Small Satellite Technologies for Atmospheric Monitoring

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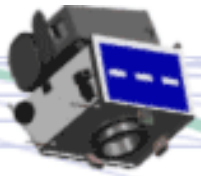
UN/Austria/ESA Symposium "Space Tools and Solutions for Monitoring the Atmosphere in Support of Sustainable Development"
11 September 2007
Graz, Austria

Overview

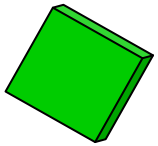
- Introduction
  - Small satellite classification
  - Constellations and applications
- UV Capabilities and Examples
  - Ozone Mapping Detector (OMAD)
  - Atmospheric Ozone Measurements
- Future intrumentation
  - Requirements and Specifications
  - UV Spectral Imaging
- Conclusions

Introduction

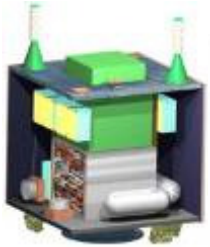
- Satellite Classification
- Disaster Monitoring Constellation

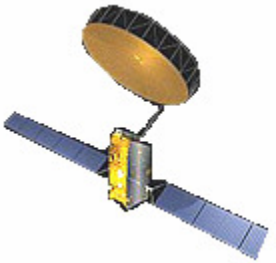


Small Satellite Classification







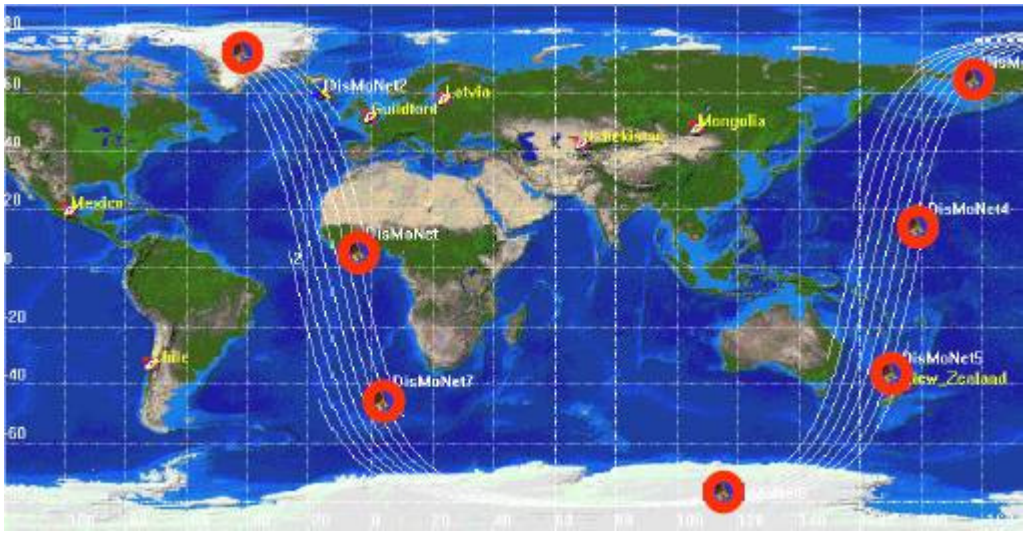


PCBSat	PalmSat	SNAP-1	PICOSat	UK-DMC	GIOVE-A	*Inmarsat-4*
100 g	~1 kg	6.5 kg	67 kg	166 kg	660 kg	5945 kg
1-100 g	0.1–1 kg	1-10 kg	10-100 kg	100-500 kg	500-1000 kg	>1000 kg
$100-20000	$20-200K	$0.2-2M	$2-10M	$10-50M	$50-100M	$0.1-2B
Femtosatellite	Picosatellite	Nanosatellite	Microsatellite	Minisatellite	Medium satellite	Large satellite

Advantages

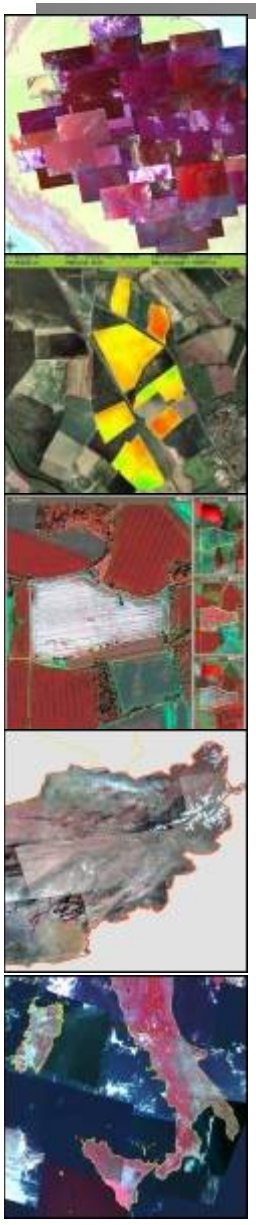
- Low-cost (Total mision: Satellite, launch, operation)
- Short schedules to launch (~1 year, piggyback oportunities)
- Flexible design (According to customer needs)

Disaster Monitoring Constellation



- Constellation of small-satellites reducing revisit time
- Individually owned with collaborative operation
- 32-m resolution (VIS & NIR)
- 24 hr revisit time worldwide (Mitigates cloud cover)
- Large Swath (~660 km swath)
- Built by SSTL (Technology transfer programs)

DMC Applications

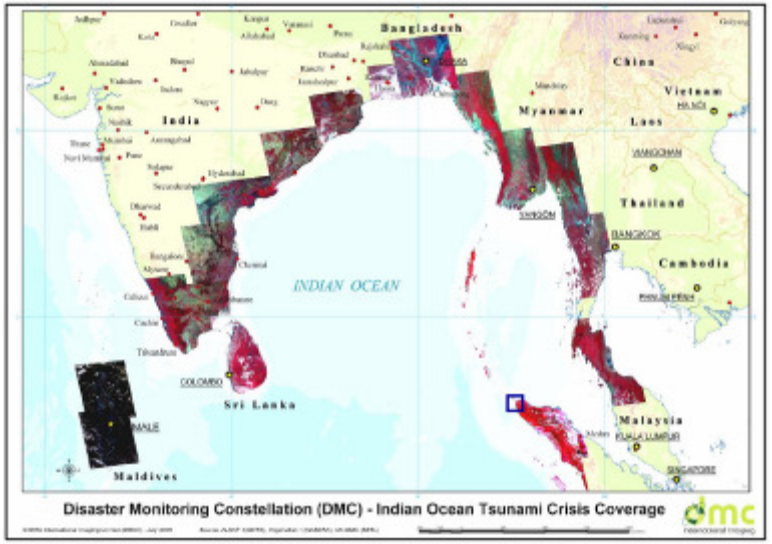


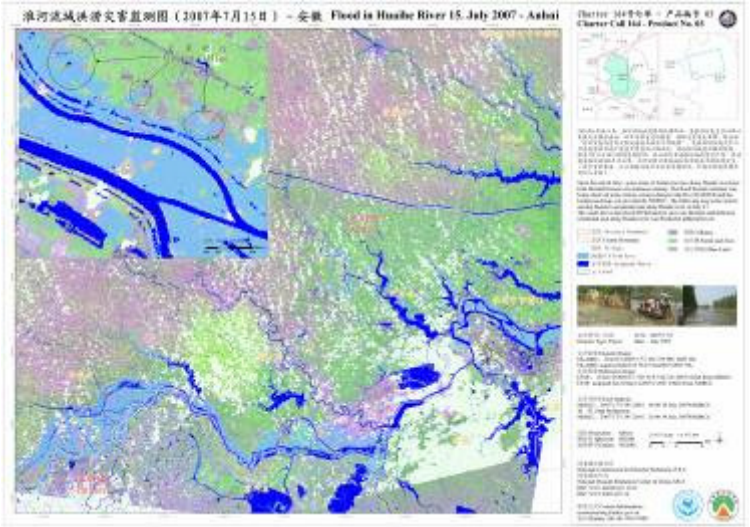
http://www.dmcii.com/applications.htm

- Amazon Deforestation (INPE Brazil)
- Precision Farming (GEOSYS France)
- Agricultural Control (JRC Europe)
- Illicit Crop Monitoring (FCO UK)
- Environment Mapping (JRC Italy)

DMC Disasters

- Tsunami (Asia)
- Hurricanes (U.S.A.)
- Floods (Vietnam, UK, China)
- Earthquake (Peru)



