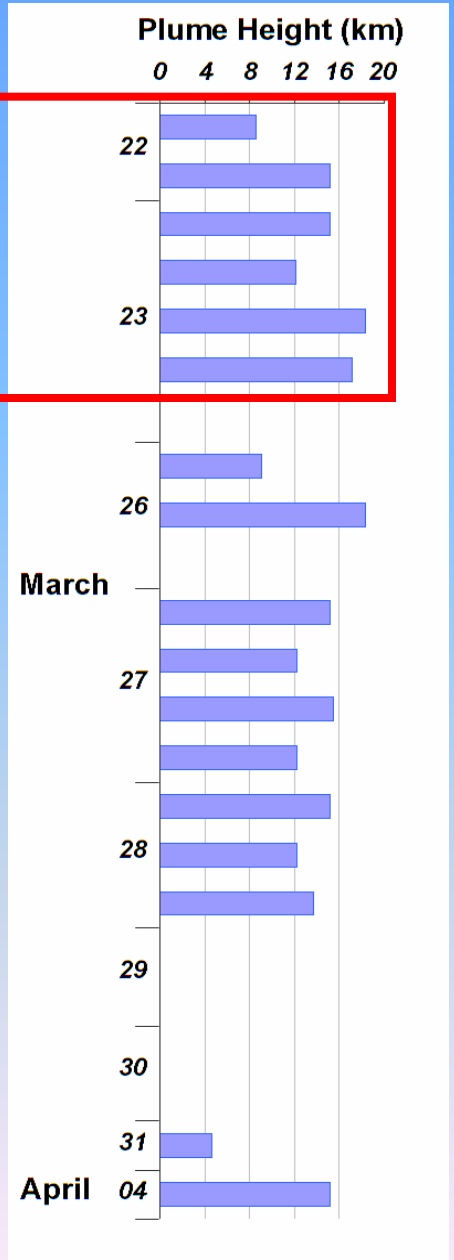

SO2 vertical column [DU]
2 April 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
00:34
00:32
22:55
22:54
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

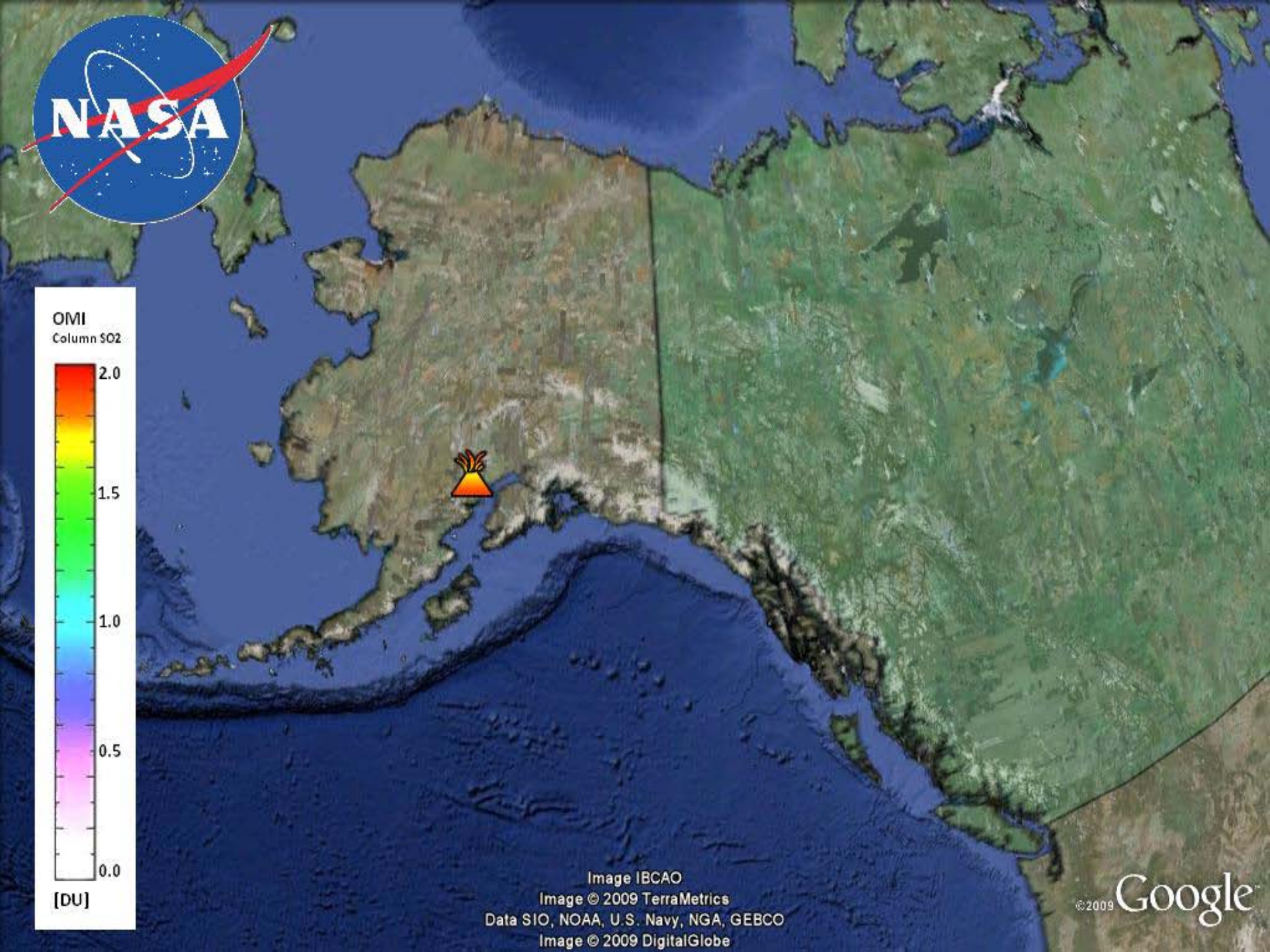

SO2 vertical column [DU]
3 April 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
23:39
23:37
22:00
21:58
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

