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http://www.cira.colostate.edu/

Interaction between gravity waves and nightglow as observed by the Suomi-NPP Day/Night Band

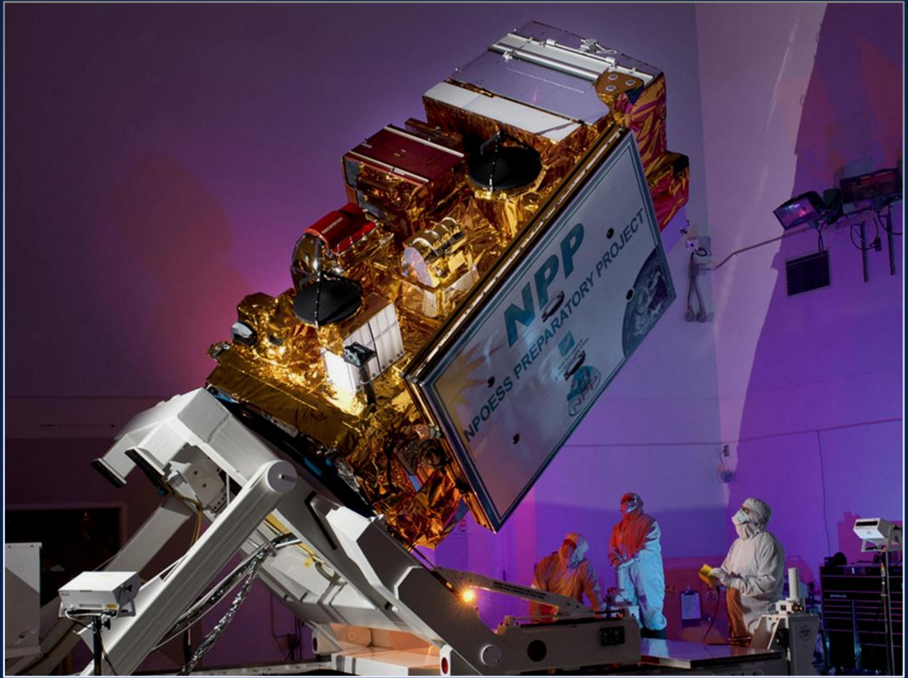
26th General Assembly of the International Union of Geodesy and Geophysics (IUGG),
Praha, Czech Republic, 23 June – 02 July 2015

29 June 2015 (IAMAS)

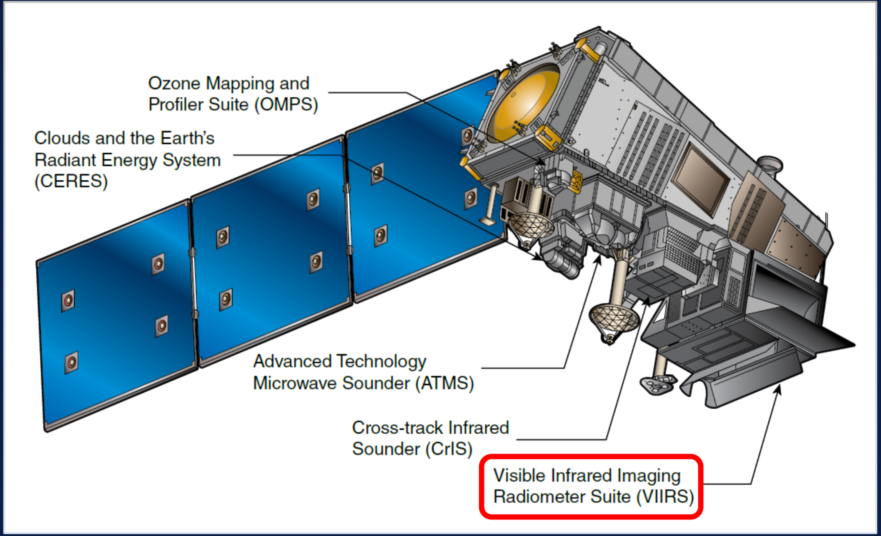
Suomi NPP satellite – basic information

NPP = National Polar-orbiting Partnership
satellite named after Verner Suomi

JPSS = Joint Polar Satellite System



Launched on 28 October 2011, 833 km polar orbit,
with ~ 01:30 and 13:30 crossing time (local time)



- Visible Infrared Imaging Radiometer Suite (VIIRS)
- Advanced Technology Microwave Sounder (ATMS)
- Cross-track Infrared Sounder (CrIS)
- Ozone Mapping and Profiler Suite (OMPS)
- Clouds and the Earth's Radiant Energy System (CERES)

Suomi-NPP VIIRS (Visible Infrared Imaging Radiometer Suite)

		Band No.	Wave-length (µm)	Horiz Sample Interval (km Downtrack x Crosstrack)		Driving EDRs	Radi-ance Range	Ltyp or Ttyp	Signal to Noise Ratio (dimensionless) or NEΔT (Kelvins)		
				Nadir	End of Scan				Required	Predicted	Margin
VIS/NIR FPA	Silicon PIN Diodes	M1	0.412	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	44.9	352	483	37%
						Aerosols	High	155	316	827	162%
		M2	0.445	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	40	380	501	32%
						Aerosols	High	146	409	774	89%
		M3	0.488	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	32	416	573	38%
						Aerosols	High	123	414	747	80%
		M4	0.555	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	21	362	482	33%
						Aerosols	High	90	315	586	86%
		I1	0.640	0.371 x 0.387	0.80 x 0.789	Imagery	Single	22	119	135	13%
		M5	0.672	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	10	242	306	26%
						Aerosols	High	68	360	450	25%
		M6	0.746	0.742 x 0.776	1.60 x 1.58	Atmospheric Corr'n	Single	9.6	199	279	40%
		I2	0.865	0.371 x 0.387	0.80 x 0.789	NDVI	Single	25	150	212	41%
		M7	0.865	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	6.4	215	467	117%
						Aerosols	High	33.4	340	467	37%
CCD		DNB	0.7	0.742 x 0.742	0.742 x 0.742	Imagery	Var.	6.70E-05	6	6.2	3%
S/MWIR	PV HgCdTe (HCT)	M8	1.24	0.742 x 0.776	1.60 x 1.58	Cloud Particle Size	Single	5.4	74	109	47%
		M9	1.378	0.742 x 0.776	1.60 x 1.58	Cirrus/Cloud Cover	Single	6	83	156	88%
		I3	1.61	0.371 x 0.387	0.80 x 0.789	Binary Snow Map	Single	7.3	6.0	71	1084%
		M10	1.61	0.742 x 0.776	1.60 x 1.58	Snow Fraction	Single	7.3	342	461	35%
		M11	2.25	0.742 x 0.776	1.60 x 1.58	Clouds	Single	0.12	10	14	44%
		I4	3.74	0.371 x 0.387	0.80 x 0.789	Imagery Clouds	Single	270 K	2.500	0.236	68%
		M12	3.70	0.742 x 0.776	1.60 x 1.58	SST	Single	270 K	0.396	1.039	141%
		M13	4.05	0.742 x 0.259	1.60 x 1.58	SST	Low	300 K	0.107	0.051	111%
						Fires	High	380 K	0.423	0.353	20%
LWIR	PV HCT	M14	8.55	0.742 x 0.776	1.60 x 1.58	Cloud Top Properties	Single	270 K	0.091	0.057	60%
		M15	10.763	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K	0.070	0.034	105%
		I5	11.450	0.371 x 0.387	0.80 x 0.789	Cloud Imagery	Single	210 K	1.500	1.004	49%
		M16	12.013	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K	0.072	0.059	23%

Total of 22 spectral bands:

resolution

- **I** bands – 375 m (5)
- **M** bands – 750 m (16)
- DNB band – 750 m (1)

Day/Night Band (DNB)

Suomi-NPP VIIRS Day/Night Band – comparison with DMSP/OLS

Attribute	DMSP/OLS*	VIIRS/DNB on Suomi NPP*
Orbit	Sun-synchronous, ~850 km	Sun-synchronous, 833 km
Nighttime Nodal Overpass Time	~ 19:30 UTC	~ 01:30 UTC
Swath Width	3000 km	3000 km
Spectral Response (FWHM)	Panchromatic 500-900 nm	Panchromatic 500-900 nm
Instantaneous Field of View	5 km (nadir) / ~7 km (edge)	0.740 ± 0.043 km (Scan) 0.755 ± 0.022 km (track)
Spatial Resolution (Ground Sample Distance)	2.7 km; 'smooth' data	< 0.820 km (Scan) < 0.750 km (track)
Minimum Detectable Signal	4×10^{-5} W m^{-2} sr^{-1}	3×10^{-5} W m^{-2} sr^{-1}
Noise Floor	$\sim5\times10^{-6}$ W m^{-2} sr^{-1}	$\sim5\times10^{-7}$ W m^{-2} sr^{-1}
Radiometric Quantization	6 bit	13 - 14 bit
Accompanying Spectral Bands	1	11 (night) / 21 (day)
Radiometric Calibration	None	On-Board Solar Diffuser
Saturation	In Urban Cores	None

DMSP = Defense Meteorological Satellite Program
OLS = Operational Linescan System

VIIRS = Visible/Infrared Imaging Radiometer Suite
DNB = Day/Night Band

Detailed information about the VIIRS Day-Night Band:

Miller, Steven D., Cynthia L. Combs, Stanley Q. Kidder, Thomas F. Lee, 2012: Assessing Moonlight Availability for Nighttime Environmental Applications by Low-Light Visible Polar-Orbiting Satellite Sensors. *J. Atmos. Oceanic Technol.*, **29**, 538–557. doi: http://dx.doi.org/10.1175/JTECH-D-11-00192.1

Miller, S.D., Mills, S.P., Elvidge, C.D., Lindsey, D.T., Lee, T.F., Hawkins, J.D., 2012: Suomi satellite brings to light a unique frontier of nighttime environmental sensing capabilities. PNAS, vol. 109 no. 39, 15706–15711. doi: 10.1073/pnas.1207034109 (see also the supporting information of this paper)

Miller, S.D.; Straka, W., III; Mills, S.P.; Elvidge, C.D.; Lee, T.F.; Solbrig, J.; Walther, A.; Heidinger, A.K.; Weiss, S.C. Illuminating the Capabilities of the Suomi National Polar-Orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band. *Remote Sens.* **2013**, *5*, 6717-6766. doi: 10.3390/rs5126717

Satellite data sources and processing (used/applied in this study):

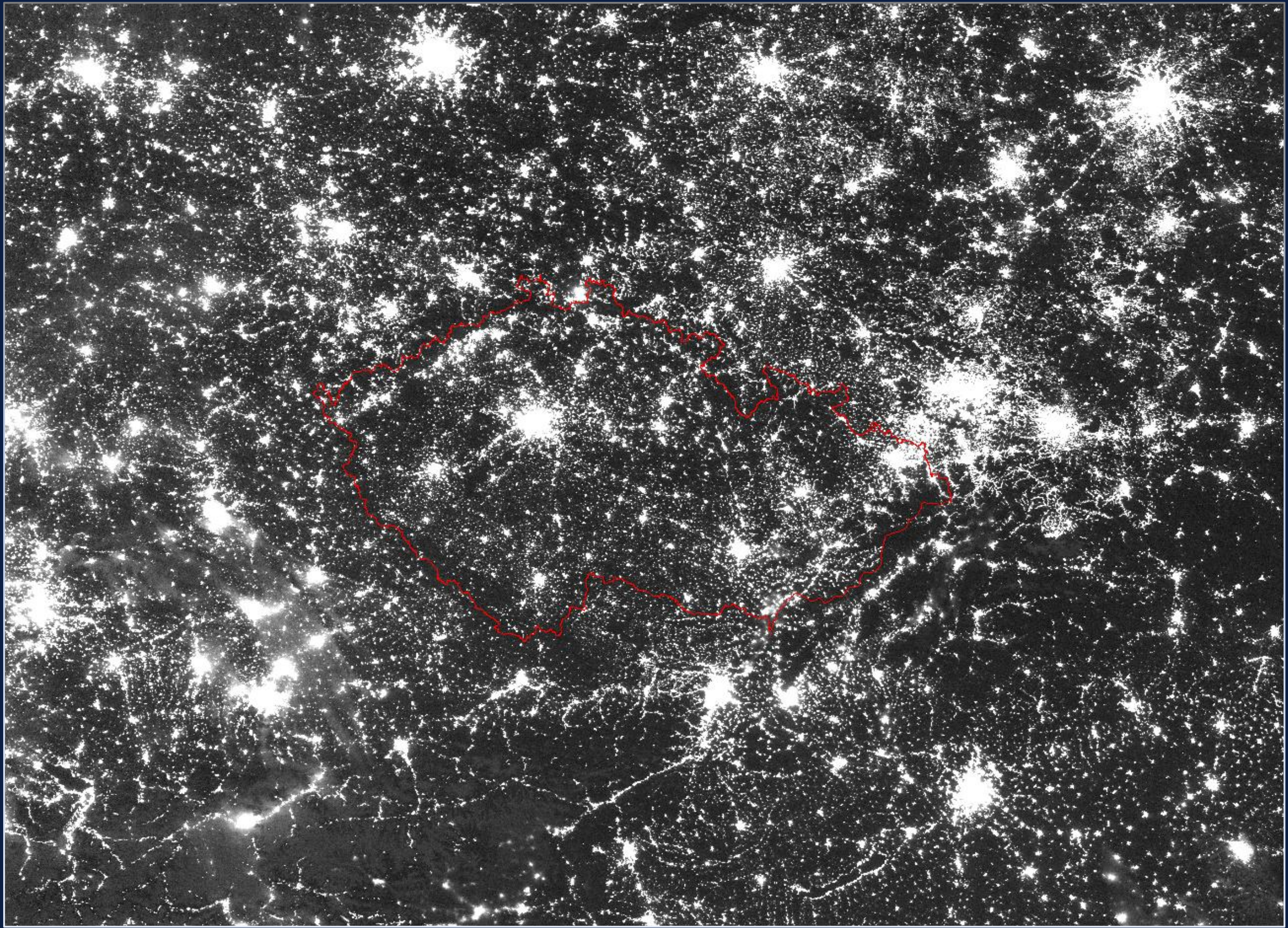
- Suomi-NPP VIIRS data (DNB and M-bands): NOAA CLASS archive
- other supporting satellite data and imagery: EUMETSAT

VIIRS DNB and M-bands data processed by ENVI software and its VCTK plug-in, final image processing done in Adobe Photoshop (CS5).