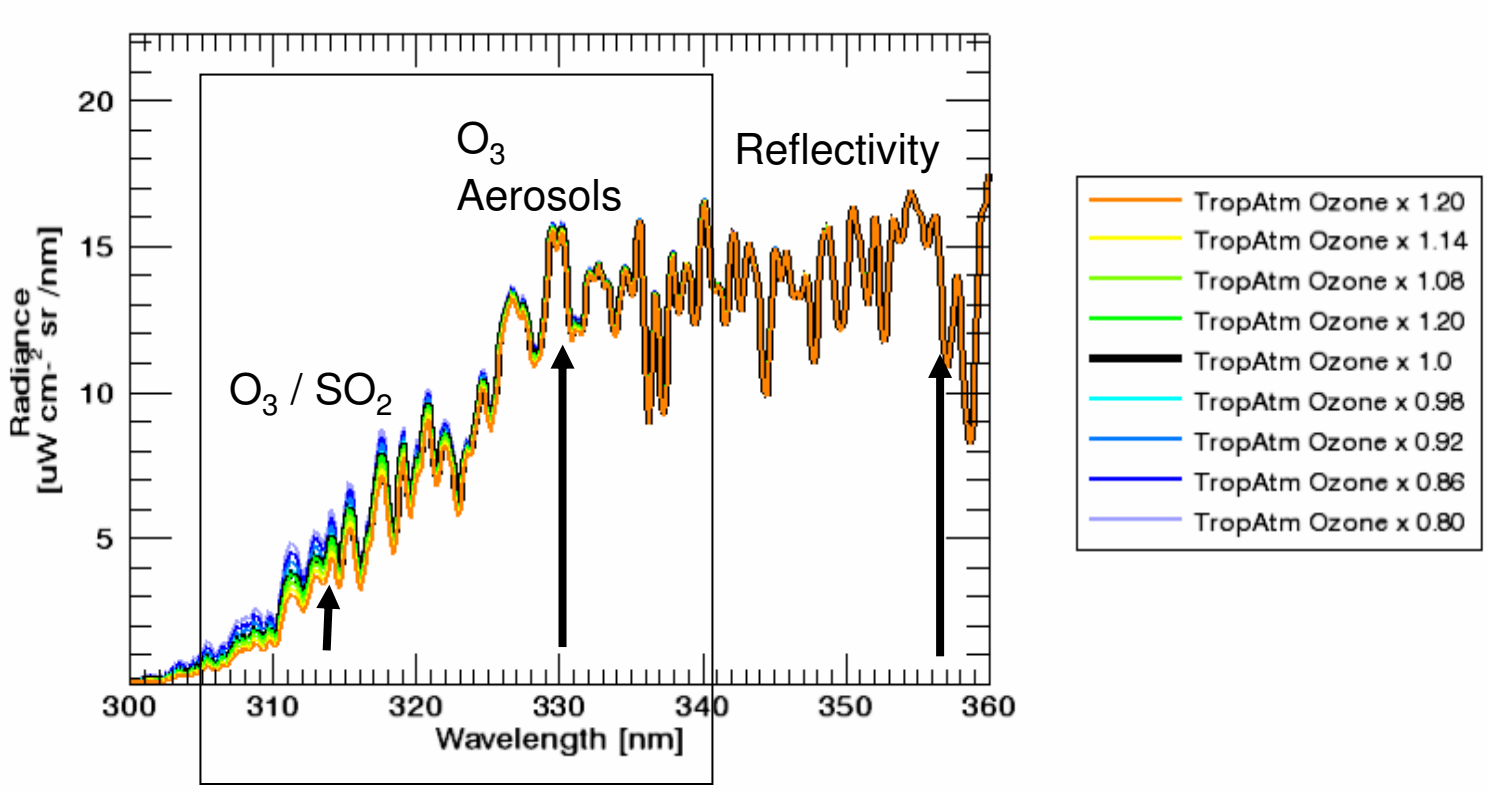


Examples of Atmospheric Capabilities

- UV Radiance and Algorithms
- Ozone Mapping Detector (OMAD)

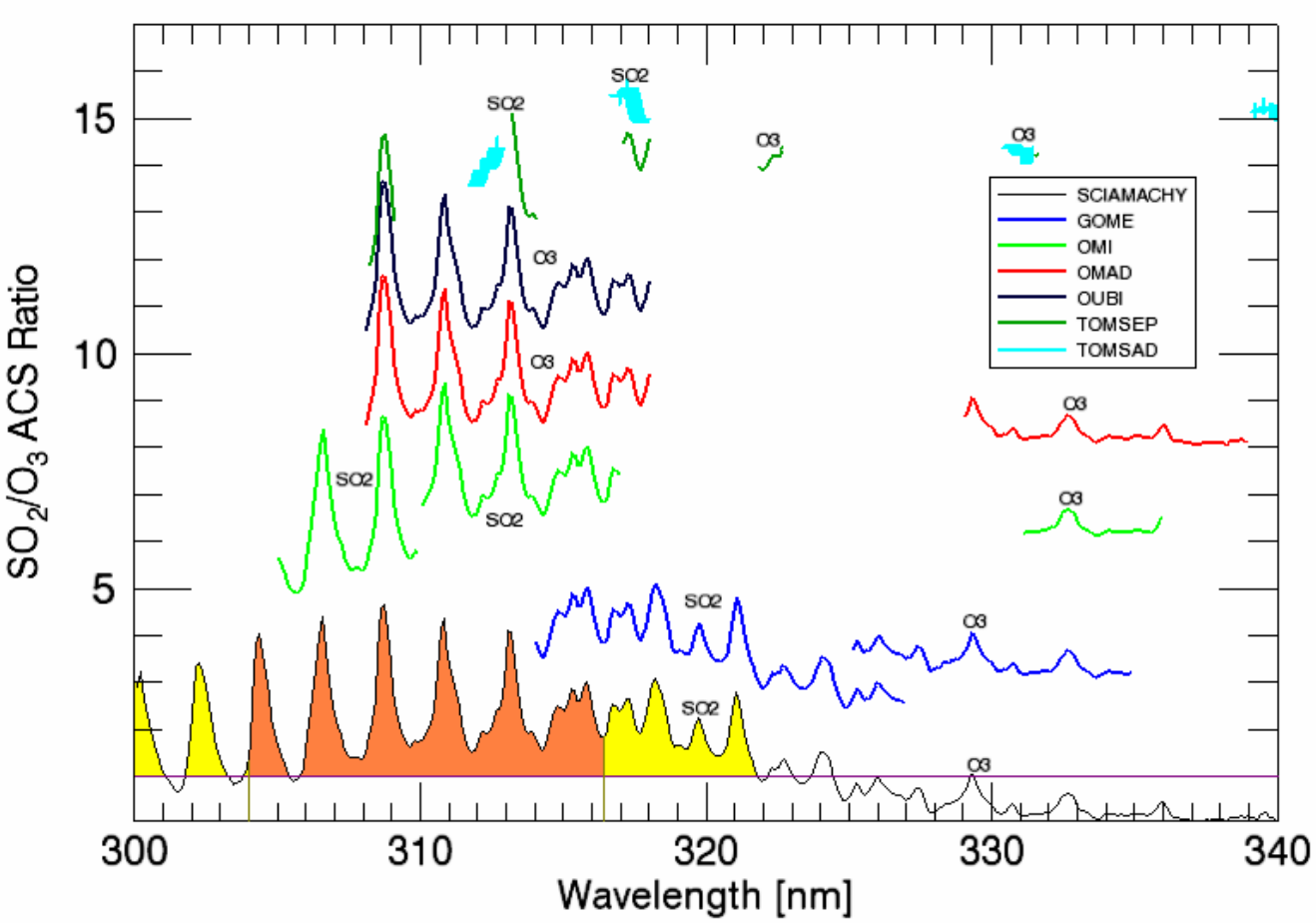
Ozone Determination

- Ozone absorbs in UV range < 325 nm
- Channel ratios are used normally
  - TOMS v.8.0: 317.5 / 331.2 nm
  - OMAD v.2.0: 313 / 334 nm



Spectral Requirements

Spectral Bands used for O_3 and SO_2 detection



TOMS EP/AD (1 nm)

OLME

JBI + OMAD) (10 nm)

OMI

GOME < 1 nm

SCIAMACHY

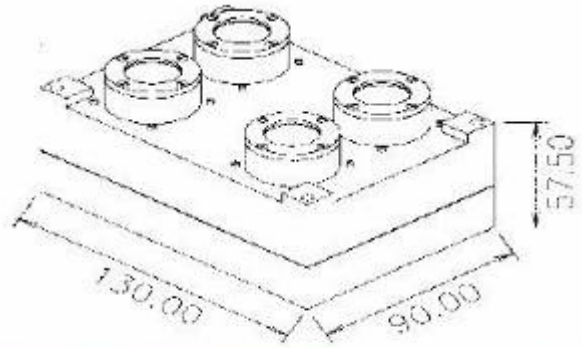
Ozone Mapping Detector

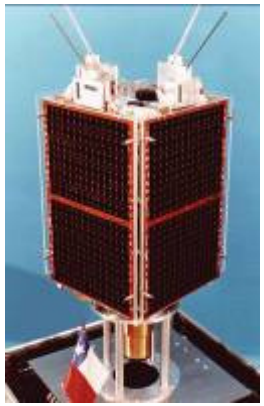
OMAD

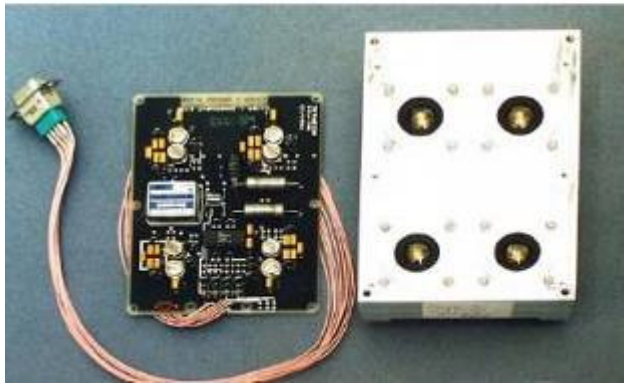
Chilean Airforce FACH in collaboration with Surrey Space Centre (SSC) and SSTL.