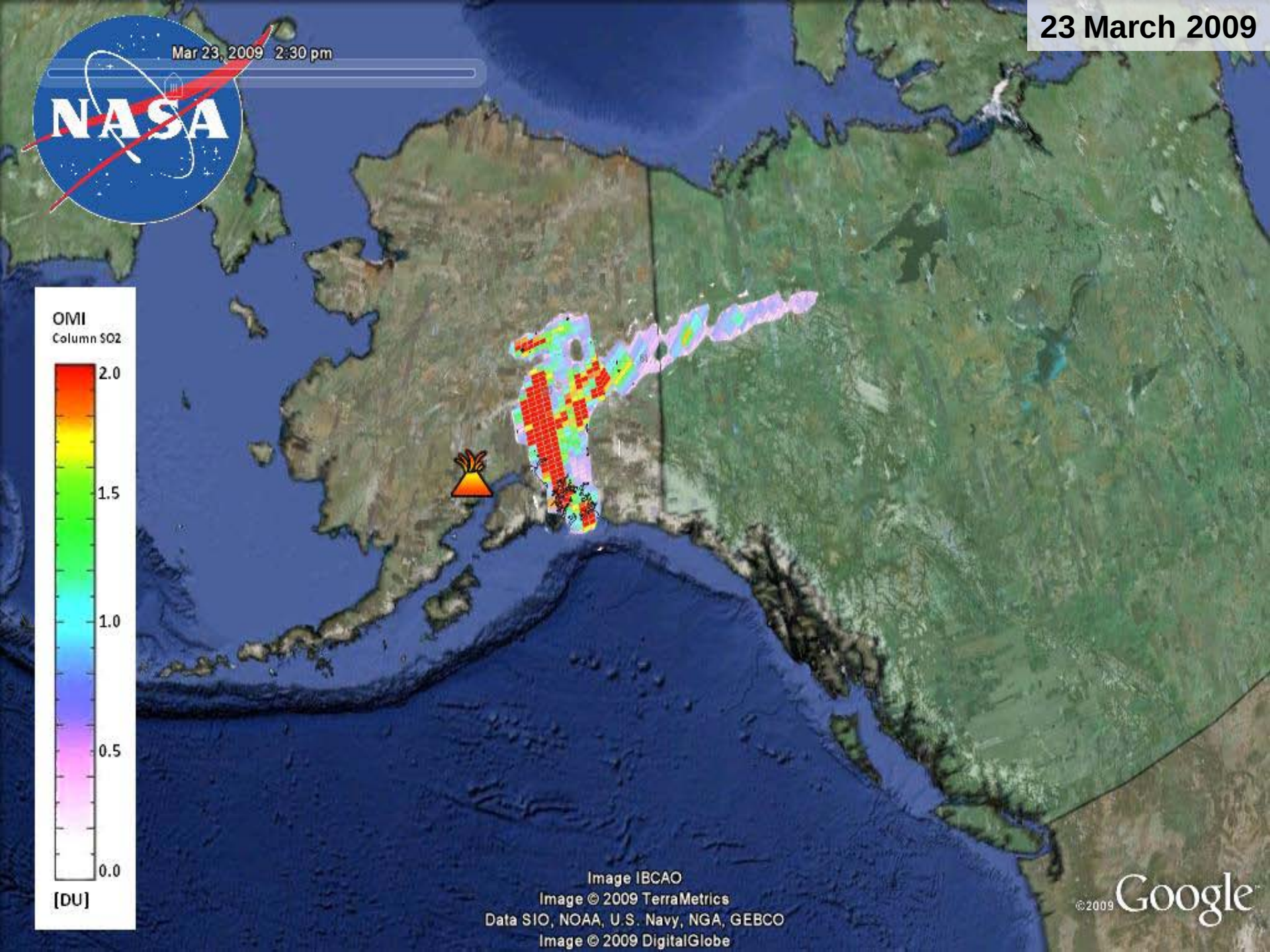

SO2 vertical column [DU]
4 April 2009
OMI – KNMI/BIRA-IASB/NASA
160
170
-180
-170
-160
-150
-140
-130
-120
-110
-100
70
65
60
55
50
45
40
00:22
00:20
22:43
22:41
-160
-150
-140
0.0
0.4
0.8
1.2
1.6
2.0
>10