Day/Night Band

2015-06-06 01:00 UTC

- clouds of convective storms and terrain illuminated by the Moon
- twilight in the NE
- city lights

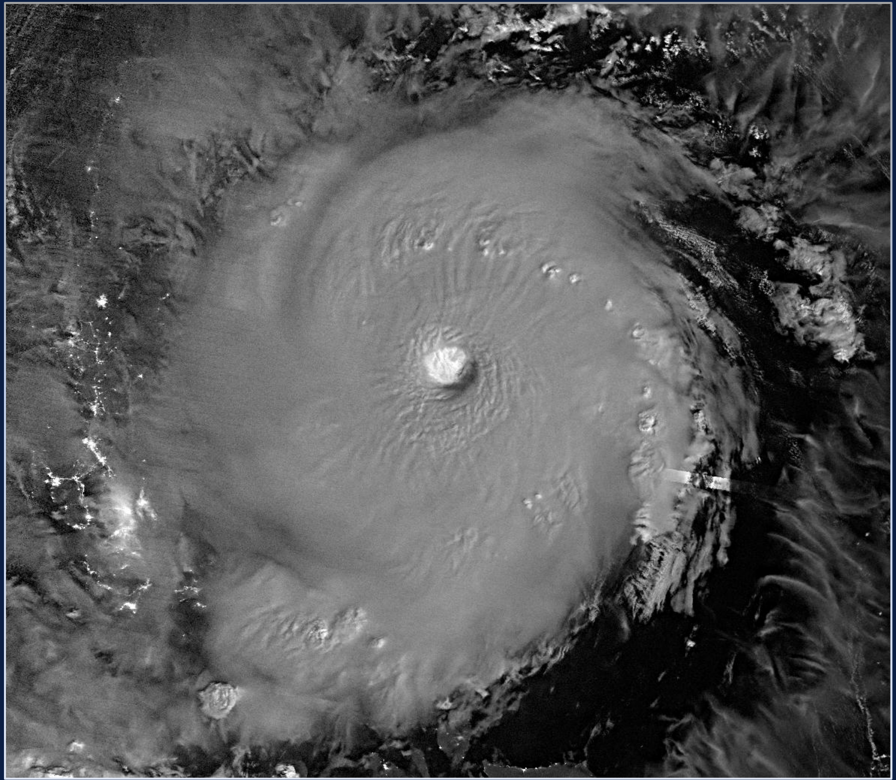


Day/Night Band

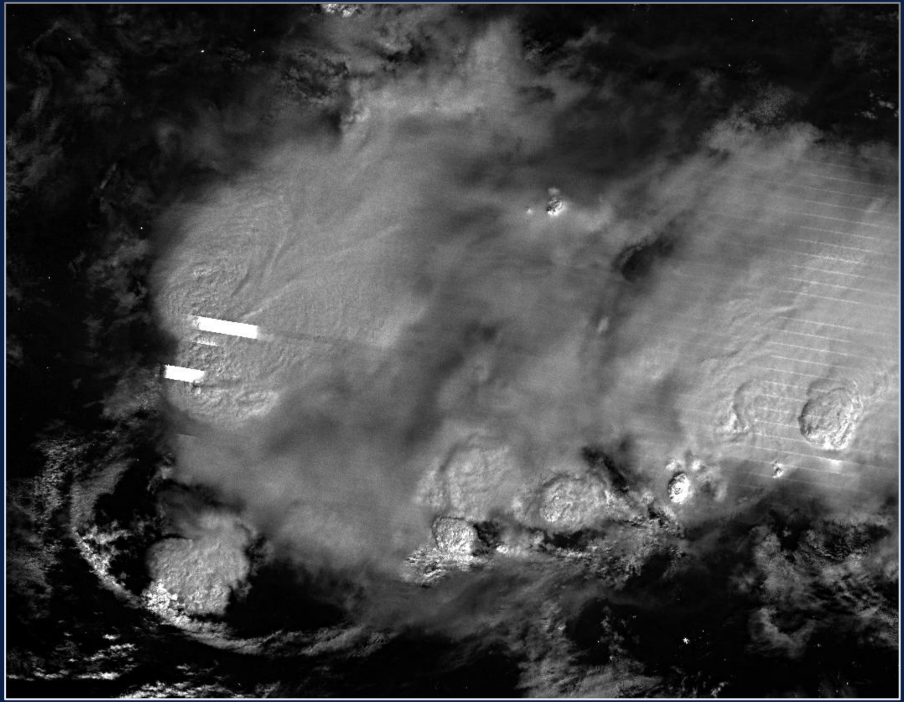
2015-03-18 01:00 UTC

- urban lights on a dark moonless night

Day/Night Band – clouds illuminated by the Moon



2015-05-09 16:46 UTC, typhoon Noul (east of Philippines), illuminated by Moon two days before last quarter



2015-05-09 01:55 UTC, convective storms (with lightning, above-anvil plume, and outflow boundary) above Liberia and Ivory Coast, illuminated by Moon two days before last quarter

DNB images recorded on dark moonless nights

Clouds and land (snow-covered land, icebergs, frozen sea) illumination sources:

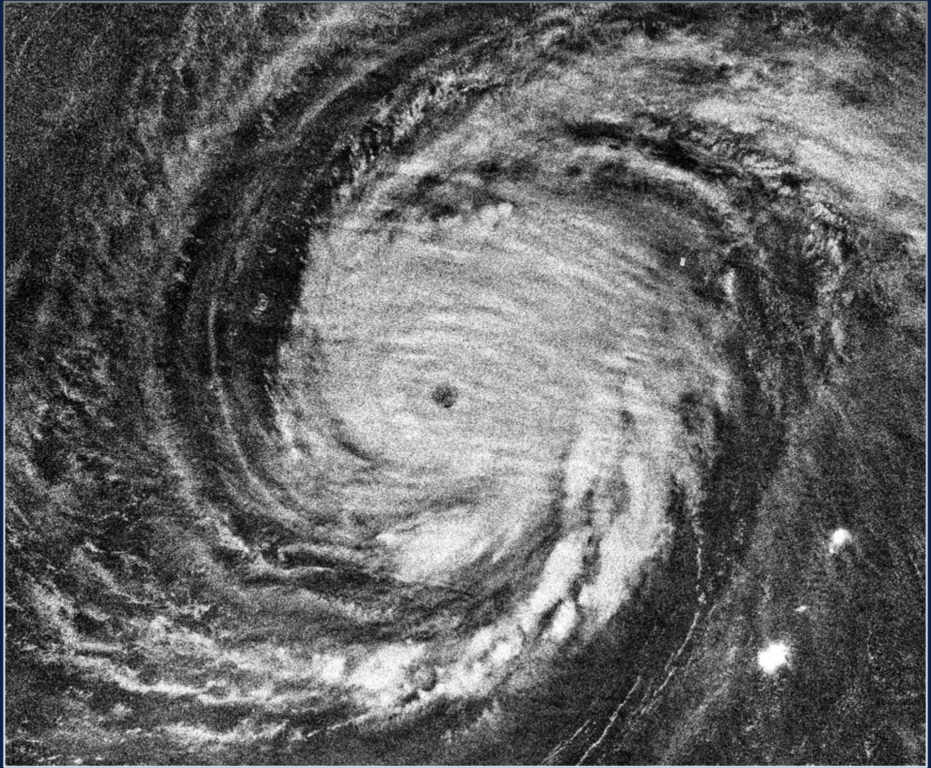
- Aurora (higher latitudes only)
- City lights and diffuse light from other artificial light sources ("light pollution")
- Stars (including Milky Way) and bright planets
- Airglow (nightglow)

Atmospheric phenomena (other than clouds) which can be detected in DNB imagery:

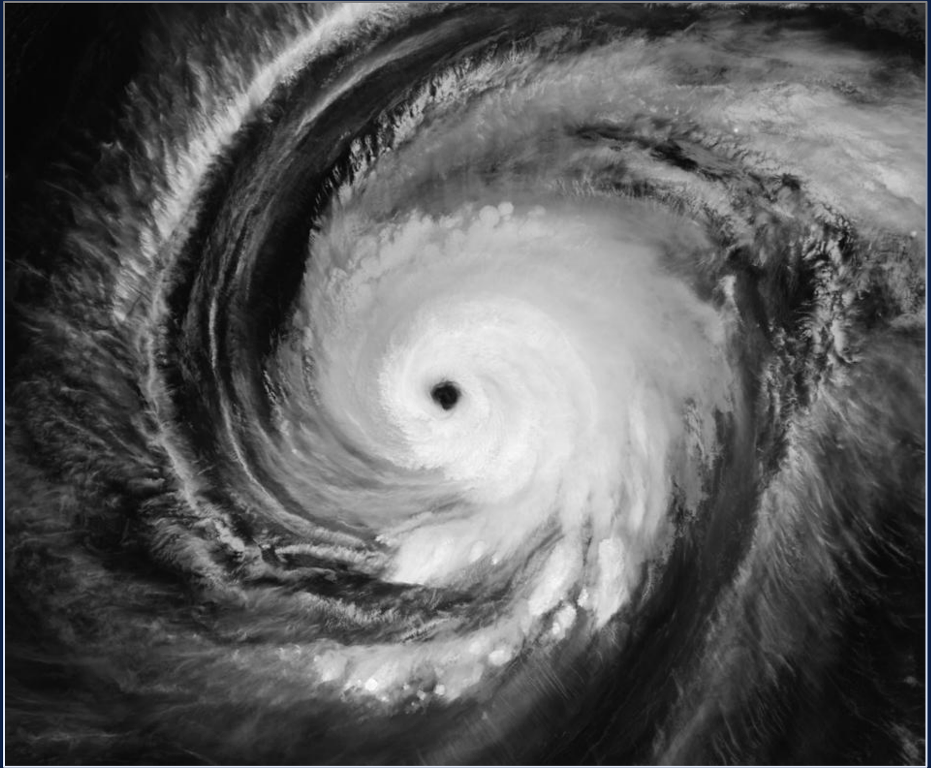
- Aurora Borealis and Australis
- **Airglow/nightglow** (waves and other disturbances)

Day/Night Band, moonless night – typhoon Dolphin

2015-05-16 16:15 UTC, Pacific Ocean (east of Philippines)