- 4-channel radiometer with 289, 313, 334 and 380 nm
- 10-nm resolution bands
- Ground resolution: 150x150 km.
- Nadir Looking only
- Silicon Photodiodes
- 500 mW in operation

Channel [nm]	Gain [V/A]	Responsivity [A/W]	Total Nominal Transmission factors	Transmission at CW [%]	Spectral Bandwidth [nm]
289	1.00E+10	0.13	0.422	0.141	9.5
313	4.13E+07	0.14	0.734	0.305	9.4
334	5.40E+06	0.15	0.719	0.71	10.3
380	4.13E+07	0.18	0.147	0.48	10

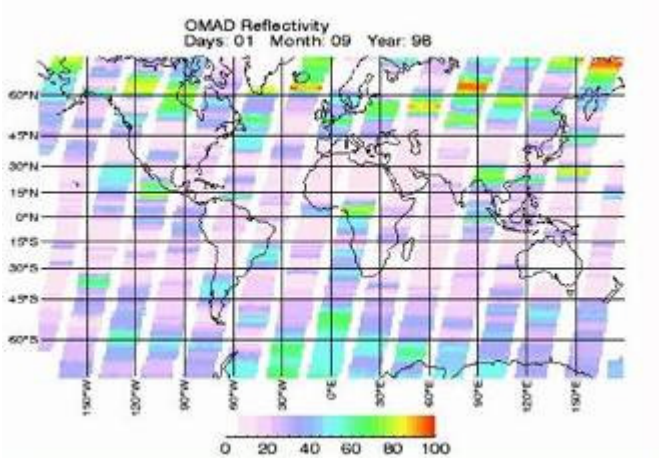




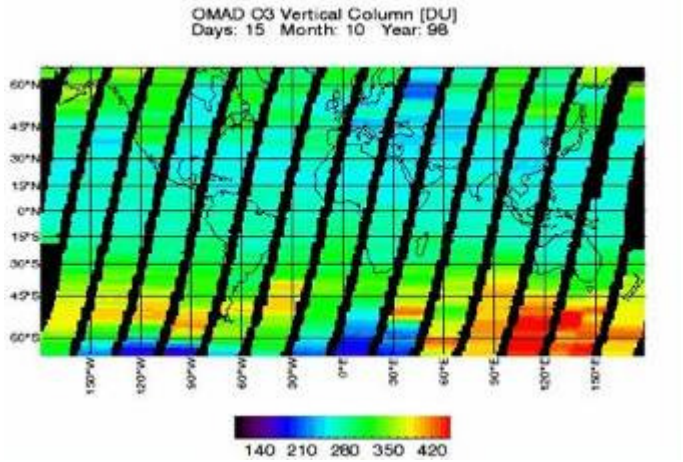