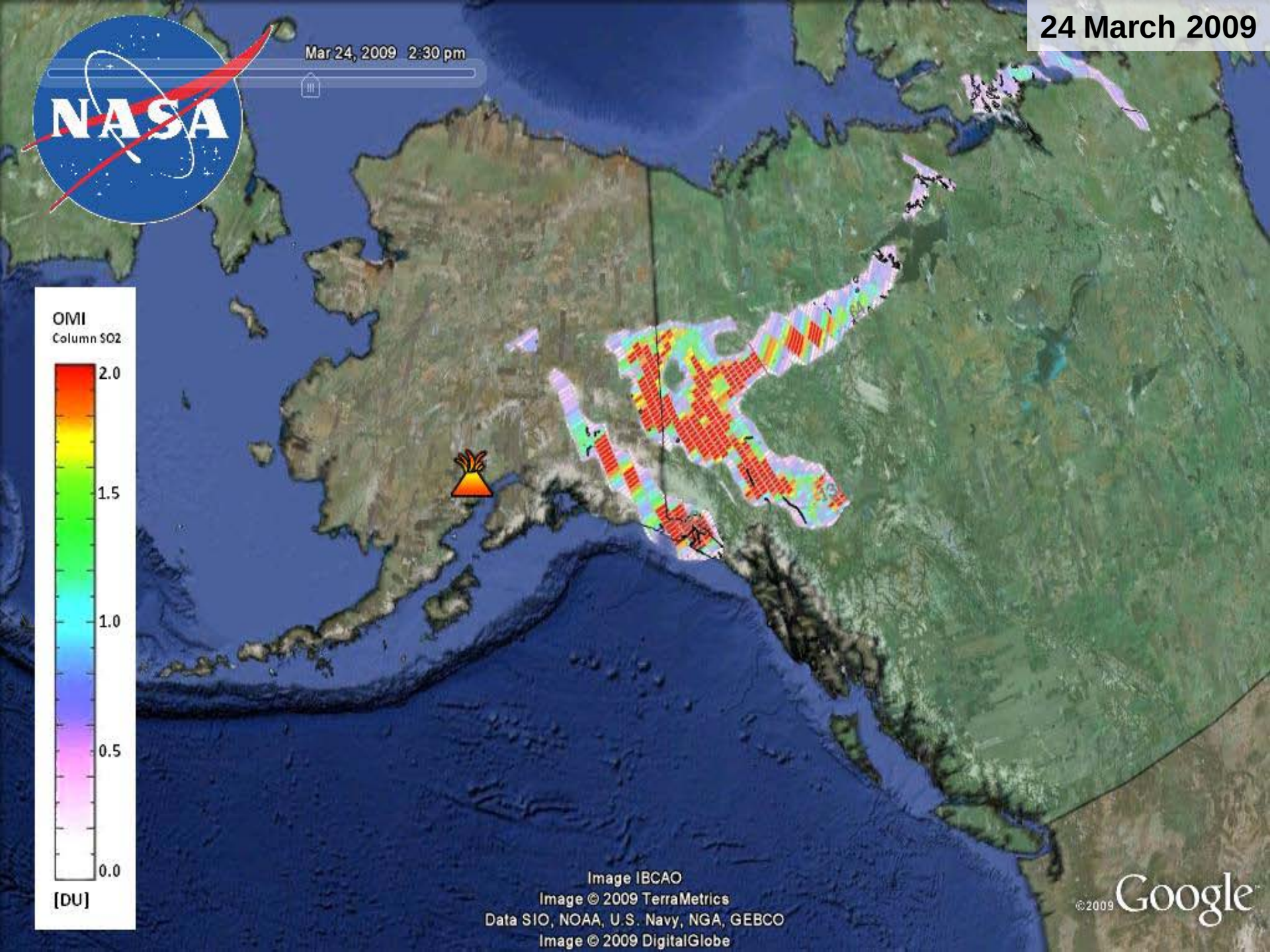
Plume Height

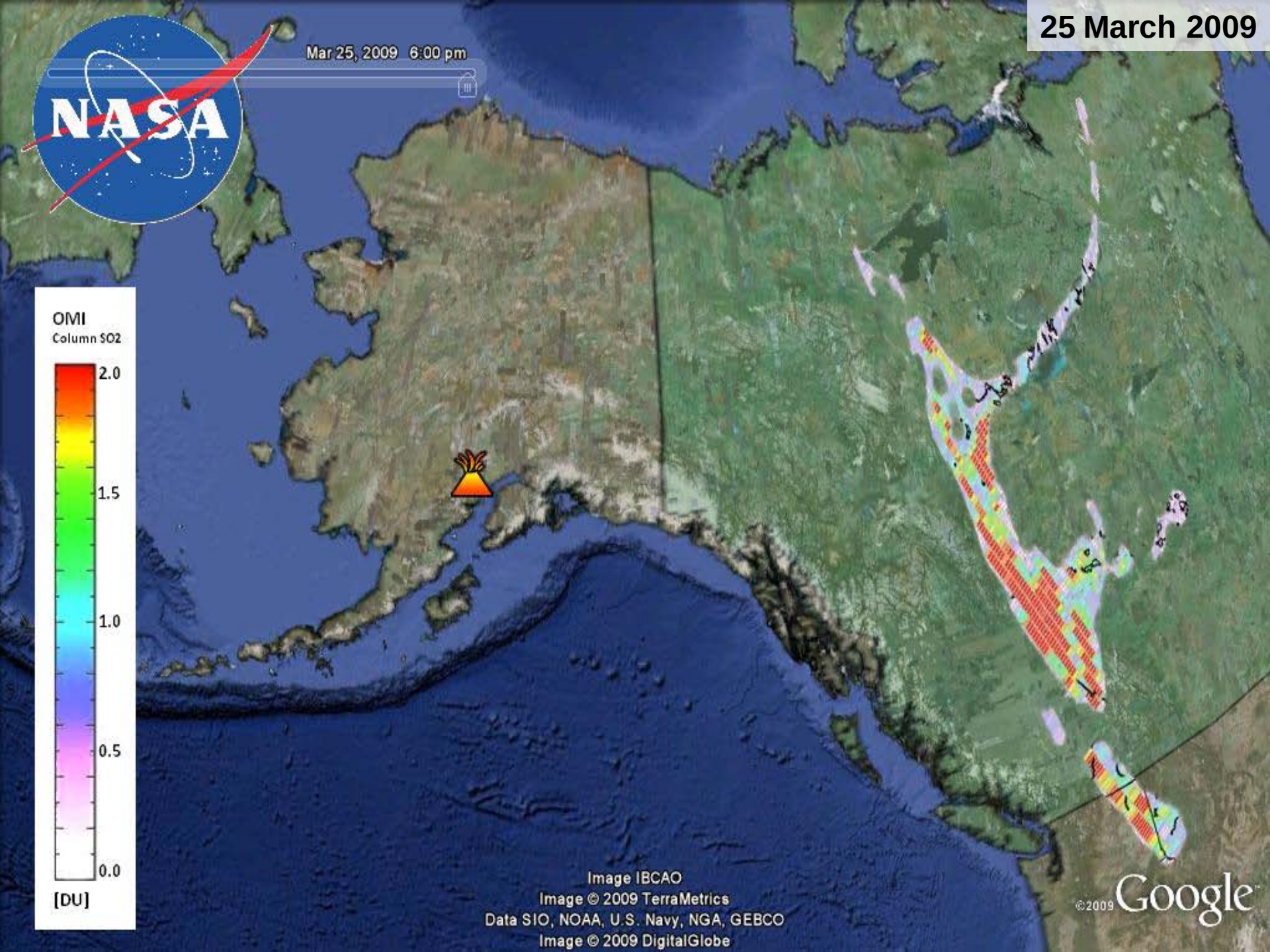
		Time (AKDT)	Time (UTC)	Plume Height (km)
22 March 2009	1	10:38 PM	6:38	**8.6**
	2	11:02 PM	7:02	**15.2**
23 March 2009	3	12:14 AM	8:14	**15.2**
	4	1:39 AM	9:39	**12.1**
	5	4:31 AM	12:31	**18.3**
	6	7:41 PM	3:41	**17.1**
	7	8:40 PM	4:40	
26 March 2009	8	8:34 AM	16:30	**9.1**
	9	9:24 AM	17:24	**18.3**
	10	11:48 PM	7:48	
27 March 2009	11	8:39 AM	16:39	**15.2**
	12	5:35 PM	1:35	**12.2**
	13	7:20 PM	3:20	**15.5**
	14	11:20 PM	7:20	**12.2**
28 March 2009	15	1:20 AM	9:20	**15.2**
	16	3:29 PM	23:29	**12.2**
	17	7:23 PM	3:23	**13.7**
29 March 2009	18	11:20 AM	19:20	
	19	11:10 PM	7:10	
30 March 2009	20	10:50 AM	18:50	
	21	11:30 PM	7:30	
31 March 2009	22	4:07 PM	0:07	**4.6**
4 April 2009	23	5:58 AM	13:58	**15.2**