Clouds of the typhoon illuminated by stars and nightglow

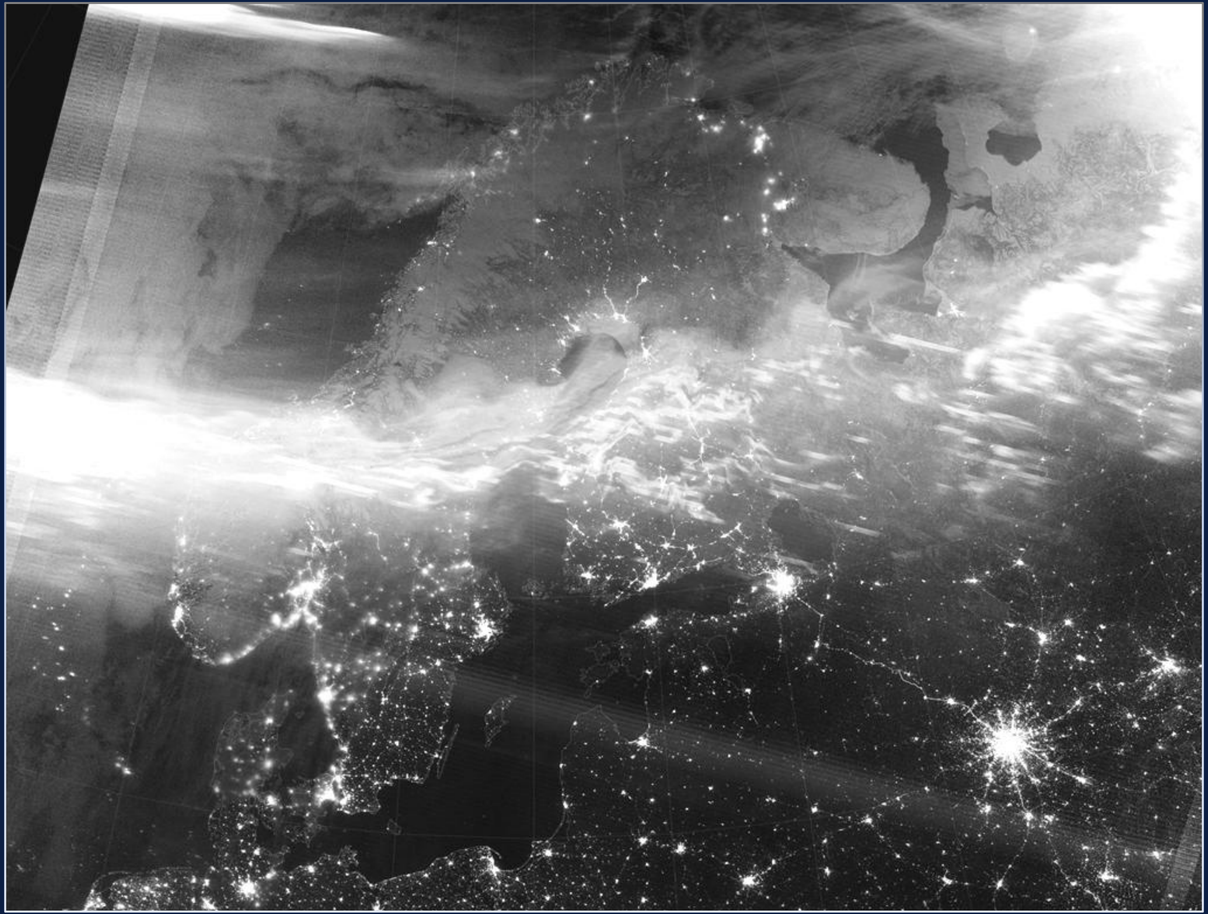


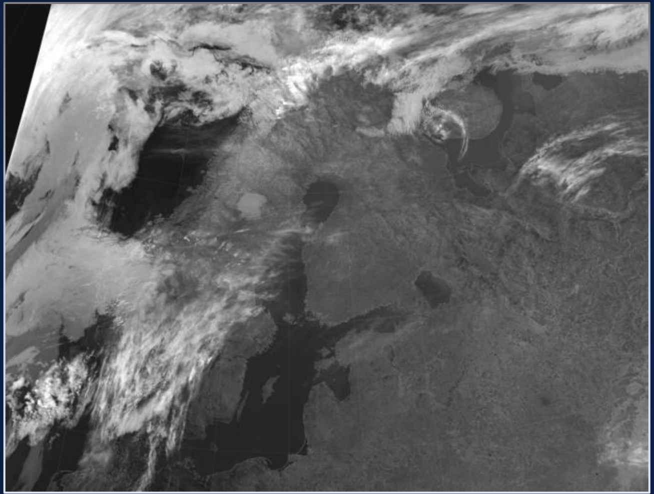
... and corresponding VIIRS M15 band (IR 10.7 μm)

Nothing matching the parallel, slightly bowed waves visible in the DNB image can be found in the IR M15 band image ⇨ **waves in airglow**

Day/Night Band, moonless night – Aurora Borealis, 17/18 March 2015

2015-03-18 00:55 UTC





Corresponding VIIRS M12 (IR 3.7 μm) band

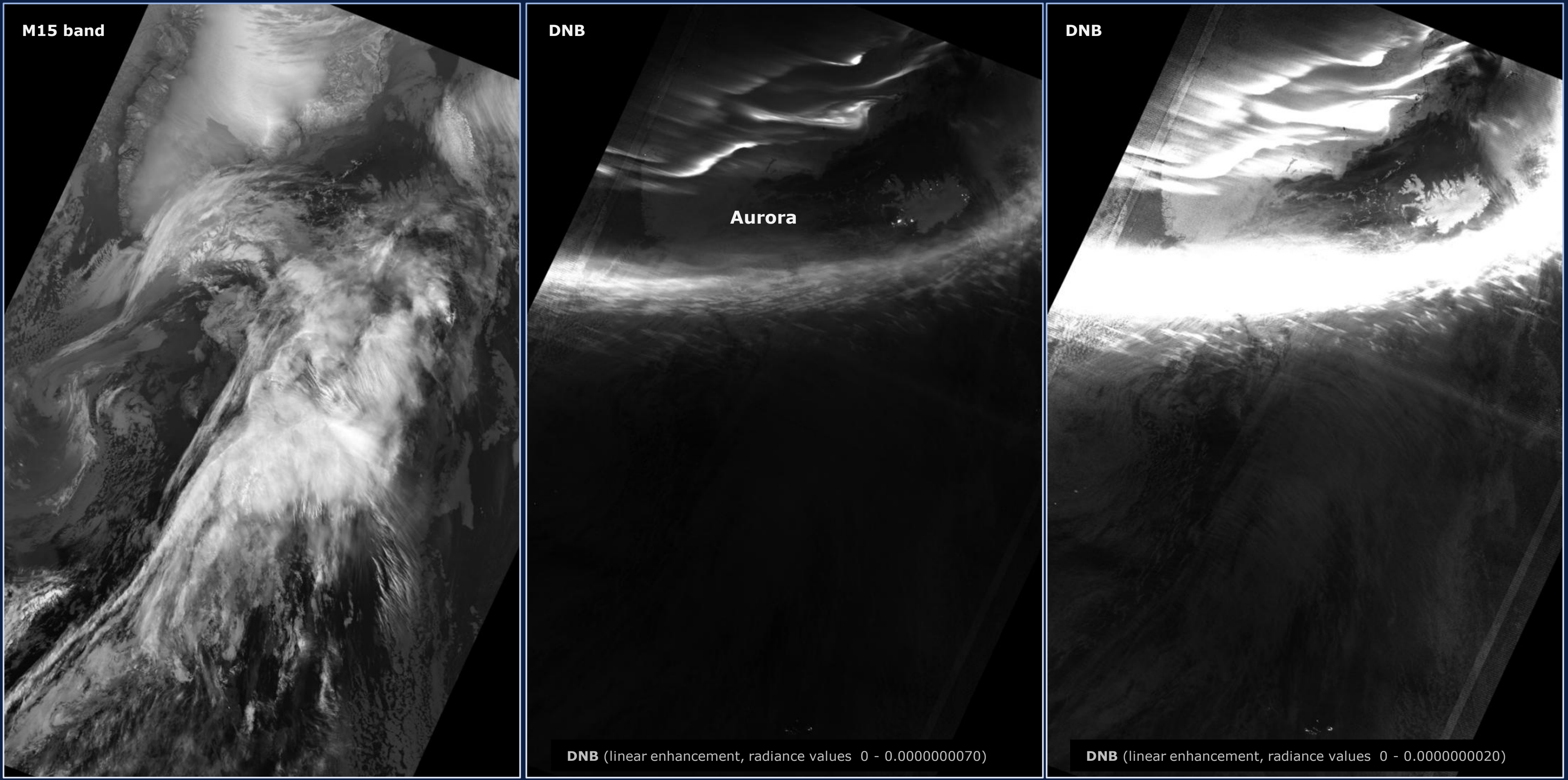
VIIRS DNB band (HDR image)

Besides the aurora itself and the city lights, it is also possible to see details of the snow-covered land, illuminated by the aurora.

Next slides show the aurora two orbits later.

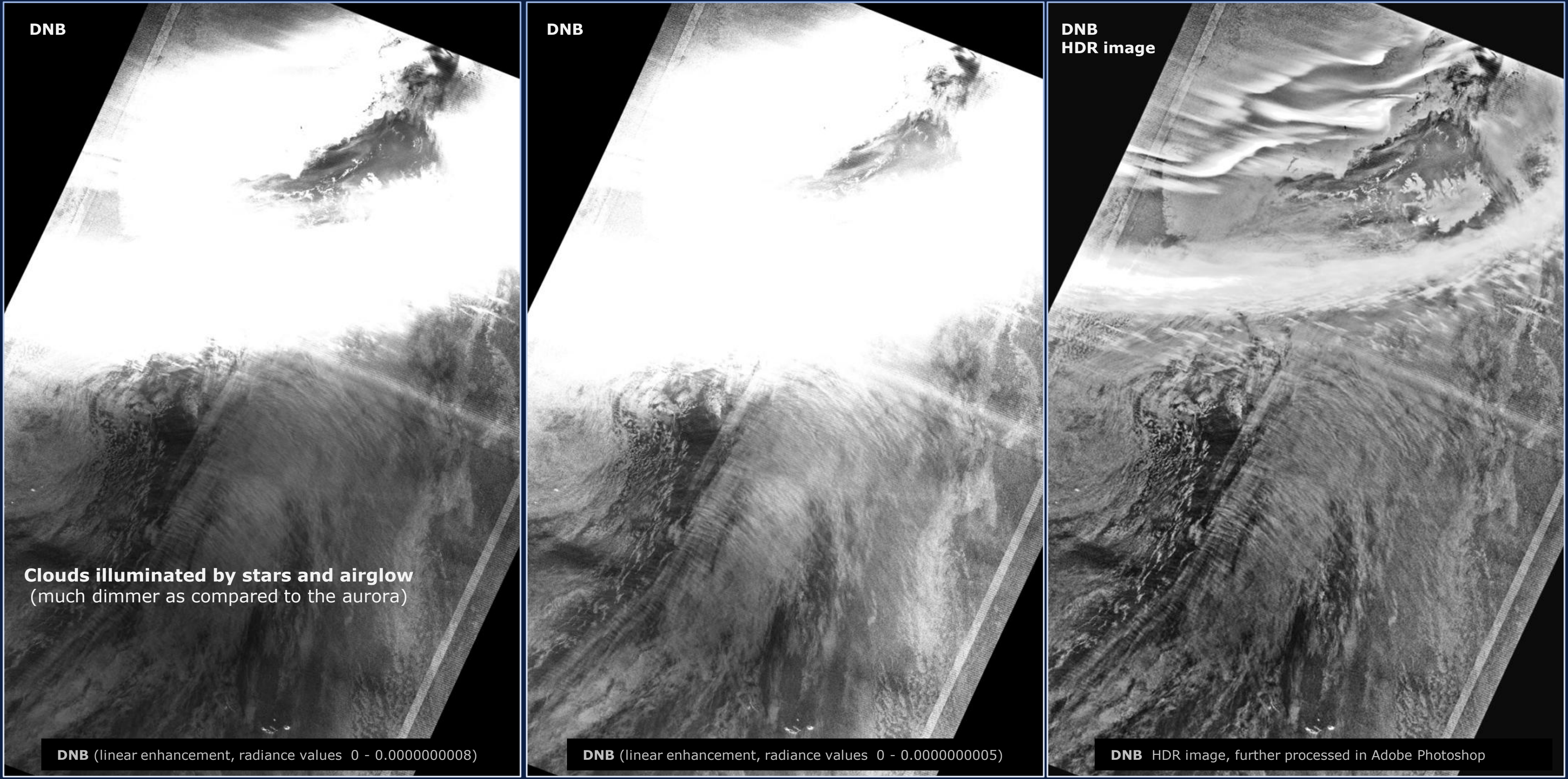
Day/Night Band, moonless night – Aurora Borealis and AIRGLOW