OMAD observations

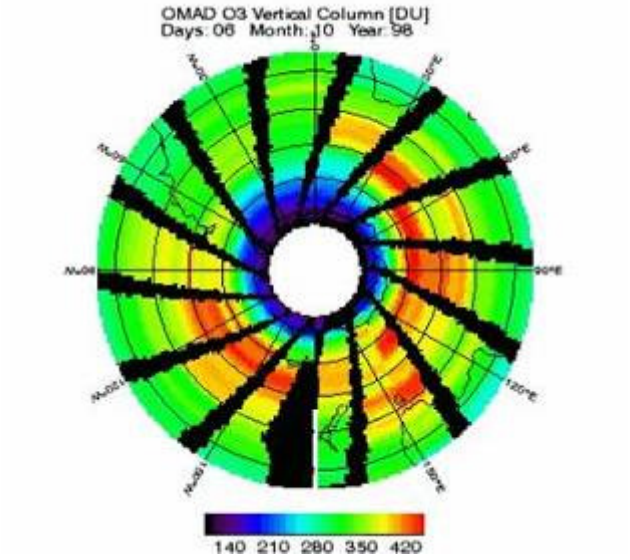
UV Reflectivity



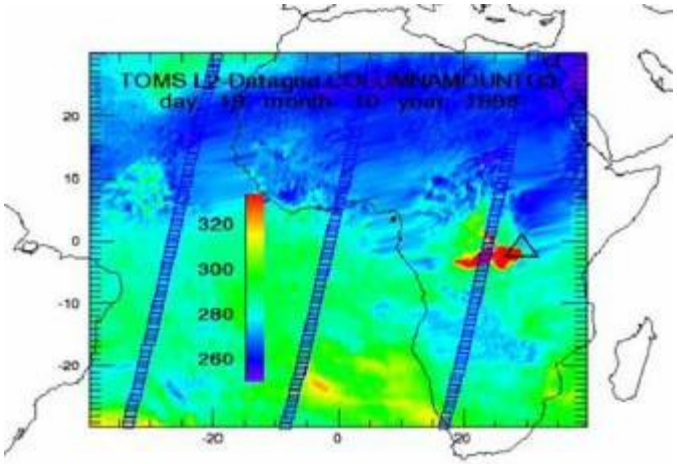
Ozone Monitoring



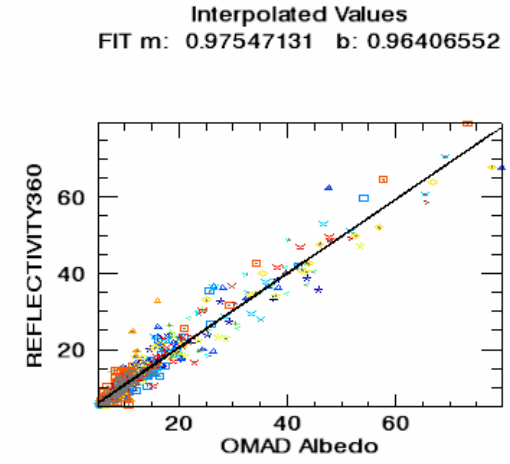
South Hemisphere Ozone Depletion

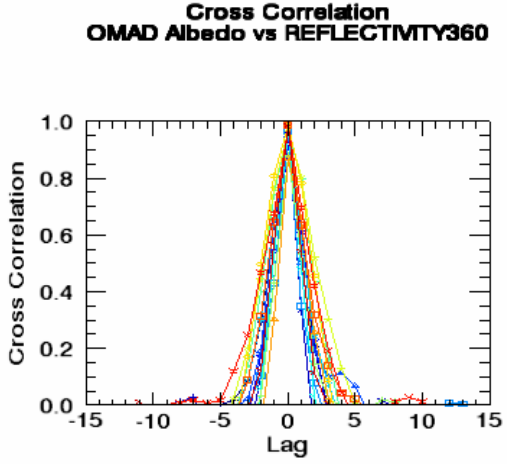


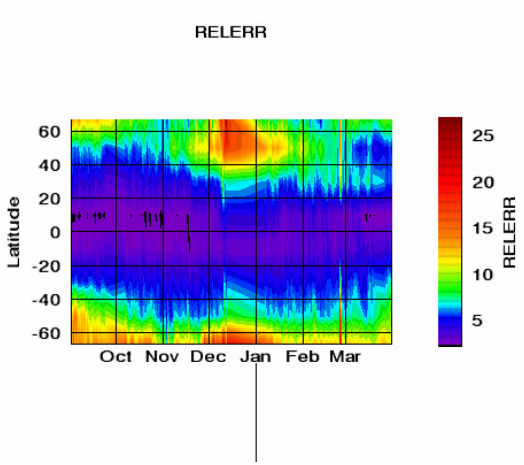
Volcanic Eruption*

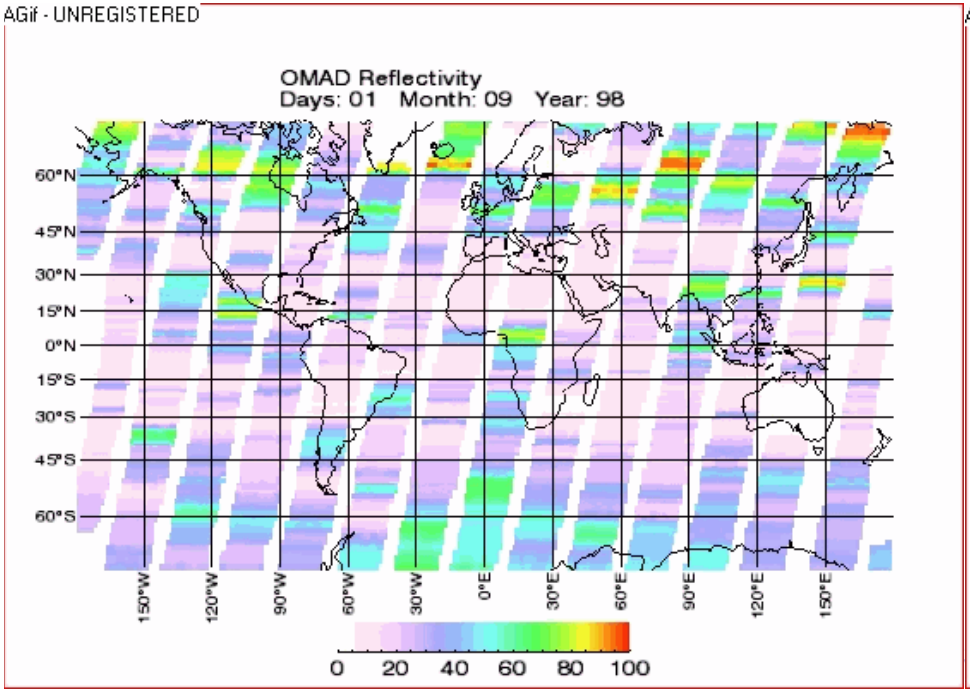


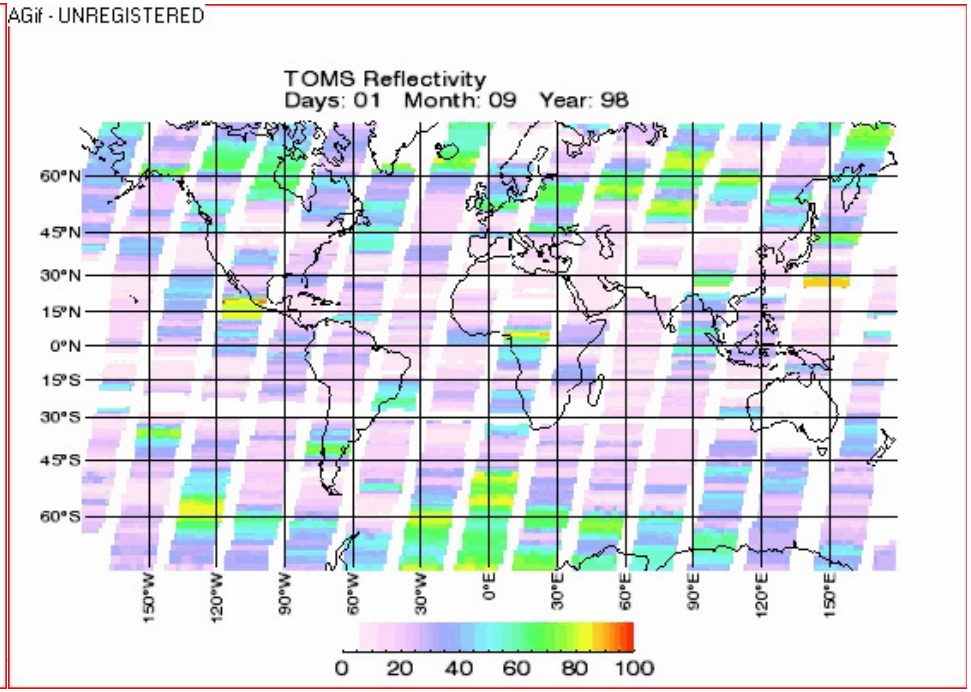
Reflectivity Analysis



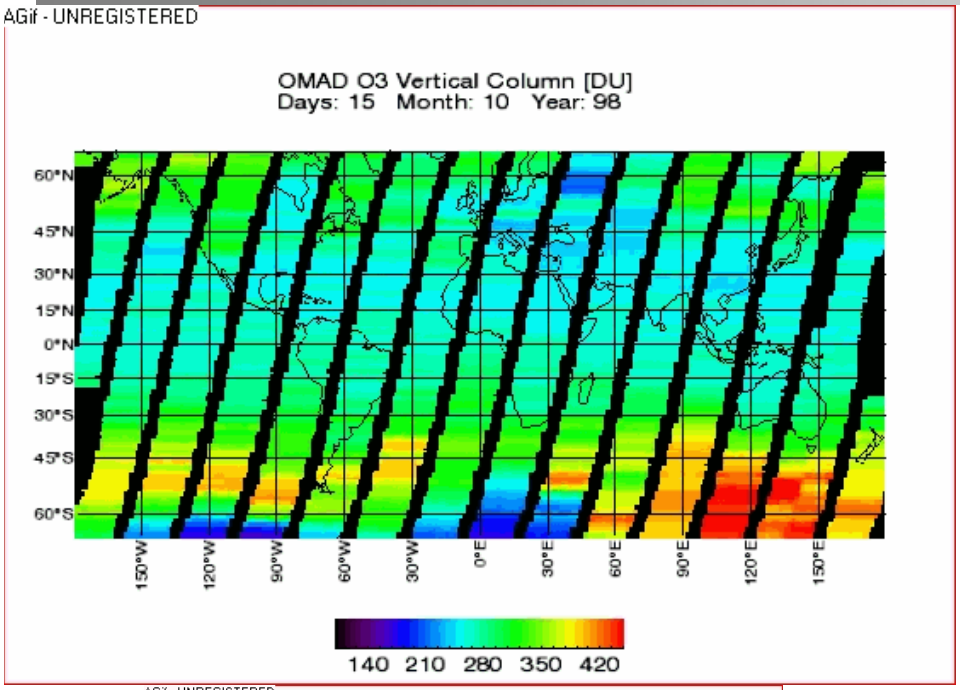