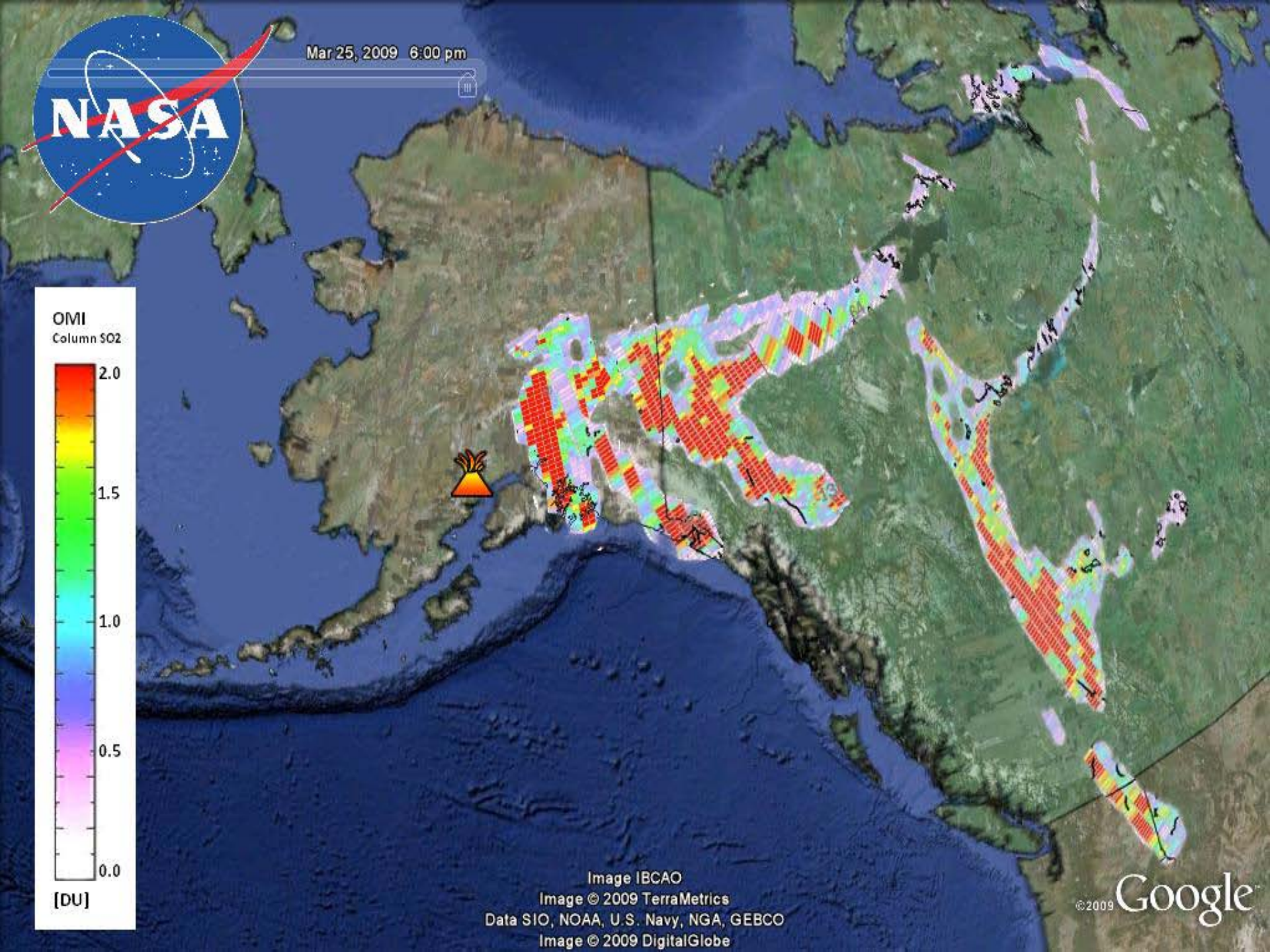


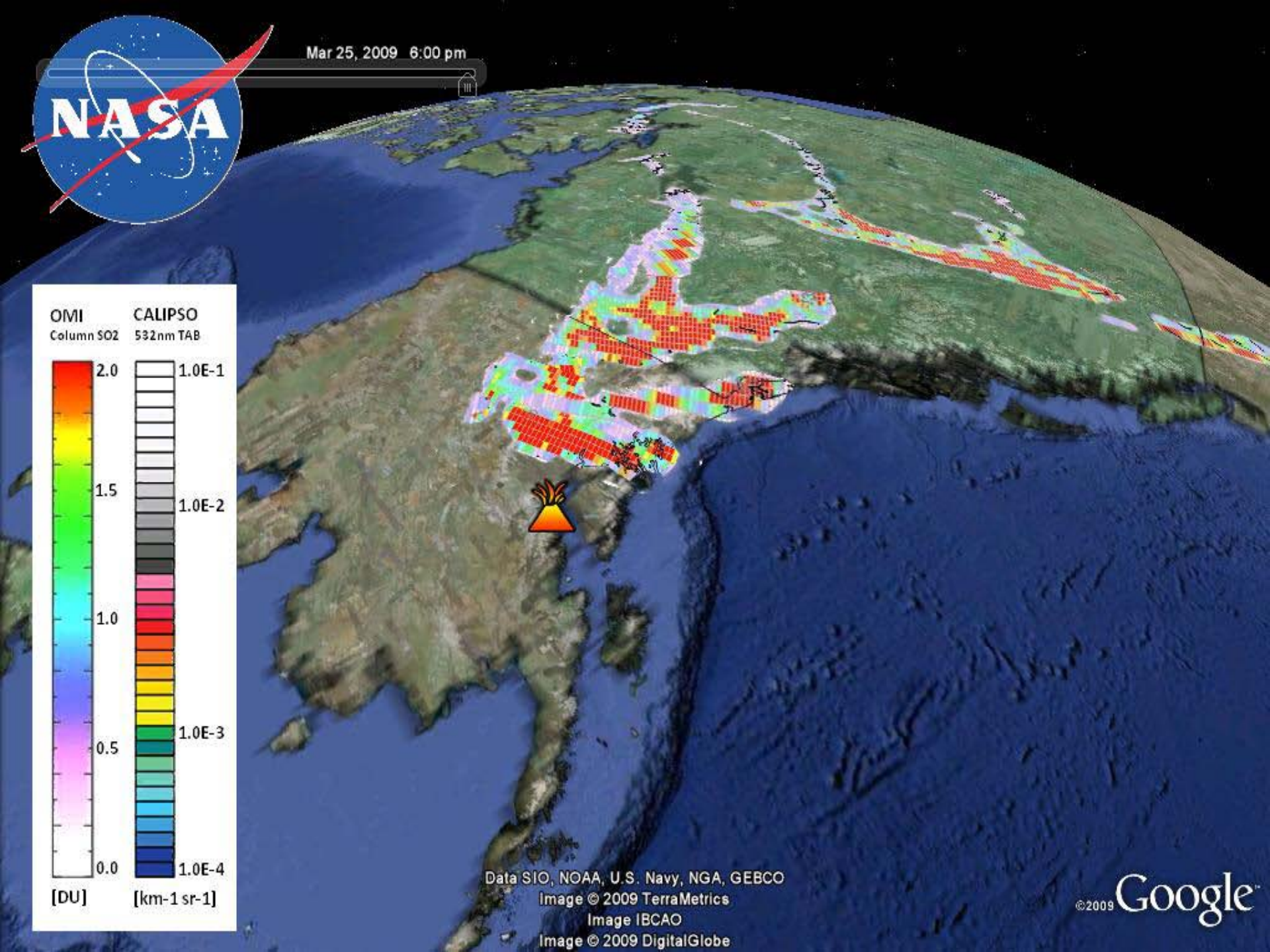

OMI
Column SO2
2.0
1.5
1.0
0.5
0.0
[DU]
Image IBCAO
Image © 2009 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 DigitalGlobe
©2009 Google