2015-03-18 04:20 UTC



Day/Night Band, moonless night – Aurora Borealis and AIRGLOW

2015-03-18 04:20 UTC



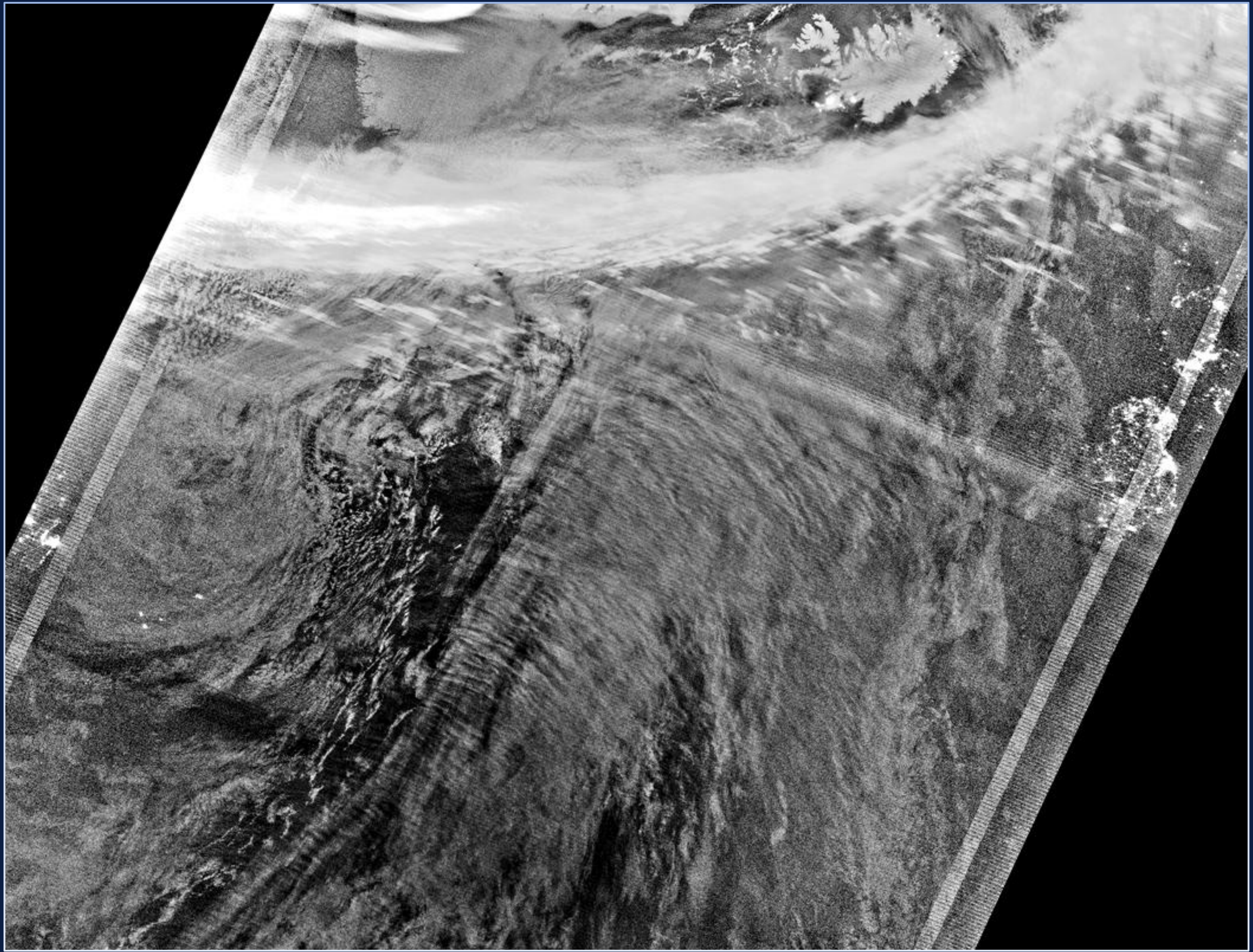
VIIRS Day/Night Band

HDR image (enhanced)

2015-03-18 04:20 UTC

Aurora (south of Greenland and Iceland), and clouds illuminated by stars and airglow.

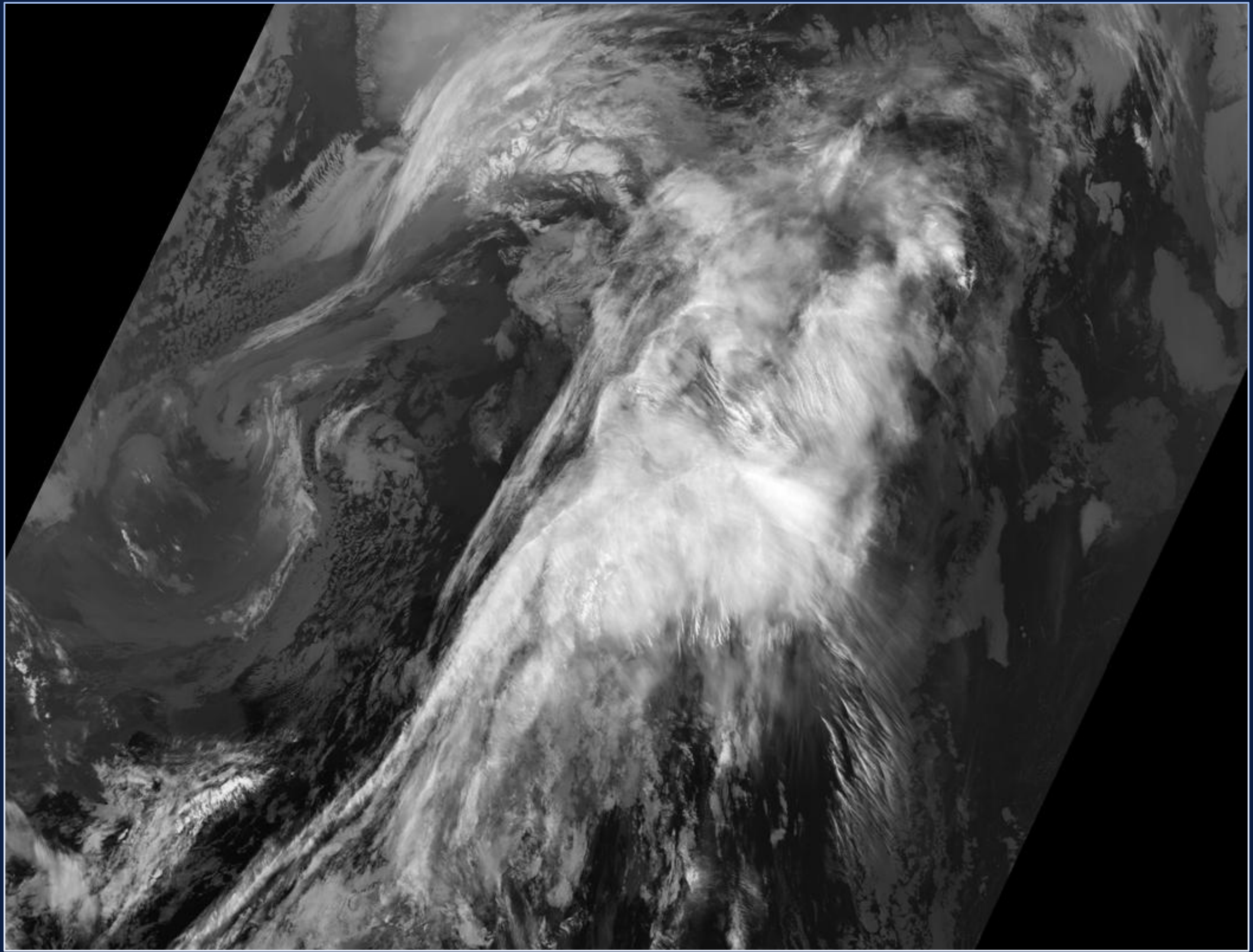
Bow-shaped waves in nightglow above clouds of a jet stream underneath.



VIIRS M15 band
(IR 10.7 μm)

2015-03-18 04:20 UTC

... and none of the waves from the DNB image can be found in the M15 IR band ⇨ prove that these indeed are not waves in clouds, but in the nightglow.



Airglow (nightglow) and the VIIRS Day/Night Band

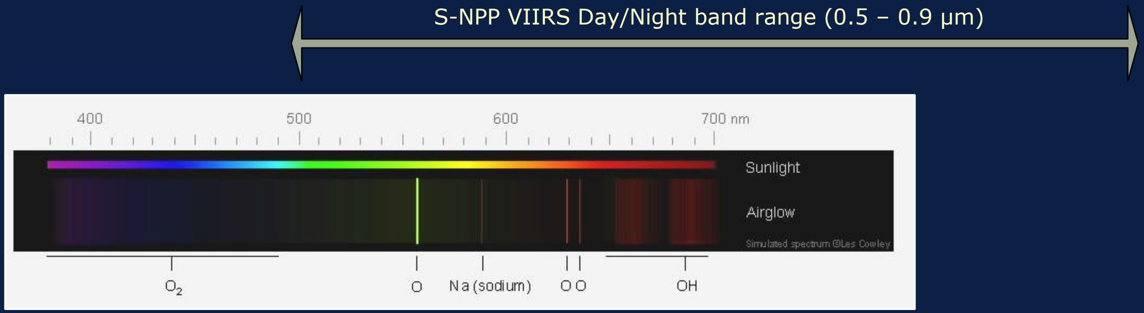


Image source: http://www.atoptics.co.uk/highsky/airglow2.htm

Airglow sources – processes related to de-excitation of atoms and molecules, excited by solar ultraviolet radiation during the daytime hours, chemiluminescence. In contrast to aurora, airglow can be observed globally.

- blue – molecular oxygen, ~ 95 km
- green – atoms of oxygen, 90 – 100 km
- yellow – sodium atoms (meteorite origin), ~ 92 km
- red – atoms of oxygen, 150 – 300 km
- red and near IR range – hydroxyl radicals (OH), 85 – 90 km

Given the broadband nature of the S-NPP VIIRS Day/Night Band, it is not possible to make any inferences about (spectral) wavelengths of the airglow features observed in this band, and neither about the height of these. All spectral lines between 0.5 and 0.9 µm and airglow layers are superimposed in DNB images.

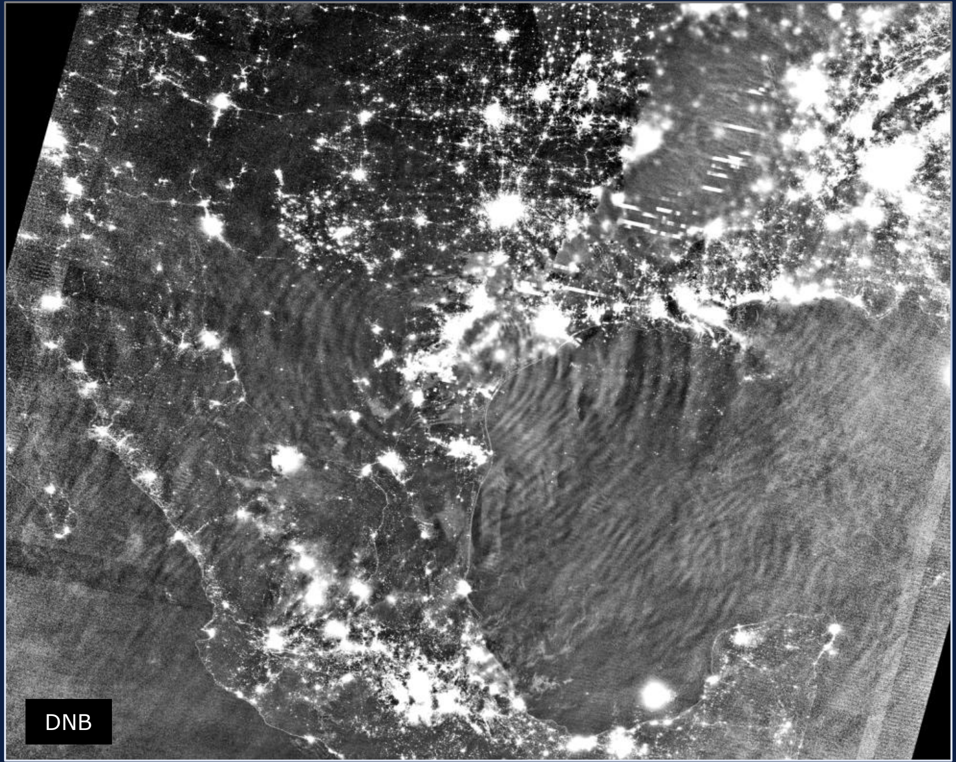
2014-01-01 **Petr Horálek,** Orava, Slovakia
http://www.astronom.cz/horalek/?p=477

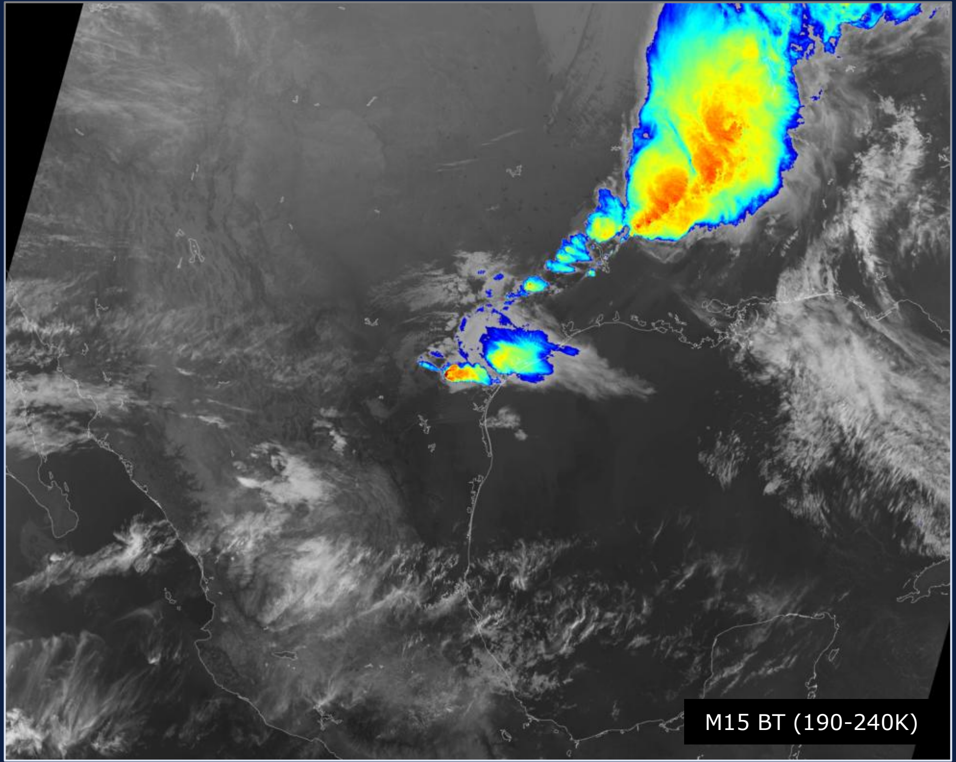
Concentric gravity waves in nightglow as observed by Suomi-NPP in its VIIRS DNB imagery

The concentric waves in nightglow are in most cases evoked by vertically propagating gravity waves generated by convective storms (namely their overshooting tops). The source of these can be typically very easily traced, comparing the DNB images with IR bands or their combinations – either from the same satellite (same time and viewing geometry as the DNB image), or following the area of interest in geostationary IR image data.