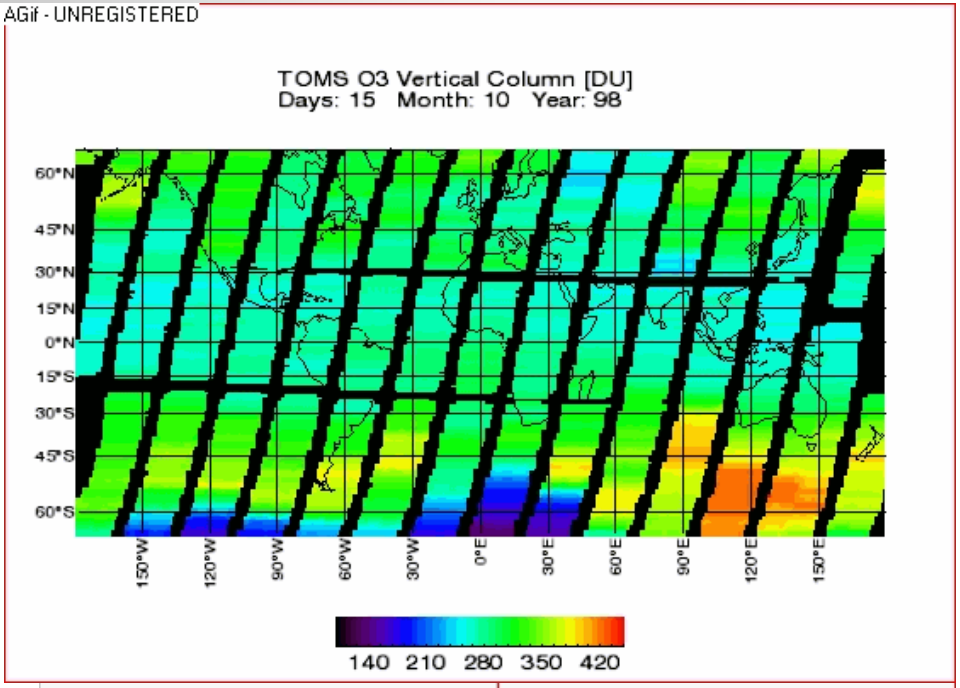


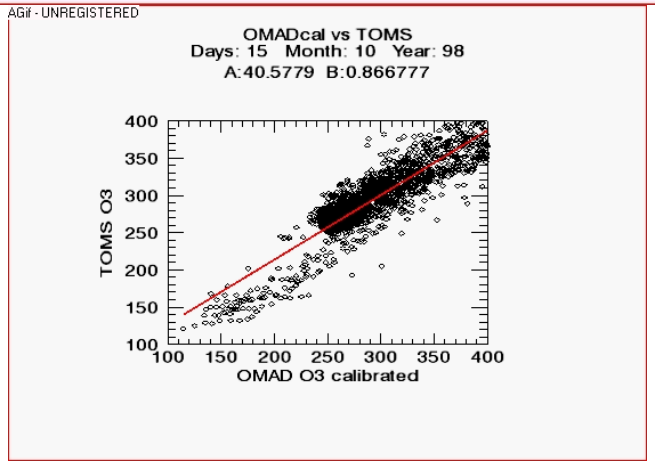


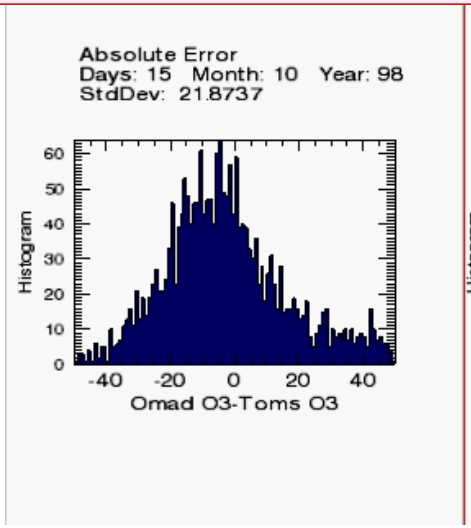


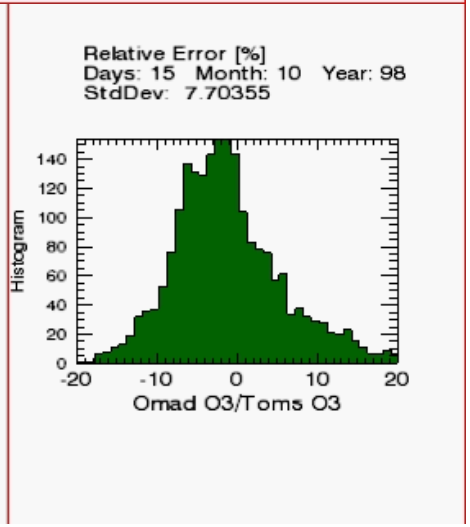
Ozone Monitoring





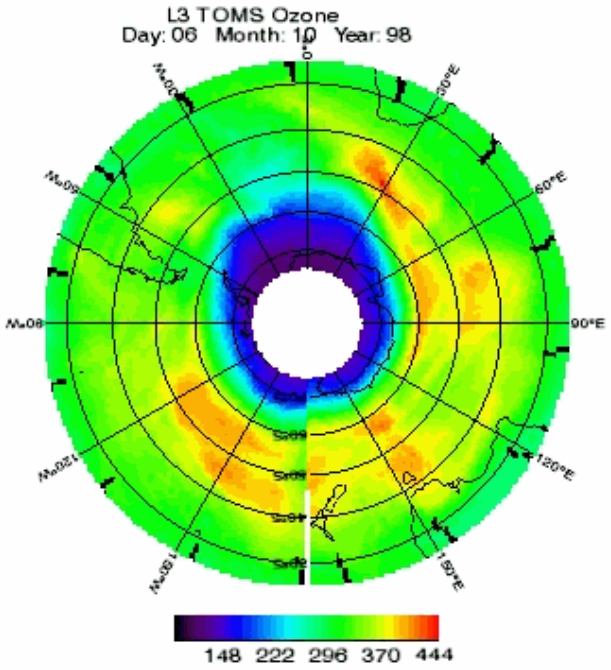


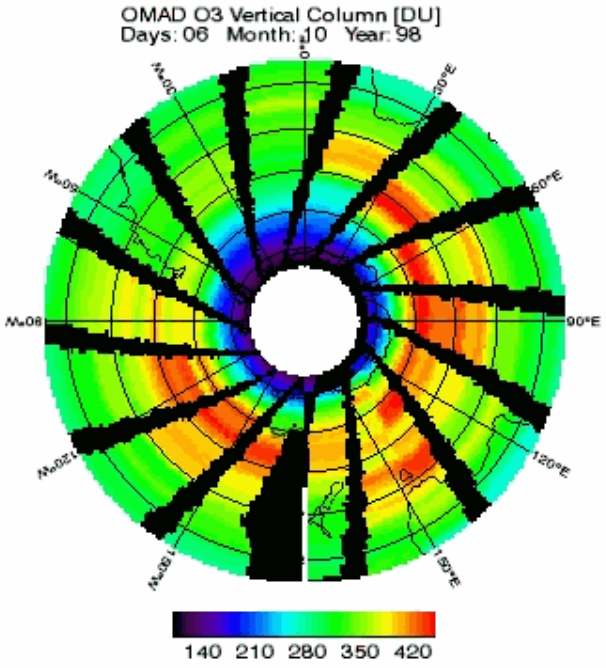


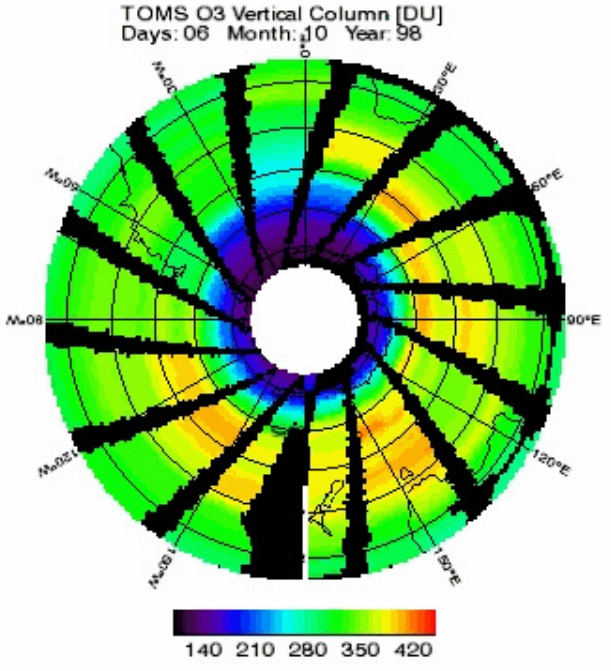


Ozone Depletion

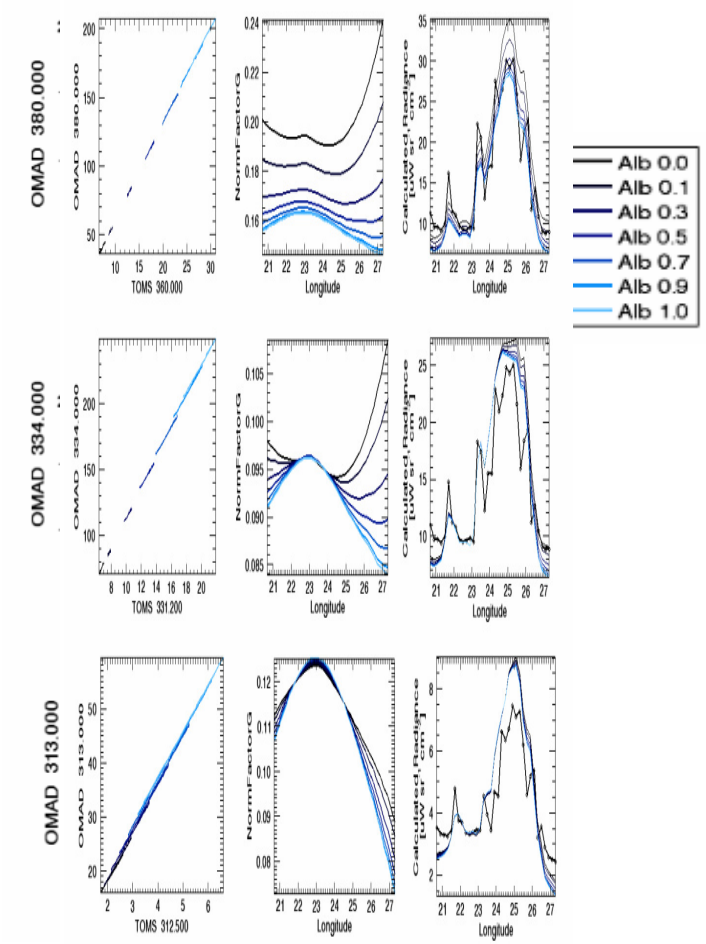
- Errors increase with latitude and Albedo
- Relative errors lower than previous version.
- Absolute errors consistent with typical O_3 below cloud