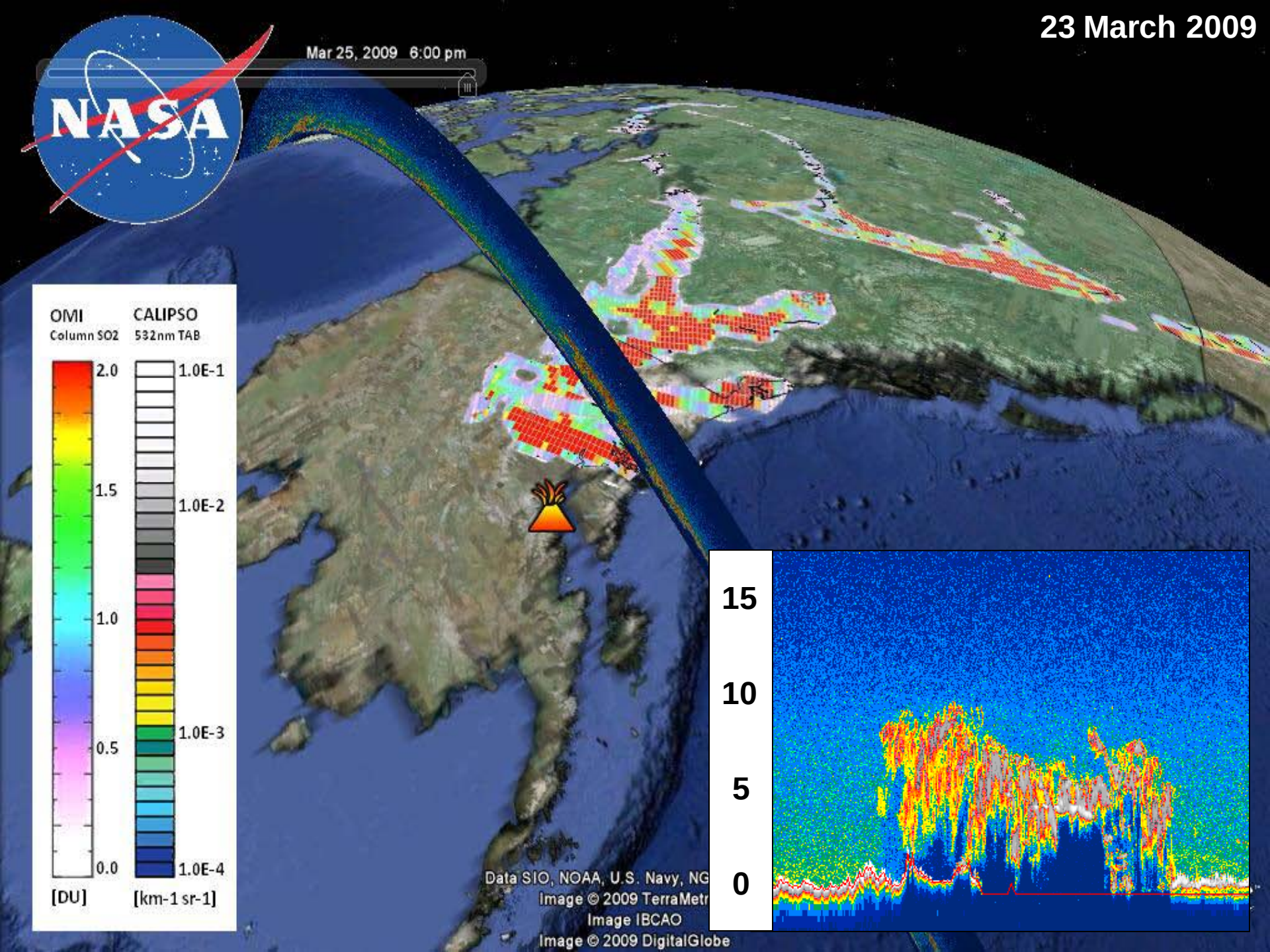

23 March 2009
Mar 23, 2009 2:30 pm
NASA
OMI
Column SO2
2.0
1.5
1.0
0.5
0.0
[DU]
Image IBCAO
Image © 2009 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 DigitalGlobe
©2009 Google

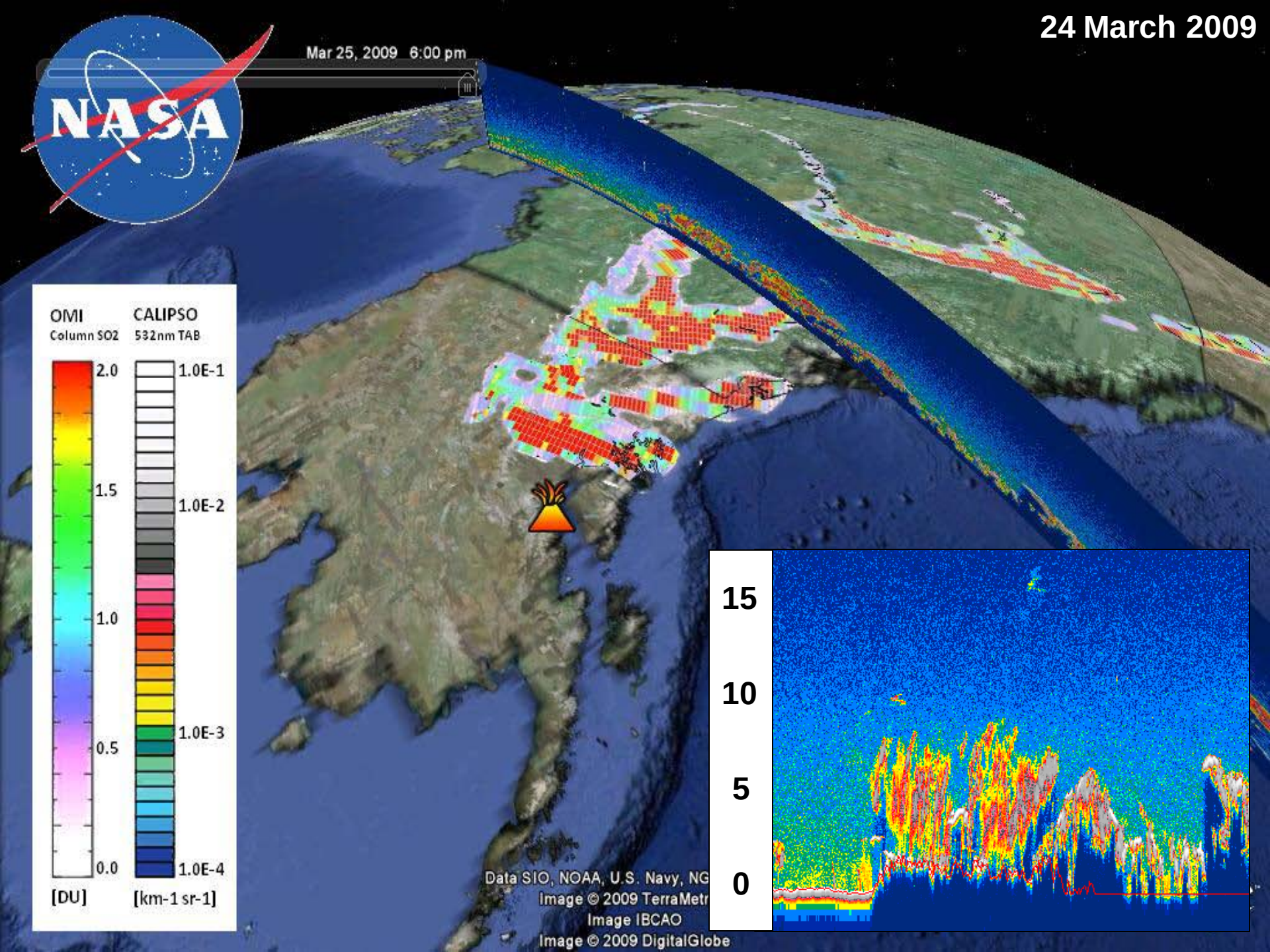

24 March 2009
Mar 24, 2009 2:30 pm
OMI
Column SO2
2.0
1.5
1.0
0.5
0.0
[DU]
Image IBCAO
Image © 2009 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 DigitalGlobe
©2009 Google


25 March 2009
Mar 25, 2009 6:00 pm
OMI
Column SO2
2.0
1.5
1.0
0.5
0.0
[DU]
Image IBCAO
Image © 2009 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 DigitalGlobe
©2009 Google