Concentric waves in nightglow above storms in Texas – 4 April 2014

2014-04-04 08:15 UTC

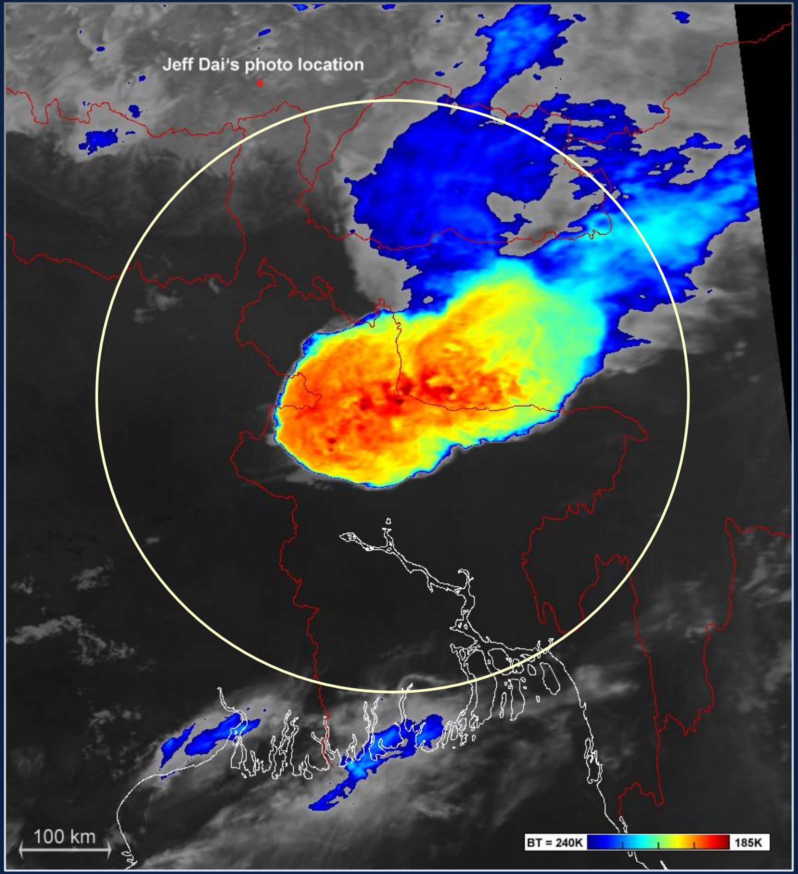




Convectively-generated mesospheric airglow waves over Texas (CIMSS Satellite Blog)
http://cimss.ssec.wisc.edu/goes/blog/archives/15299

Severe Weather in the Mesosphere (VIIRS Imagery and Visualization Team Blog)
http://rammb.cira.colostate.edu/projects/npp/blog/index.php/uncategorized/severe-weather-in-the-mesosphere/

Concentric waves in nightglow above Bangladesh – 27 April 2014



2014-04-27 15:50 UTC
Metop-2 band 4 (IR 10.5 µm)

This Metop-2 image was taken almost exactly at the same time as Jeff Dai took his famous "rippled sky" photo (next slide) from the Tibetan Plateau in China.

This storm started to evolve about 1 hour prior to this image and Jeff Dai's observations. For evolution of these storms see the Meteosat-7 IR loop at the first of the links below.

Suomi-NPP VIIRS (next slides) captured the waves in nightglow about 3.5 hours later, when the storms were already weakening.

A Kalboishakhi storm swept across northern Bangladesh on the evening of 27 April 2014 (EUMETSAT Image Library)
http://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_2204046.html

Rippled airglow above Bangladesh storms (EUMETSAT Image Library)
http://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_2529304.html

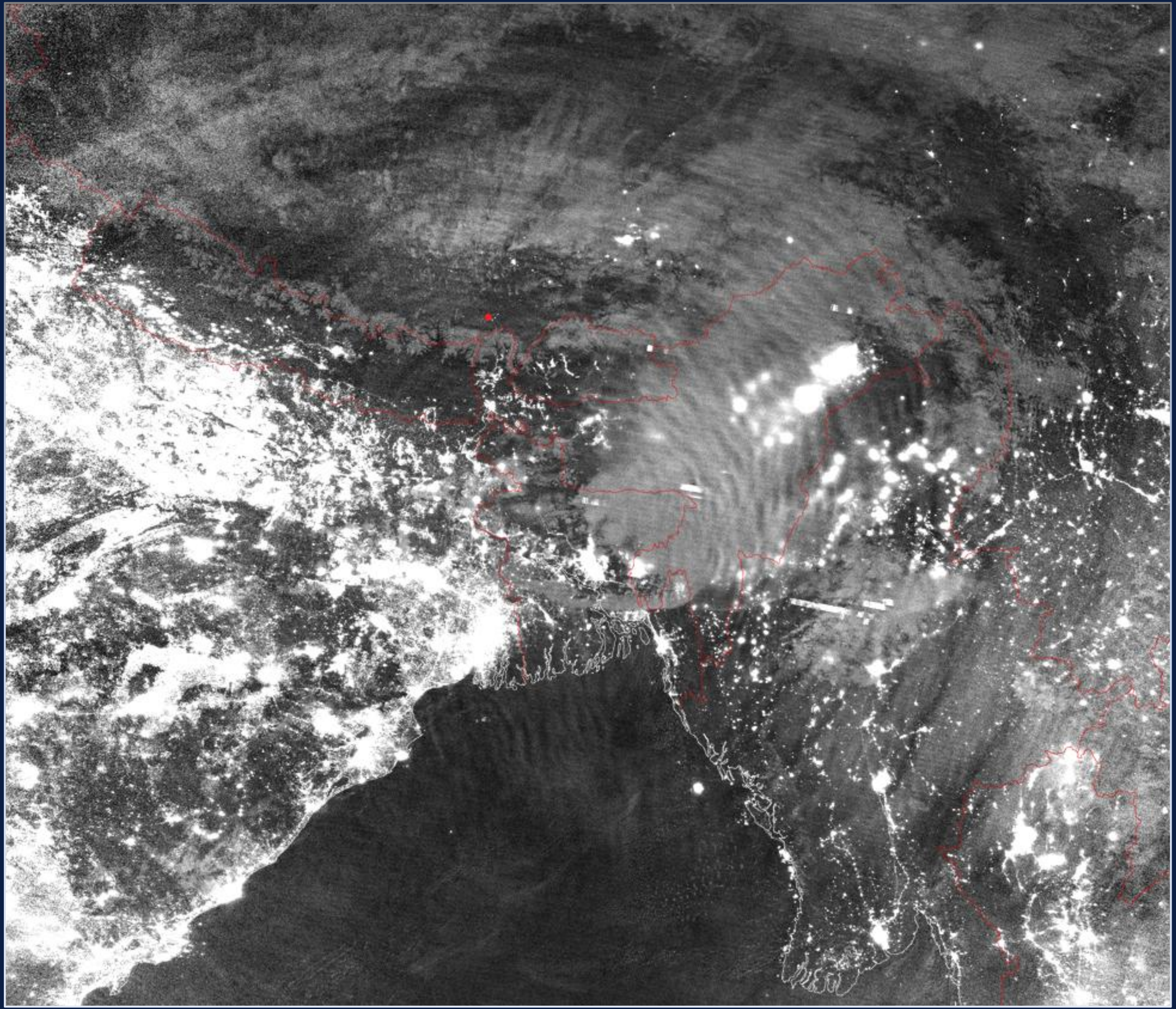
Jeff Dai

2014-04-27 15:57 UTC

2014-04-27 15:57 UTC, Jeff Dai – Tibet Plateau, China, https://www.flickr.com/photos/jeffdai/14845763849/