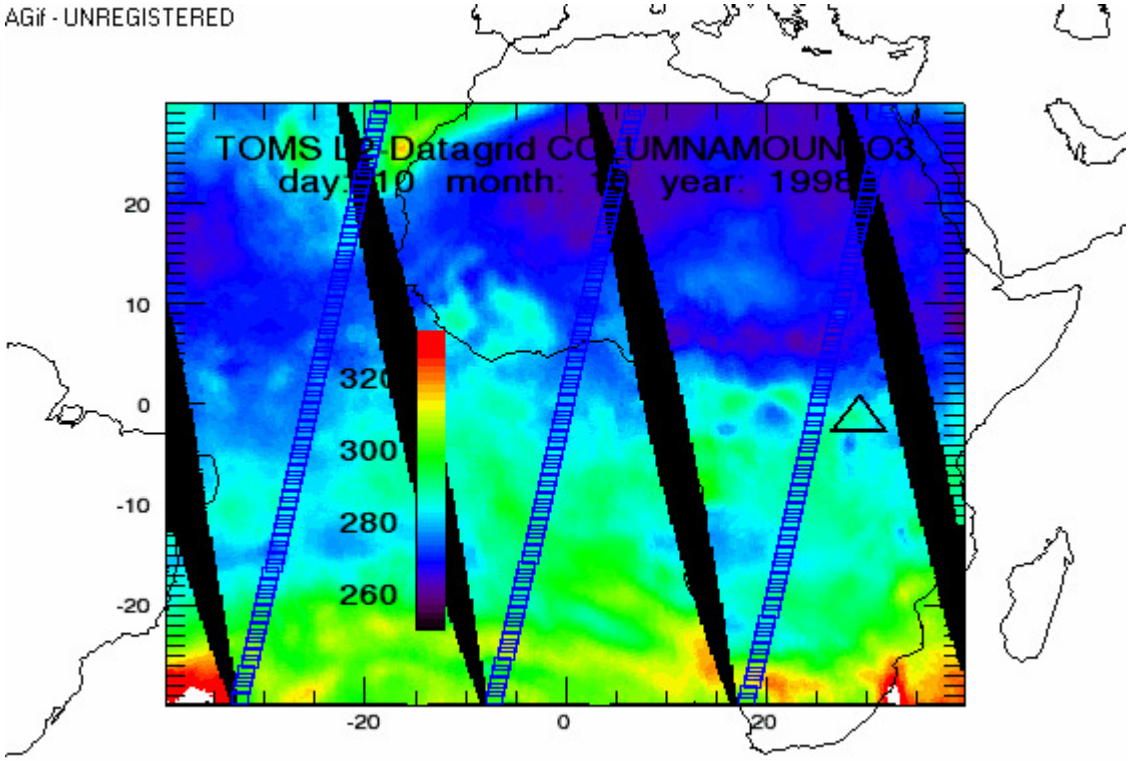




Nyamuragira Eruption

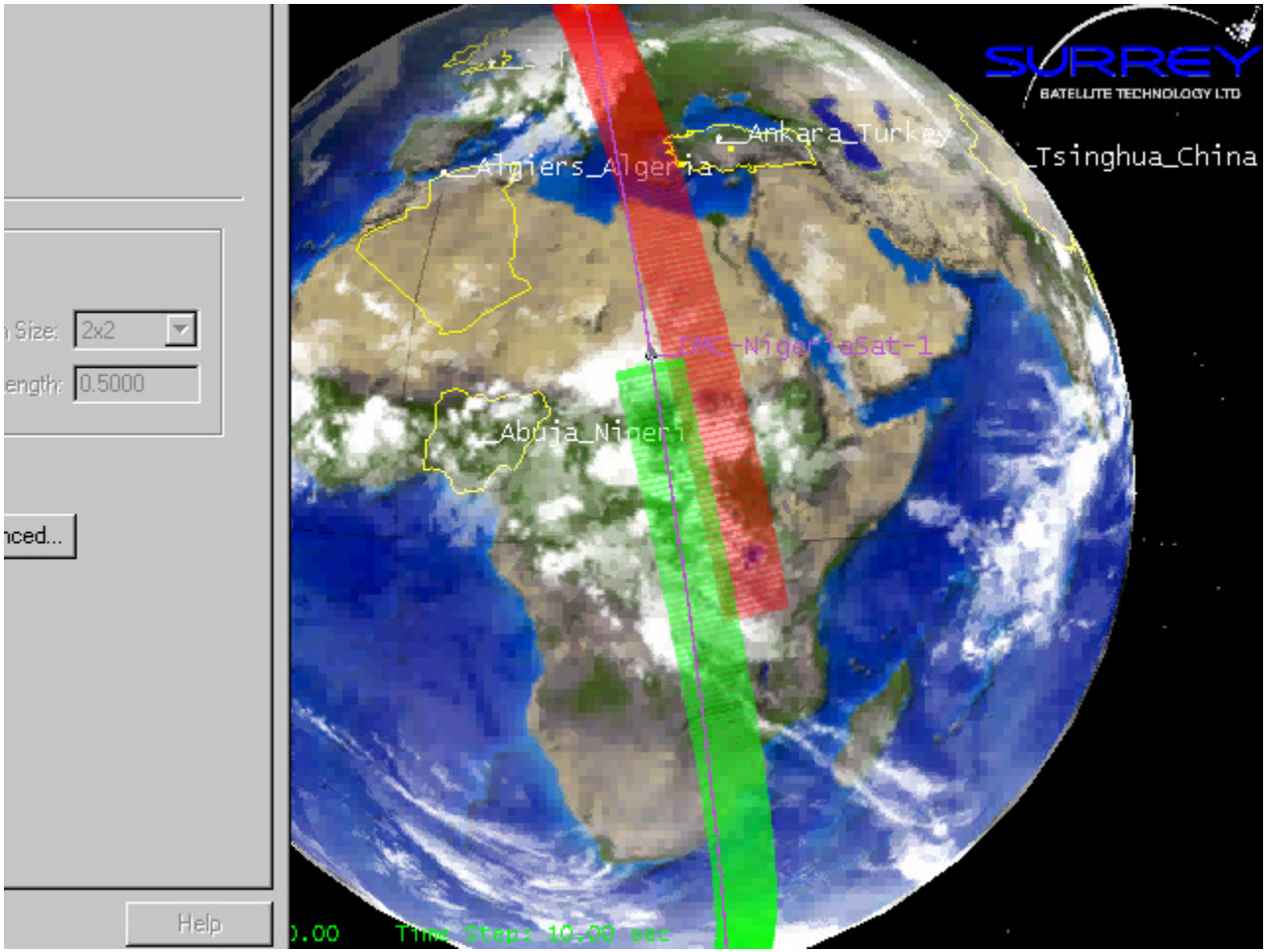


- Nyamuragira volcano Oct 1998 (Rep. Dem. Congo)
- Apparent ozone anomaly due to SO_2 emissions.



Constellation

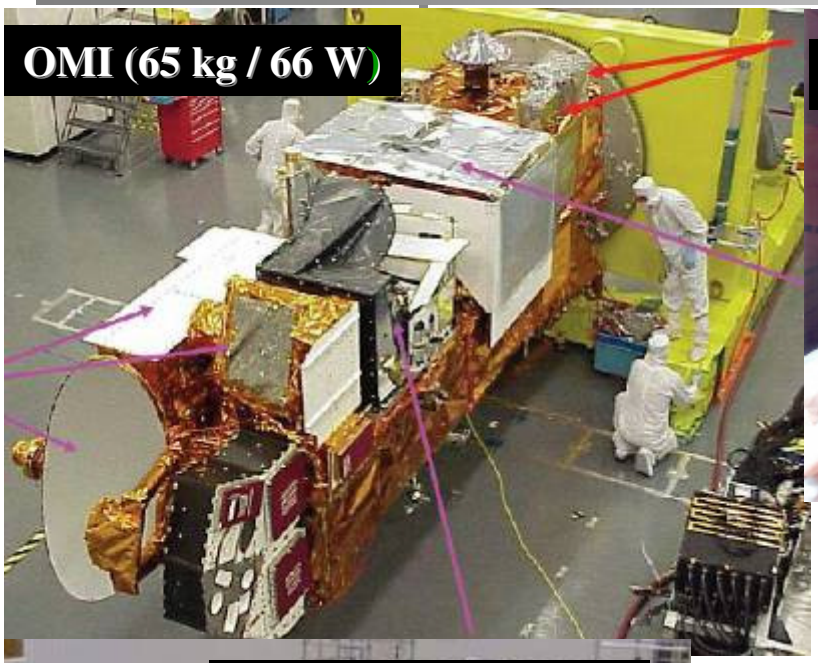
- How would DMC have observed Nyamuragira ?

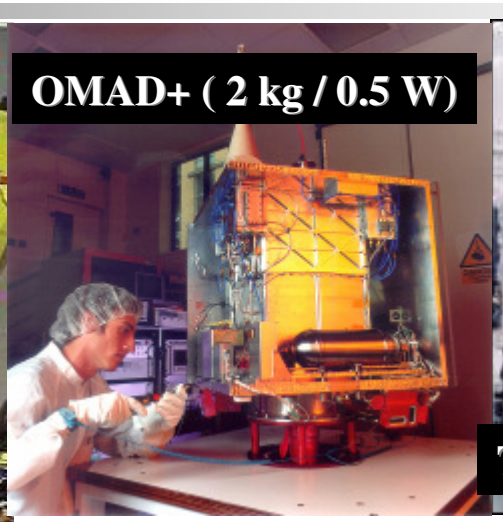


Instruments and Requirements

- Spatial and Temporal
- Spectral
- Radiometric
- Spectral Imaging

Satellites and Instruments





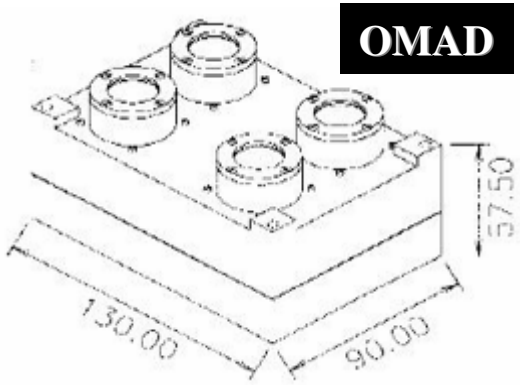
Spatial

- GOME (320 x 40) km / Swath: 960 km
- TOMS (50 x 50) km / Swath:1,500 km
- OMI (12 x 24) km / Swath: 2,600 km
- UVIm (7 x 31) km / Swath: 640 km (*two imagers*)

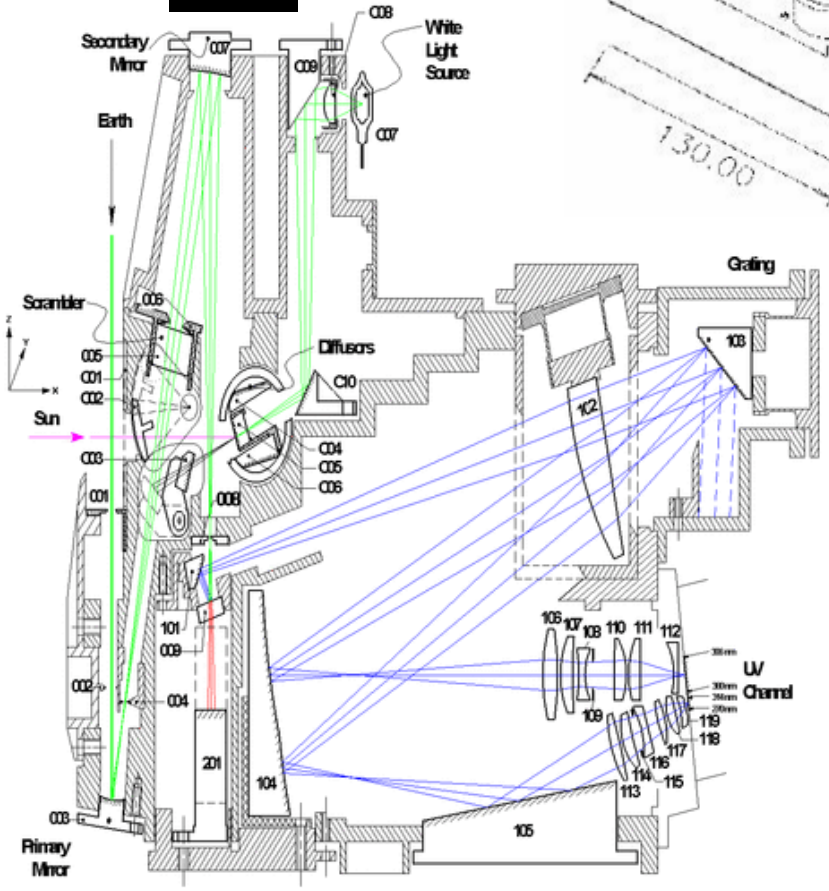
http://earthobservatory.nasa.gov/
http://www.esa.int