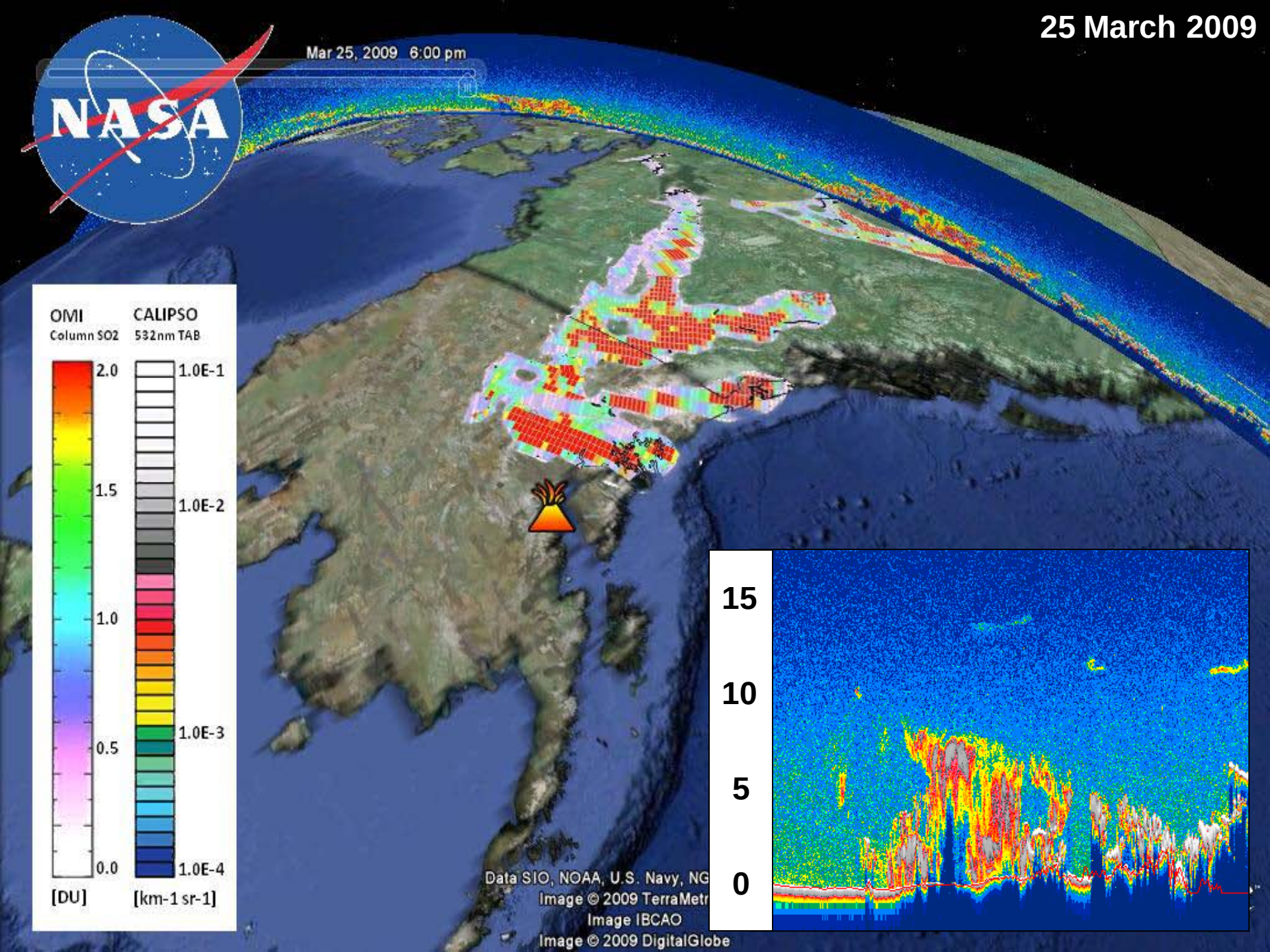

Mar 25, 2009 6:00 pm
OMI
Column SO2
2.0
1.5
1.0
0.5
0.0
[DU]
Image IBCAO
Image © 2009 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 DigitalGlobe
©2009 Google

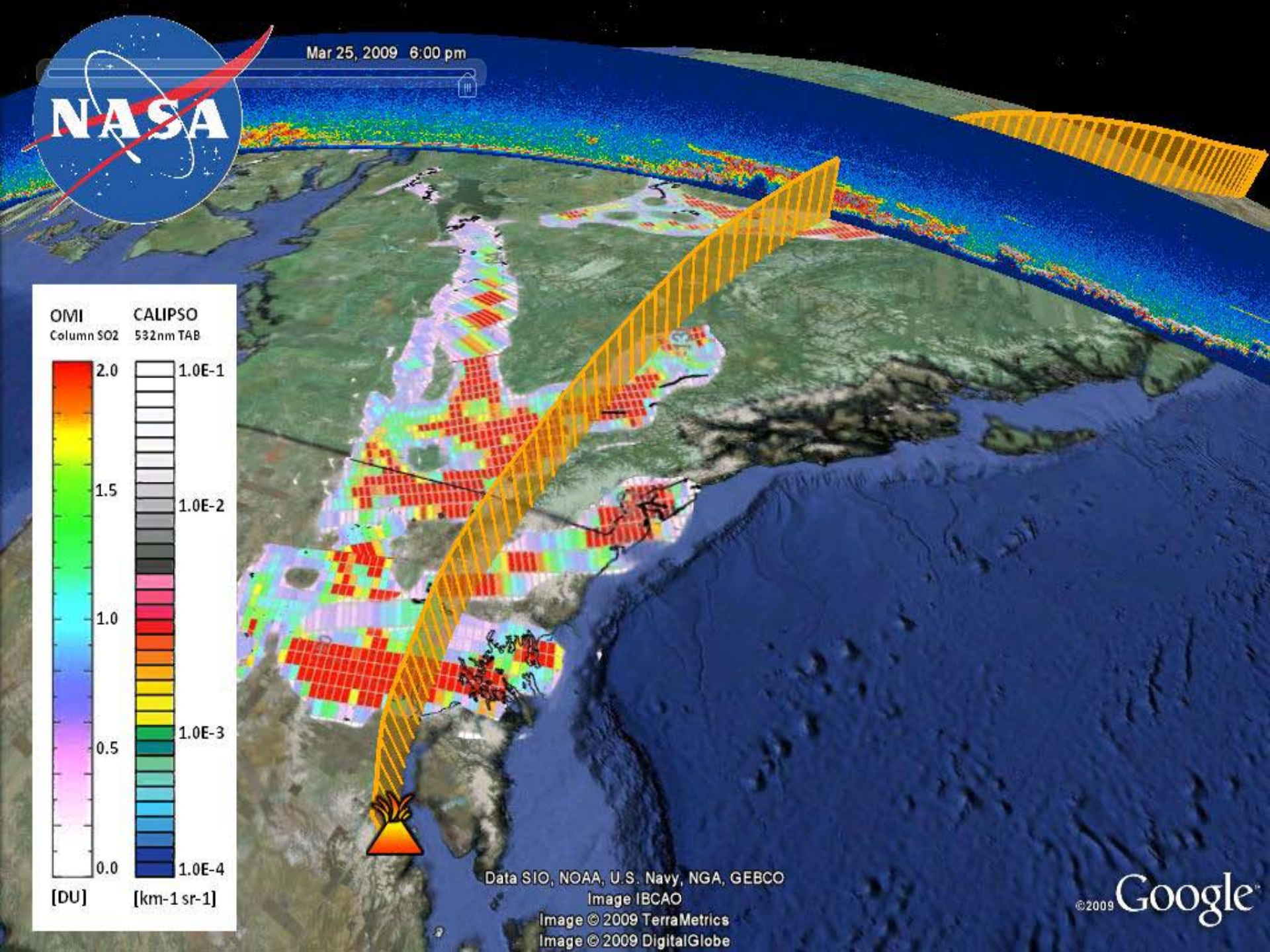

Mar 25, 2009 6:00 pm
OMI
Column SO2
CALIPSO
532nm TAB
2.0
1.5
1.0
0.5
0.0
[DU]
1.0E-1
1.0E-2
1.0E-3
1.0E-4
[km-1 sr-1]
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 TerraMetrics
Image IBCAO
Image © 2009 DigitalGlobe
©2009 Google