Suomi-NPP VIIRS

DNB image

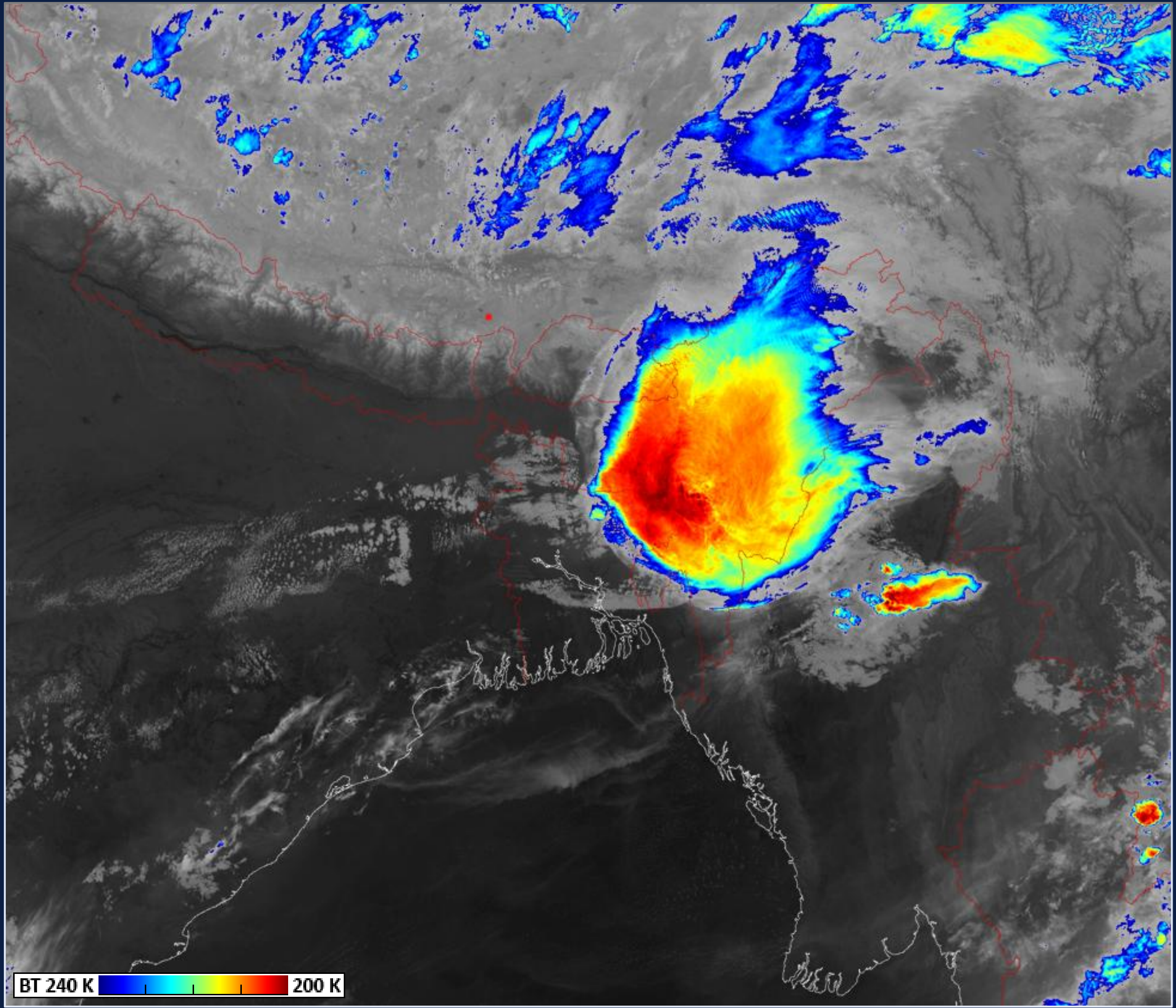


2014-04-27 19:35 UTC

Suomi-NPP VIIRS

M15 (IR 10.7 μm)
BT 200 – 240 K

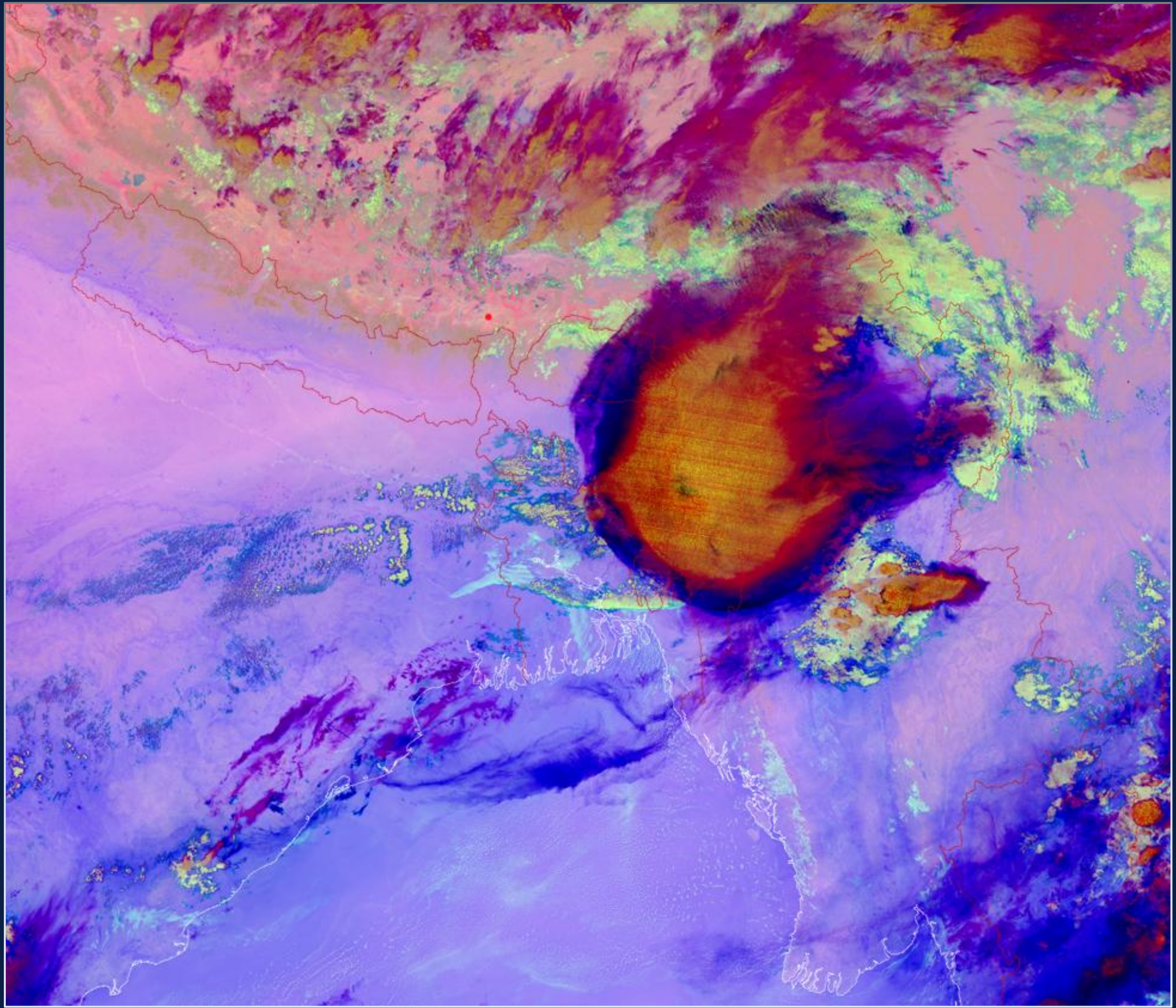
2014-04-27 19:35 UTC



Martin Setvák (CHMI), Steven Miller (CIRA)

Suomi-NPP VIIRS

M12, M15 & M16
night microphysical
RGB product



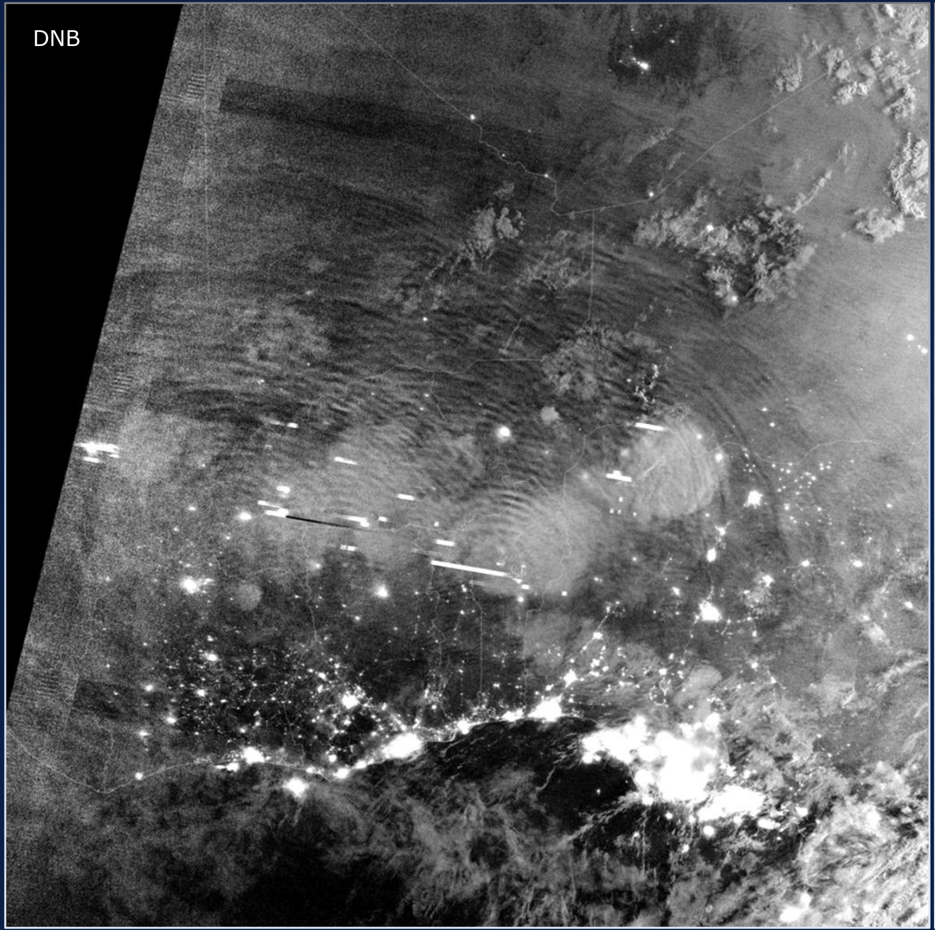
2014-04-27 19:35 UTC

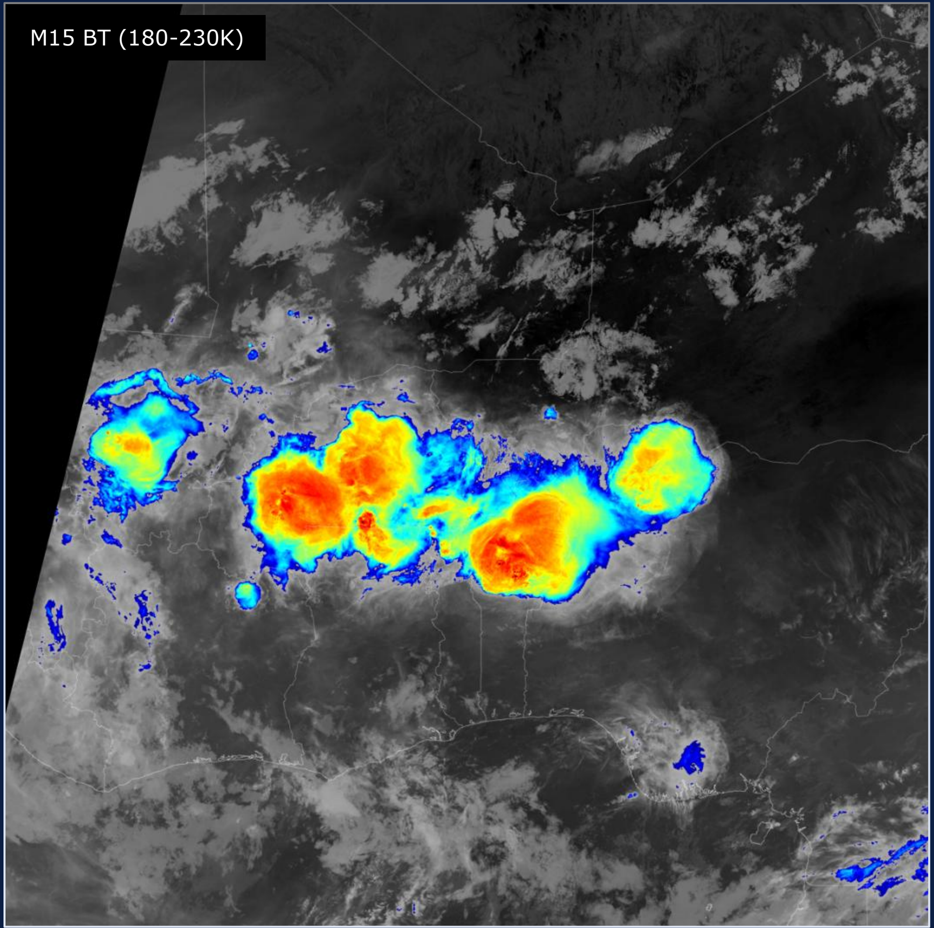
Advantage of using similar RGB products as compared to single IR band images:

- easier detection of low clouds above cold ground
- easier detection of thin transparent cirrus
- basic cloud microphysics interpretation
- detection of dust storms in deserts and other arid areas