Payloads: UV Instruments

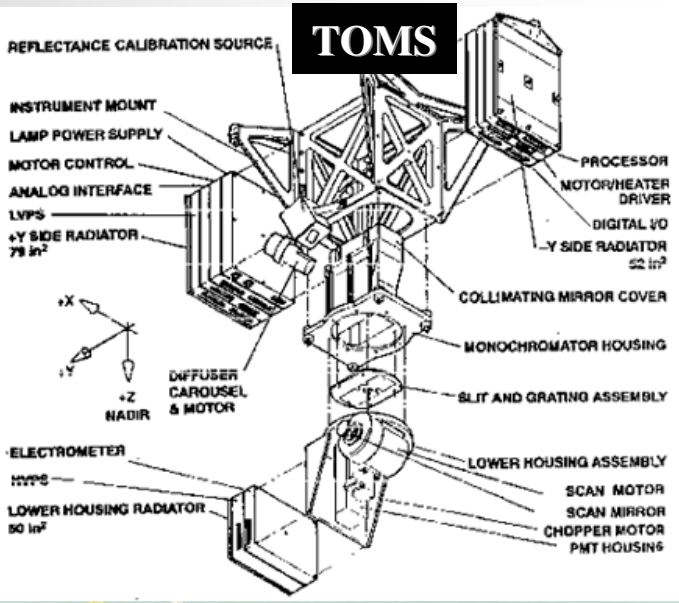
OMAD



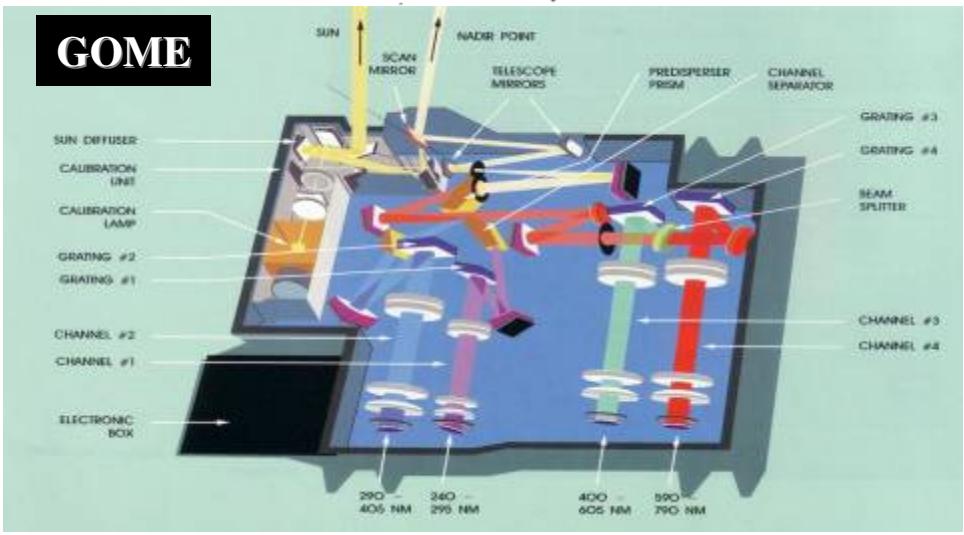
OMI



TOMS

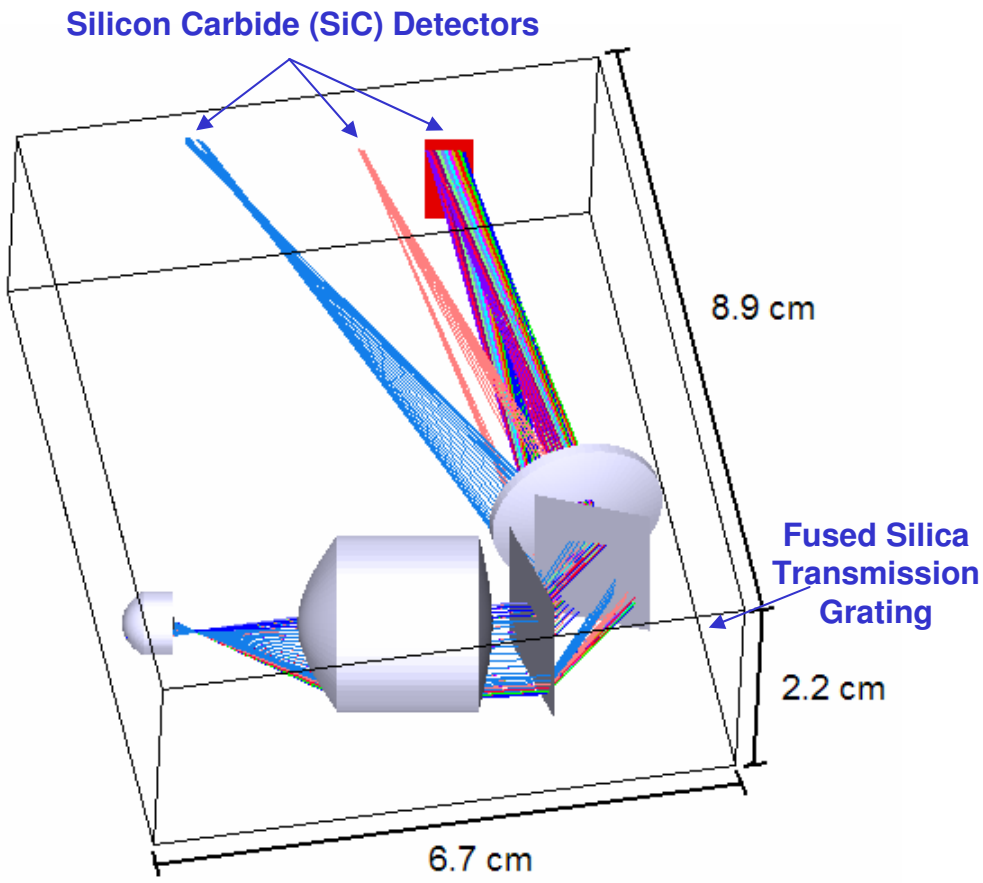


GOME



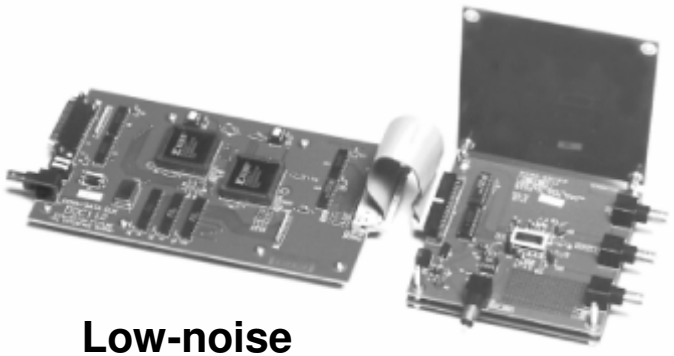
UV Imaging Spectrometer

Optical Design



(~5 kg / < 5 W)

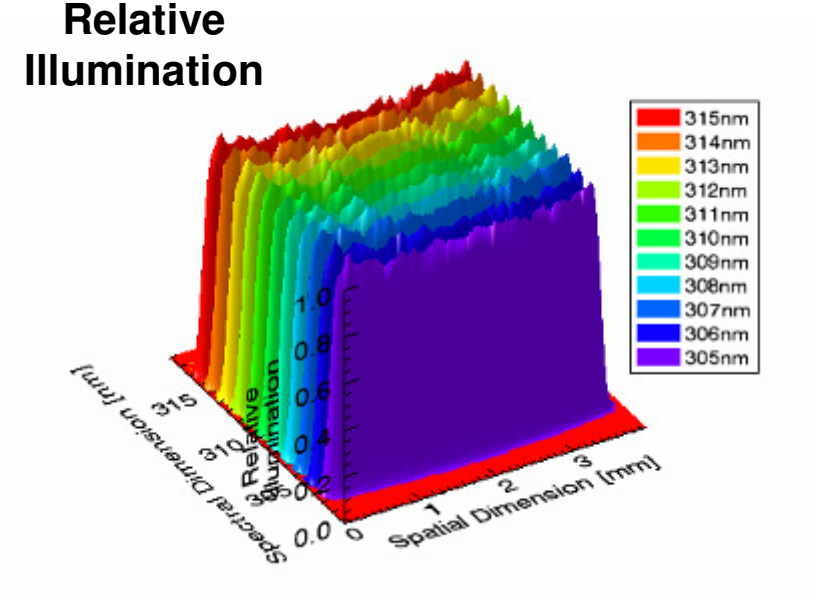
- Small, Low Power
- Reduced Wavelength Range
- Simpler Optical Layout
- High Efficiency Gratings
- Solar Blind detectors
- Very Low-Noise Electronics