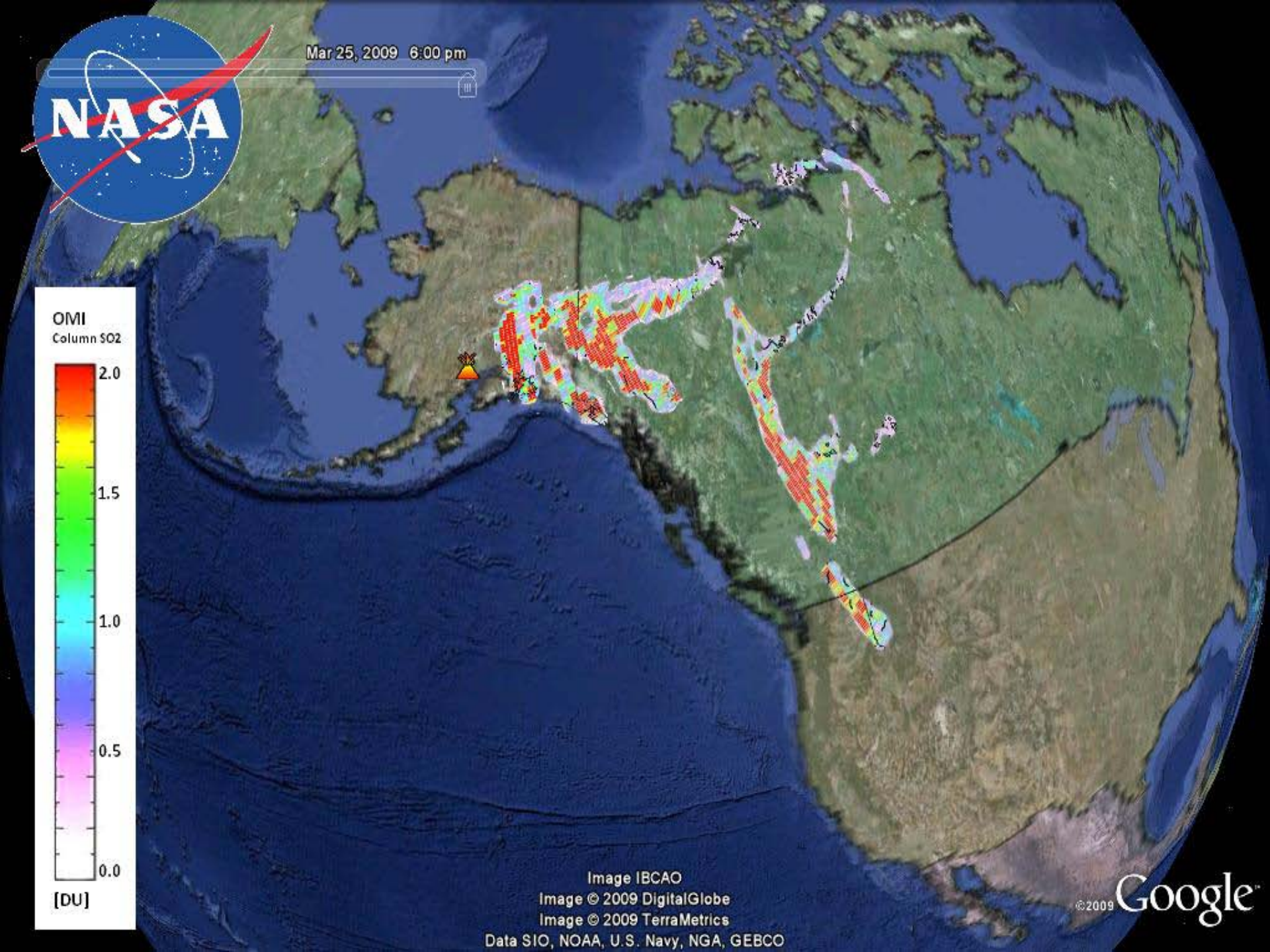

23 March 2009
Mar 25, 2009 6:00 pm
OMI
Column SO2
CALIPSO
532nm TAB
2.0
1.5
1.0
0.5
0.0
[DU]
1.0E-1
1.0E-2
1.0E-3
1.0E-4
[km-1 sr-1]
15
10
5
0
Data SIO, NOAA, U.S. Navy, NG
Image © 2009 TerraMetr
Image IBCAO
Image © 2009 DigitalGlobe

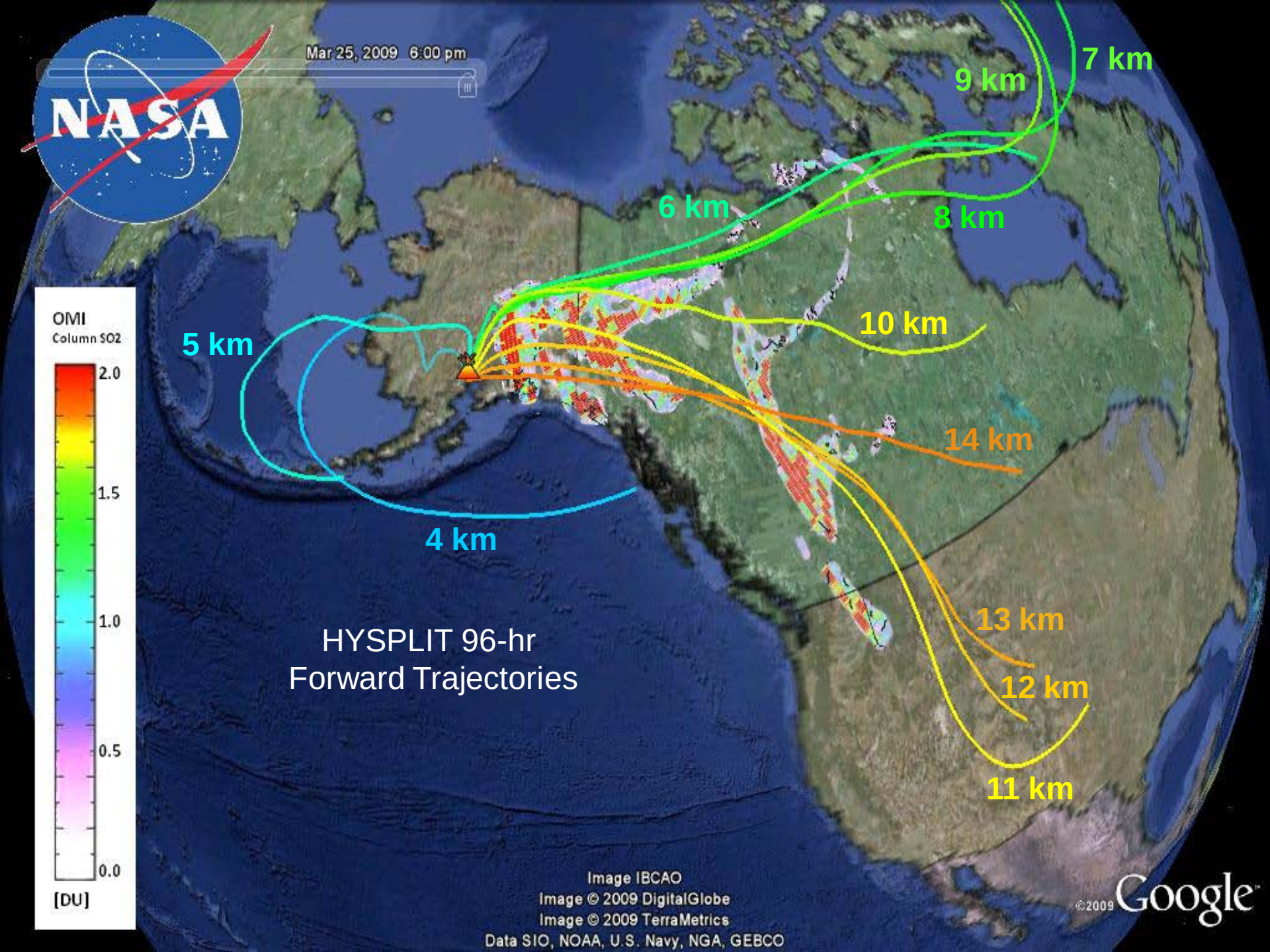

24 March 2009
Mar 25, 2009 6:00 pm
OMI
Column SO2
CALIPSO
532nm TAB
2.0
1.5
1.0
0.5
0.0
[DU]
1.0E-1
1.0E-2
1.0E-3
1.0E-4
[km-1 sr-1]
15
10
5
0
Data SIO, NOAA, U.S. Navy, NG
Image © 2009 TerraMetr
Image IBCAO
Image © 2009 DigitalGlobe