Multiple concentric waves in nightglow above western Africa – 11 June 2015

2015-06-11 01:15 UTC



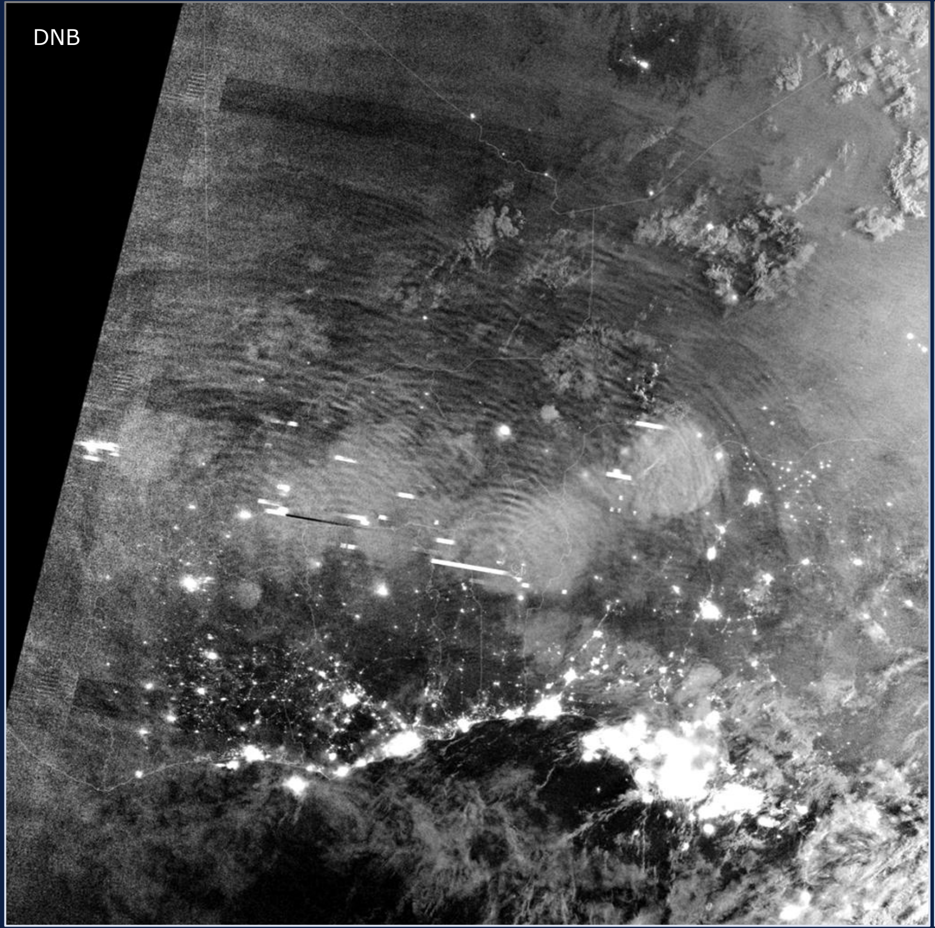


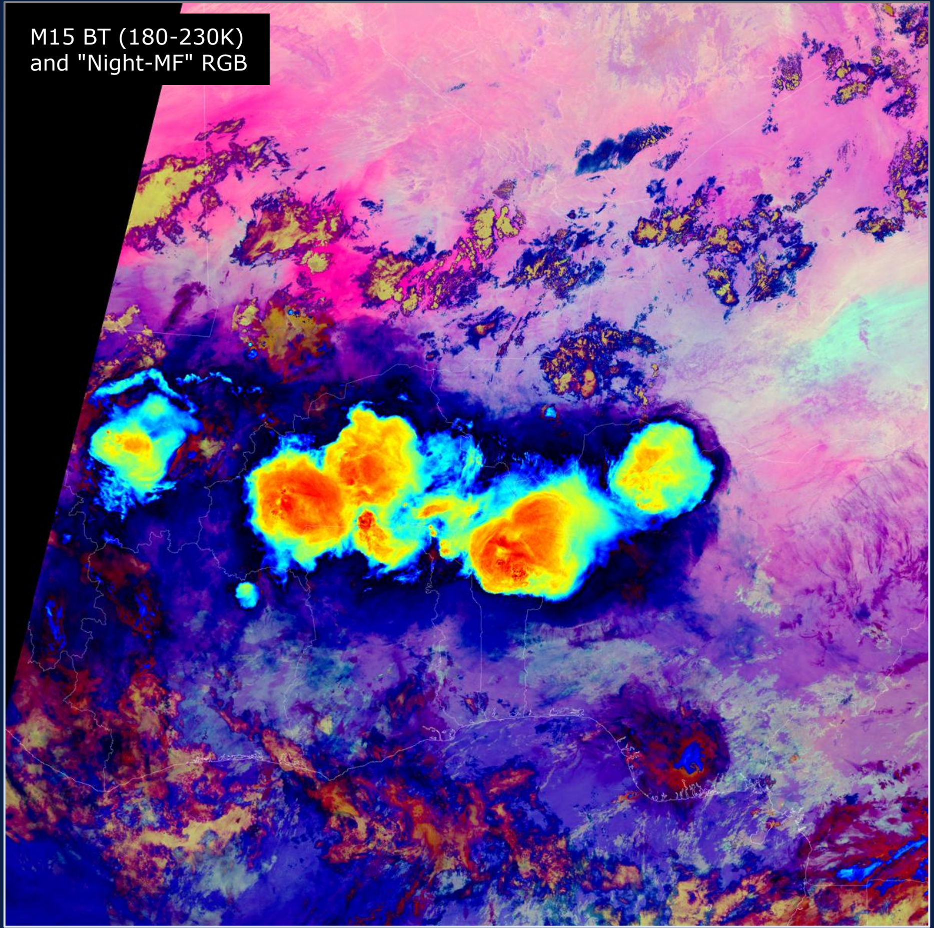
A complex of concentric gravity waves, generated by several storms in the area (several sources of the gravity waves), overlapping each other, spreading mainly north.

Martin Setvák (CHMI), Steven Miller (CIRA)

Multiple concentric waves in nightglow above western Africa – 11 June 2015

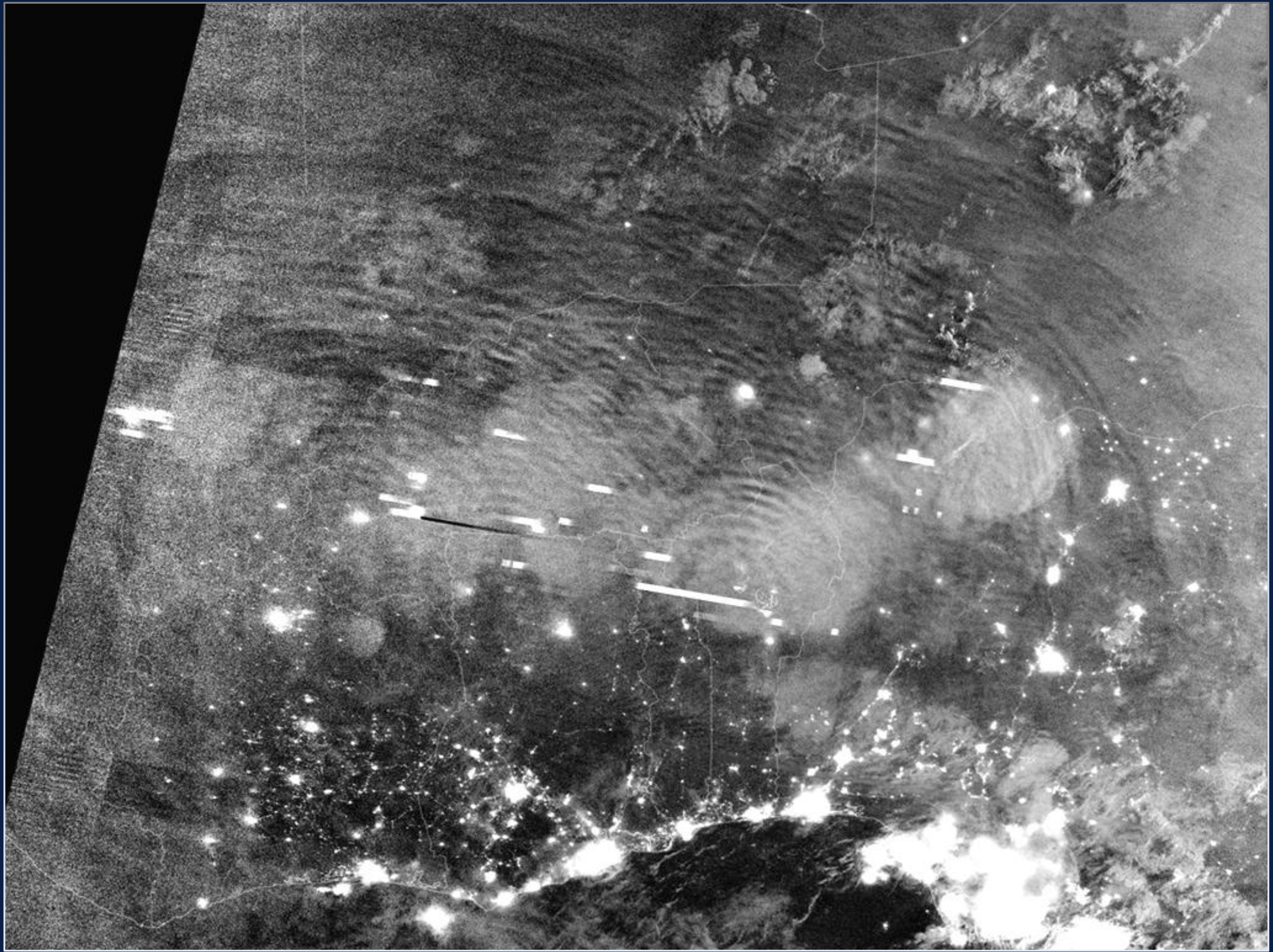
2015-06-11 01:15 UTC





A complex of concentric gravity waves, generated by several storms in the area (several sources of the gravity waves), overlapping each other, spreading mainly north.

Martin Setvák (CHMI), Steven Miller (CIRA)

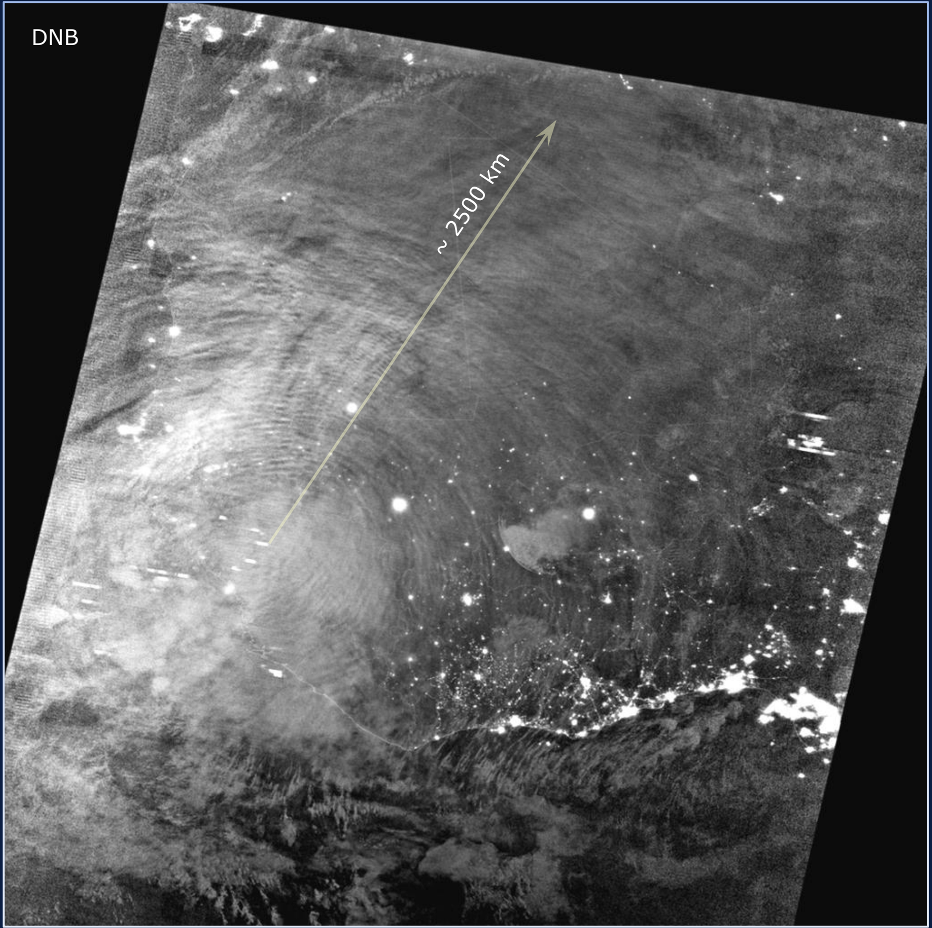


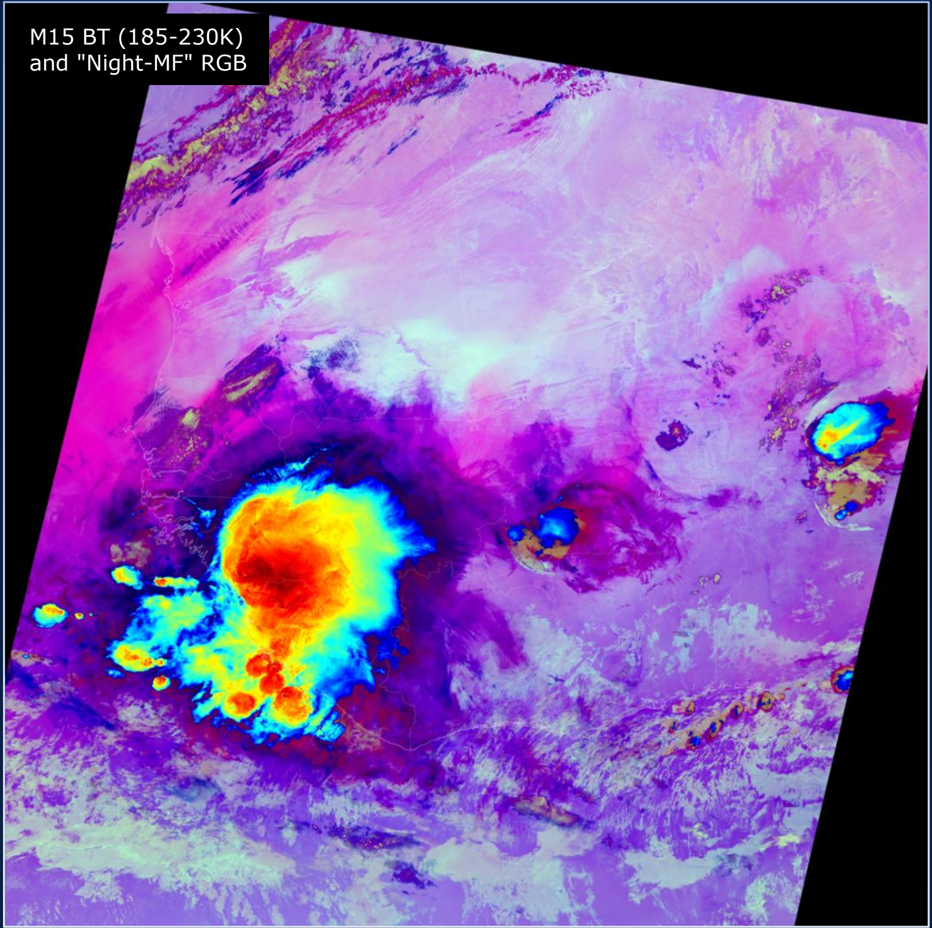
2015-06-11 01:15 UTC

DNB (detail)