Low-noise Electronics

Spectral Imaging

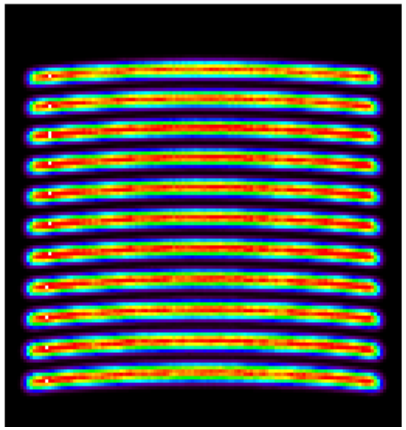
Relative Illumination



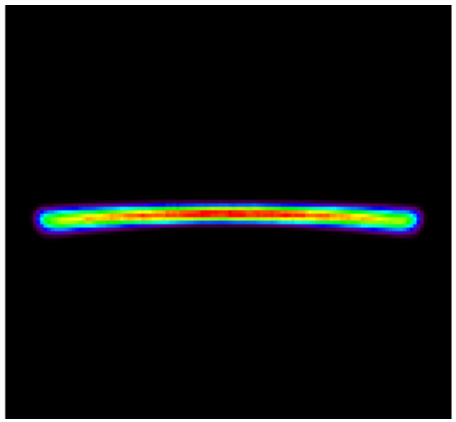
Specifications

Field of View	25.8^{o} x 0.57^{o}
Pixel sample distance	7 x 31.5 km §
Revisit Time	Daily *
Spectral Resolution	1 nm
Slit	6 x 0.100 mm
Grating	2847 lines mm^{-1}
Etendue	7.48 $x10^{-4}$ sr^{-1} cm^{-2}
S/N @ 0.1 uW sr^{-1} cm^{-2}	2,244
Entrance Pupil Diameter	4 mm
Back Focal Length	60.17 mm
Working F/#	6.33

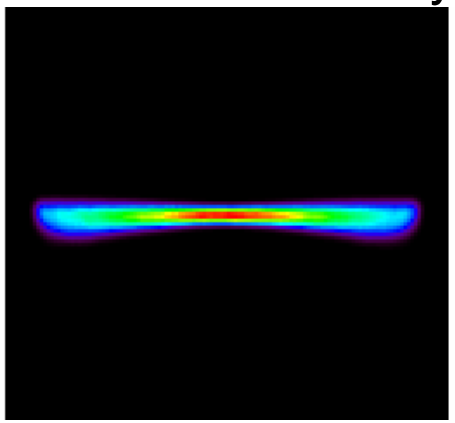
305 – 315 nm O_3/SO_2



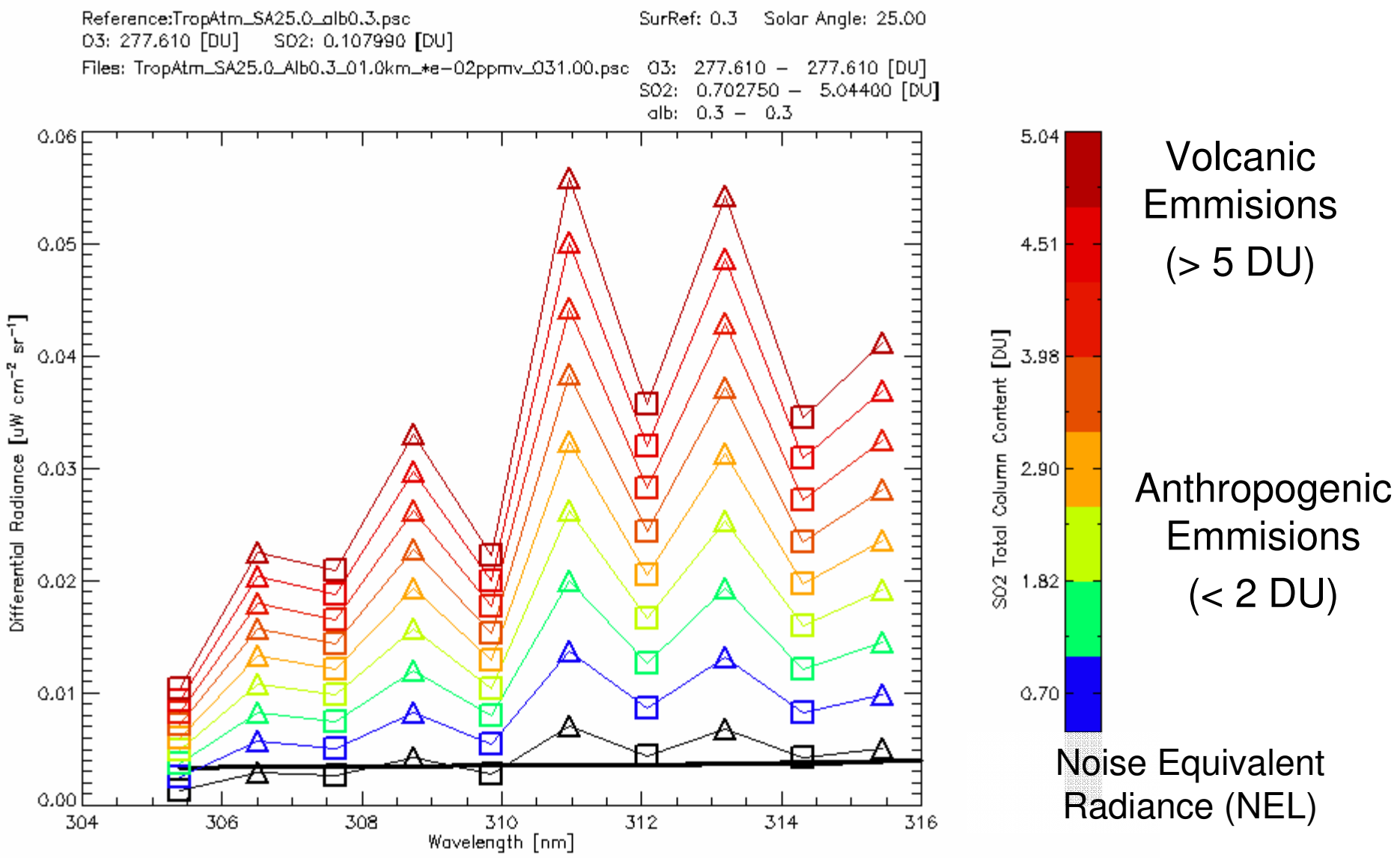
331 nm Aerosols



360 nm Reflectivity



Sensitivity to SO_2



Volcanic Emmisions (> 5 DU)

Anthropogenic Emmisions (< 2 DU)

Noise Equivalent Radiance (NEL)

Conclusions

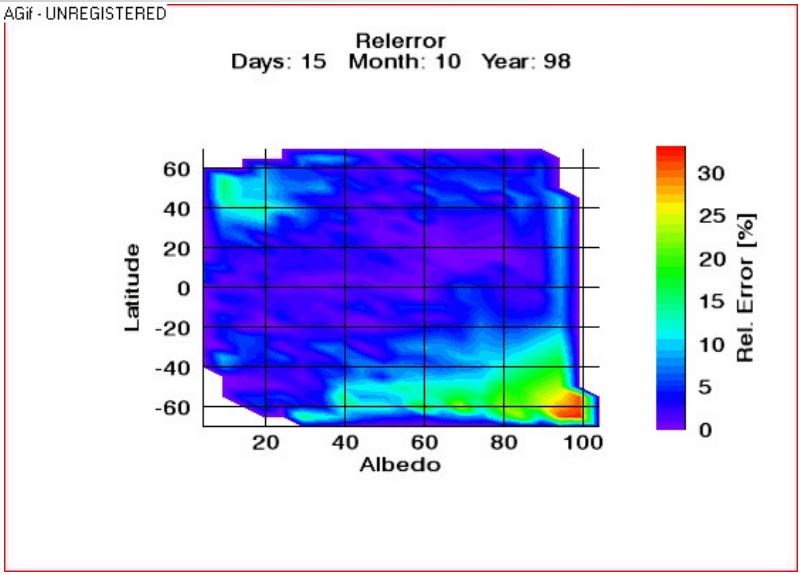
- Utility of Small Satellites and Constellations
- Atmospheric monitoring capabilities were greater than expected
- Algorithms and technology have improved
- New miniaturised UV spectrometer
- DMC + UV = Potential for monitoring atmospheric and volcanic activity
- Suitability for constellation of small satellites (Latin American, Ring of Fire countries ?)
- Spread the word !

Thank you for your attention

Questions ?

Errors in Ozone Measurements

- Errors increase with latitude and Albedo
- Relative errors lower than previous version.
- Absolute errors consistent with typical O_3 below cloud



Zones	M	B	Absolute 1-Sigma Error in OMAD O3 [DU]				Relative 1-Sigma Error in OMAD O3 [%]			
Reflectivity	20%	20%	50%	40%	30%	20%	50%	40%	30%	20%
1	227.927	-24.259	14.16	12.72	10.59	7.87	4.70	4.23	3.53	2.68
2	201.325	12.036	14.52	13.00	14.11	9.20	4.91	4.41	3.85	3.23
3	213.459	-3.531	12.09	11.12	10.14	8.49	4.50	4.13	3.75	3.16
4	187.006	26.741	10.97	10.42	9.75	8.34	3.96	3.77	3.54	3.05
5	145.384	78.466	5.60	5.50	5.28	4.72	2.10	2.06	1.98	1.78
6	80.232	161.690	6.42	6.44	6.41	5.88	2.41	2.42	2.41	2.21
7	195.810	18.558	9.33	9.15	8.32	7.33	3.31	3.20	2.99	2.66
8	191.104	26.172	7.14	6.99	6.71	6.32	2.58	2.53	2.43	2.30
9	289.933	-92.257	13.96	13.09	11.86	9.56	4.34	4.09	3.75	3.11
10	278.727	-74.309	13.70	13.16	12.27	11.06	4.42	4.26	4.00	3.65
11	351.321	-177.655	16.00	14.56	12.41	14.91	4.66	4.15	3.46	4.06
12	365.279	-199.791	16.95	15.65	13.92	9.07	5.14	4.79	4.30	2.93
All Regions Average Errors			**11.74**	**10.98**	**10.15**	**8.56**	**3.92%**	**3.67%**	**3.33%**	**2.90%**