25 March 2009

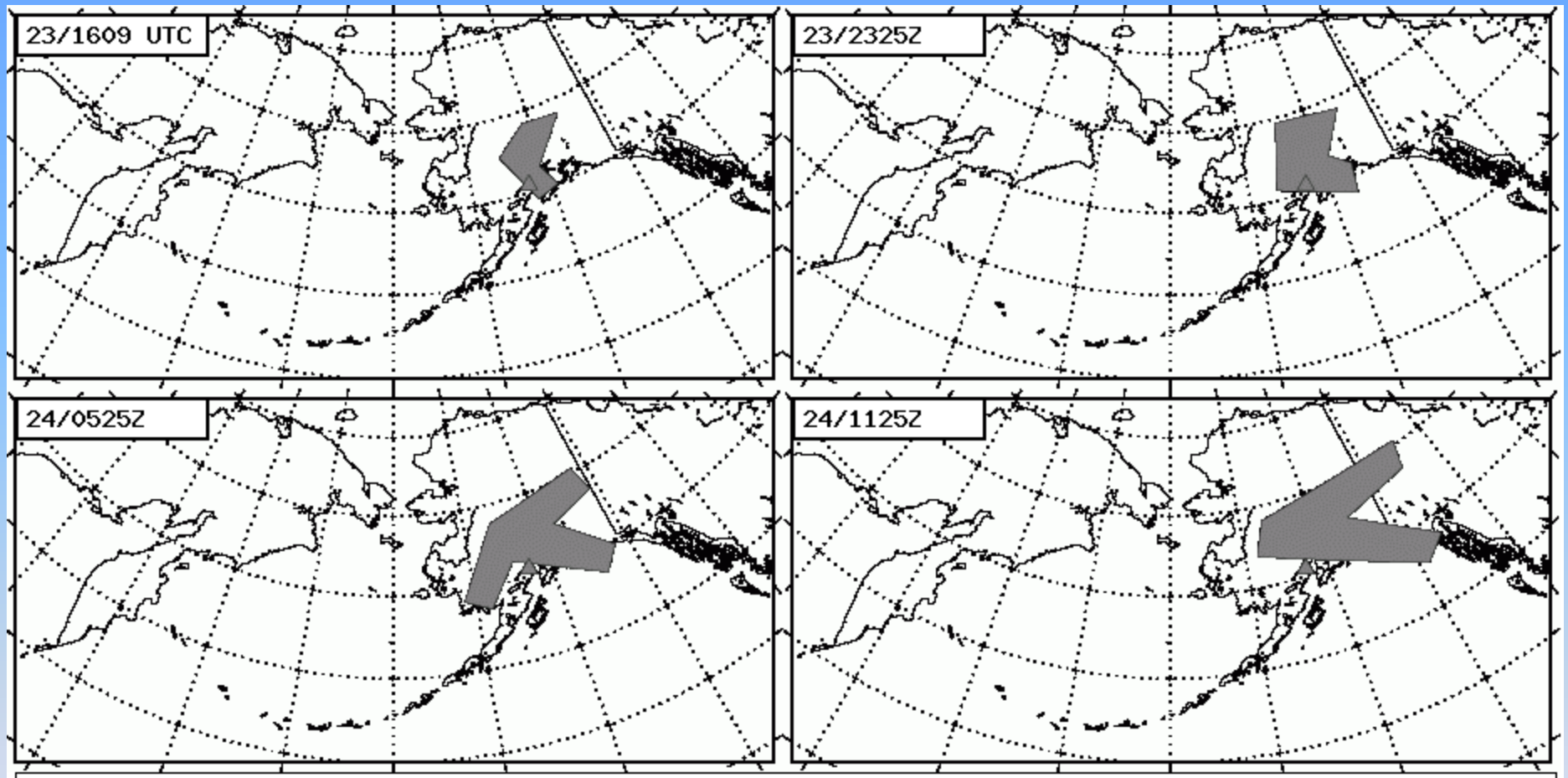



Mar 25, 2009 6:00 pm
OMI
Column SO2
CALIPSO
532nm TAB
2.0
1.5
1.0
0.5
0.0
[DU]
1.0E-1
1.0E-2
1.0E-3
1.0E-4
[km-1 sr-1]
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image IBCAO
Image © 2009 TerraMetrics
Image © 2009 DigitalGlobe
©2009 Google


Mar 25, 2009 6:00 pm
OMI
Column SO2
2.0
1.5
1.0
0.5
0.0
[DU]
Image IBCAO
Image © 2009 DigitalGlobe
Image © 2009 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
©2009 Google


Mar 25, 2009 6:00 pm
OMI
Column SO2
2.0
1.5
1.0
0.5
0.0
[DU]
7 km
9 km
6 km
8 km
10 km
5 km
14 km
4 km
13 km
12 km
11 km
HYSPLIT 96-hr
Forward Trajectories
Image IBCAO
Image © 2009 DigitalGlobe
Image © 2009 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
©2009 Google

Volcanic Ash Advisory



VOLCANIC ASH ADVISORY
DTG: 20090323/1725
VAAC: ANCHORAGE
VOLCANO: REDOUBT 1103-03
AREA: SOUTH CENTRAL ALASKA
SUMMIT ELEV: 10198ft (3109m)
ADVISORY NUM: 2009-3

INFO SOURCE: MT-SAT/GOES/AVO/KVERT/PILOT REPORT/RADAR/
ERUPTION DEAILS: EXPLOSIVE ERUPTION 231230 UTC
REMARKS: VA BLW FL200 MOV N AND W OF REDOUBT VOLCANO. VA ABV FL200 MOV N AND E OF REDOUBT VOLCANO.
NEXT ADVISORY: 20090323/2325Z

Source: http://vaac.arh.noaa.gov

Reported Impacts

- Commercial flights
  - 295 cancelled flights
  - 20,000+ displaced passengers
- Cargo flights
  - 66 (out of 68) flights cancelled on 24 March
  - Air cargo employees sent home for several days
  - A major overnight shipper temporarily moved to Seattle

Reported Ash Encounters

- Major ash encounters
  - 0 ash encounters with commercial aircraft
- Minor ash encounters
  - 1 ash encounter with a private jet (unverified)
  - 1 ash encounter with a helicopter (verified)

Conclusion

- Aviation industry well prepared for Redoubt
- Integrated solutions combining the most useful available information are the key.
- There were significant impacts economic and interruptive impacts but none were catastrophic.