Large concentric waves in nightglow above west Africa – 14 June 2015

2015-06-14 02:00 UTC



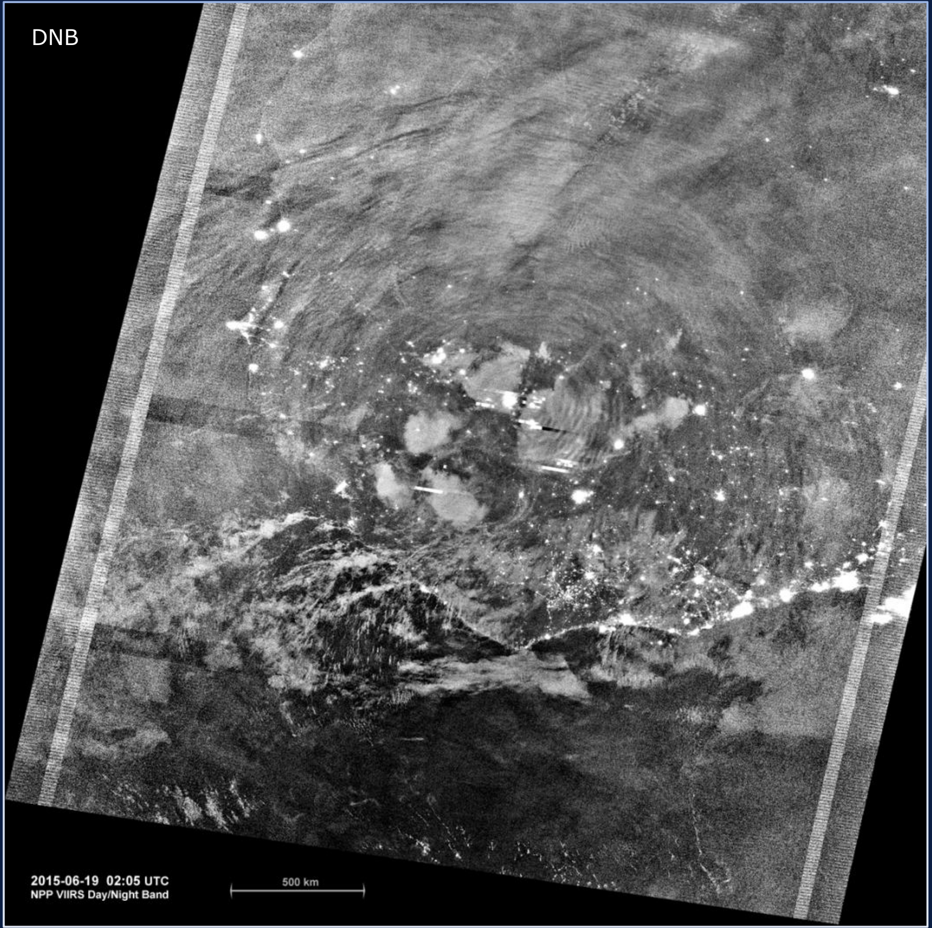


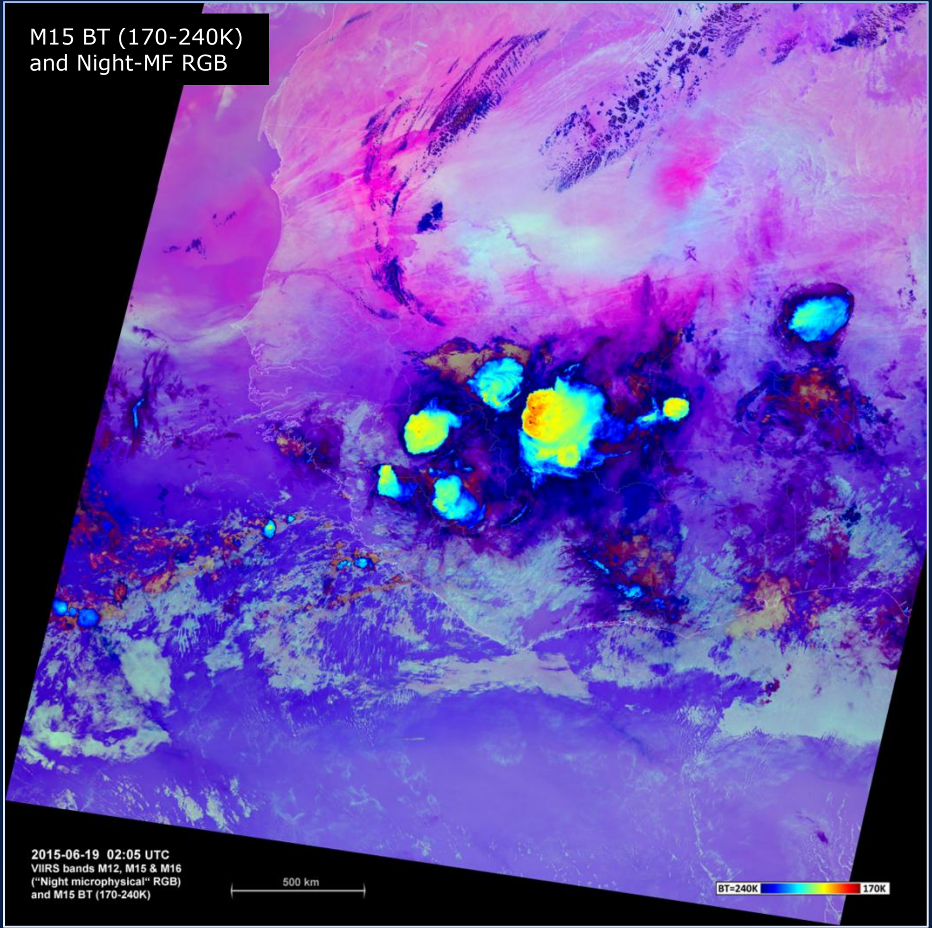
Concentric gravity waves, generated by large storms above west Africa, spreading about 2500 km northward, but to much shorter distance southward.

Martin Setvák (CHMI), Steven Miller (CIRA)

Large concentric waves in nightglow above west Africa – 19 June 2015

2015-06-19 02:05 UTC



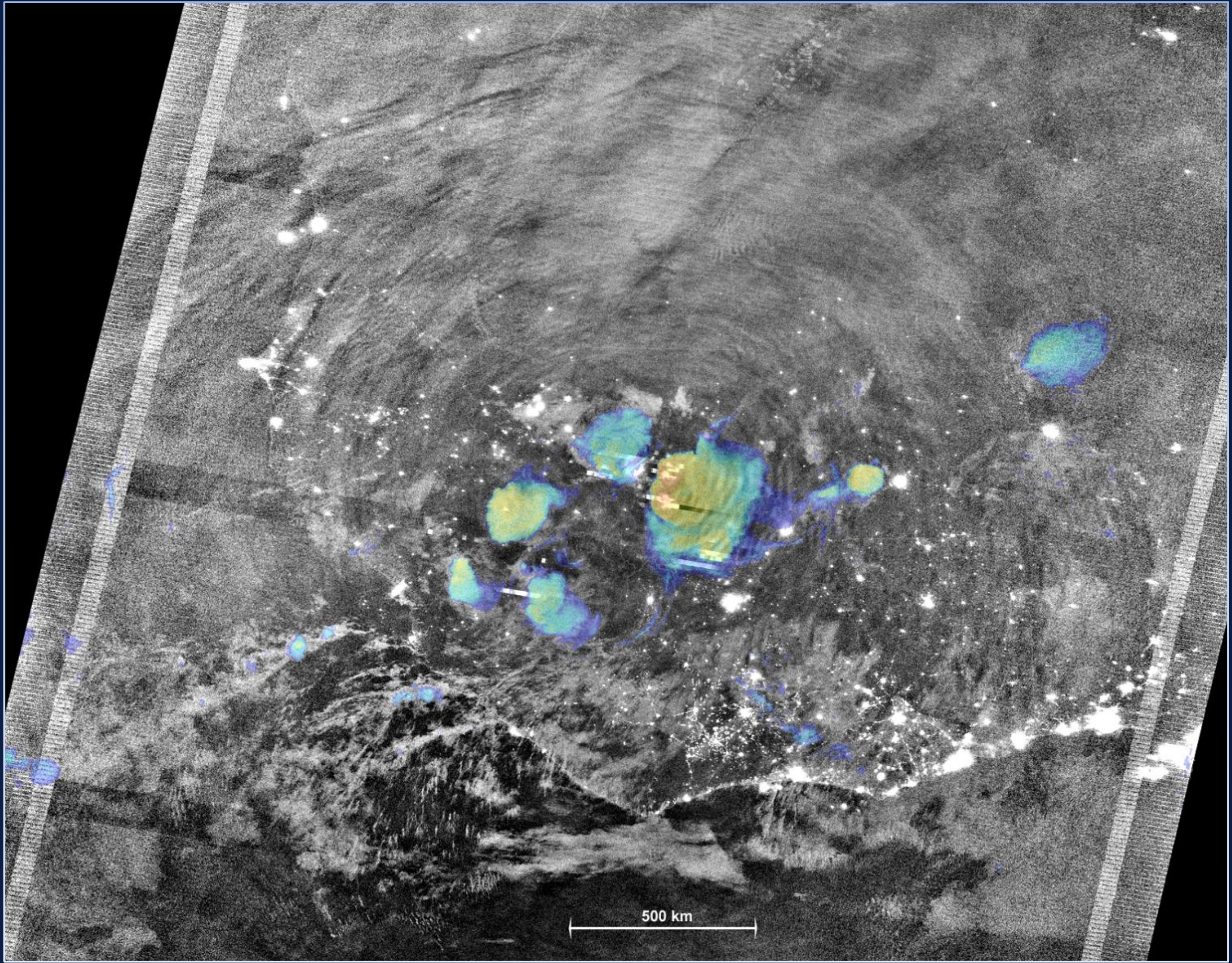


Concentric gravity waves generated by storms above west Africa, spreading to all directions, except for the south-east.

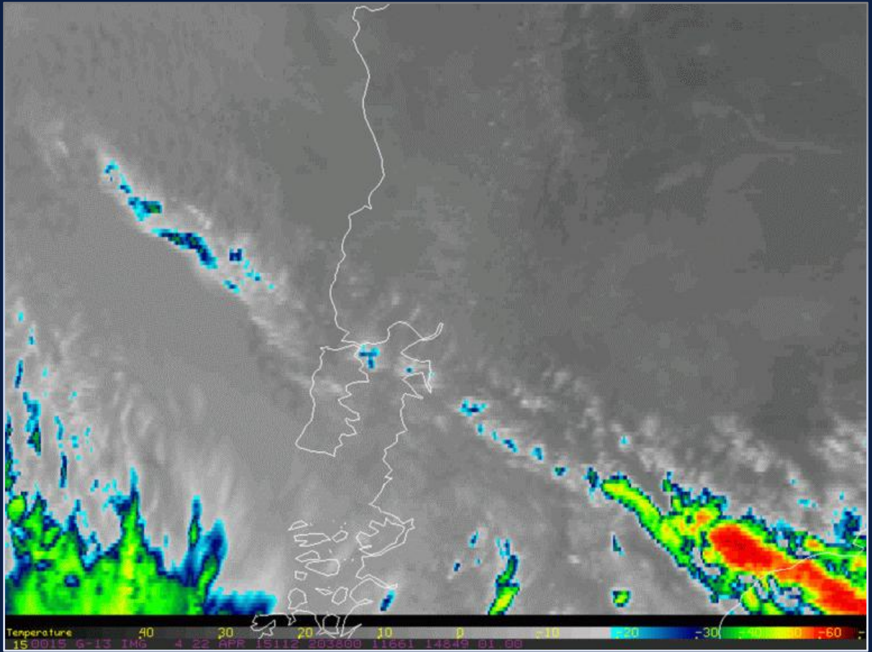
Martin Setvák (CHMI), Steven Miller (CIRA)

VIIRS DNB, and
M15 (170-240K)

2015-06-19 02:05 UTC



Calbuco Volcano eruption, Chile, 22 – 23 April 2015



GOES-13 IR, 22 April 20:38 UTC to 23 April 13:38 UTC. Source: Dan Lindsey, NOAA/CIRA.

Calbuco volcanic eruption in Chile (CIMSS Satellite Blog)
http://cimss.ssec.wisc.edu/goes/blog/archives/18206

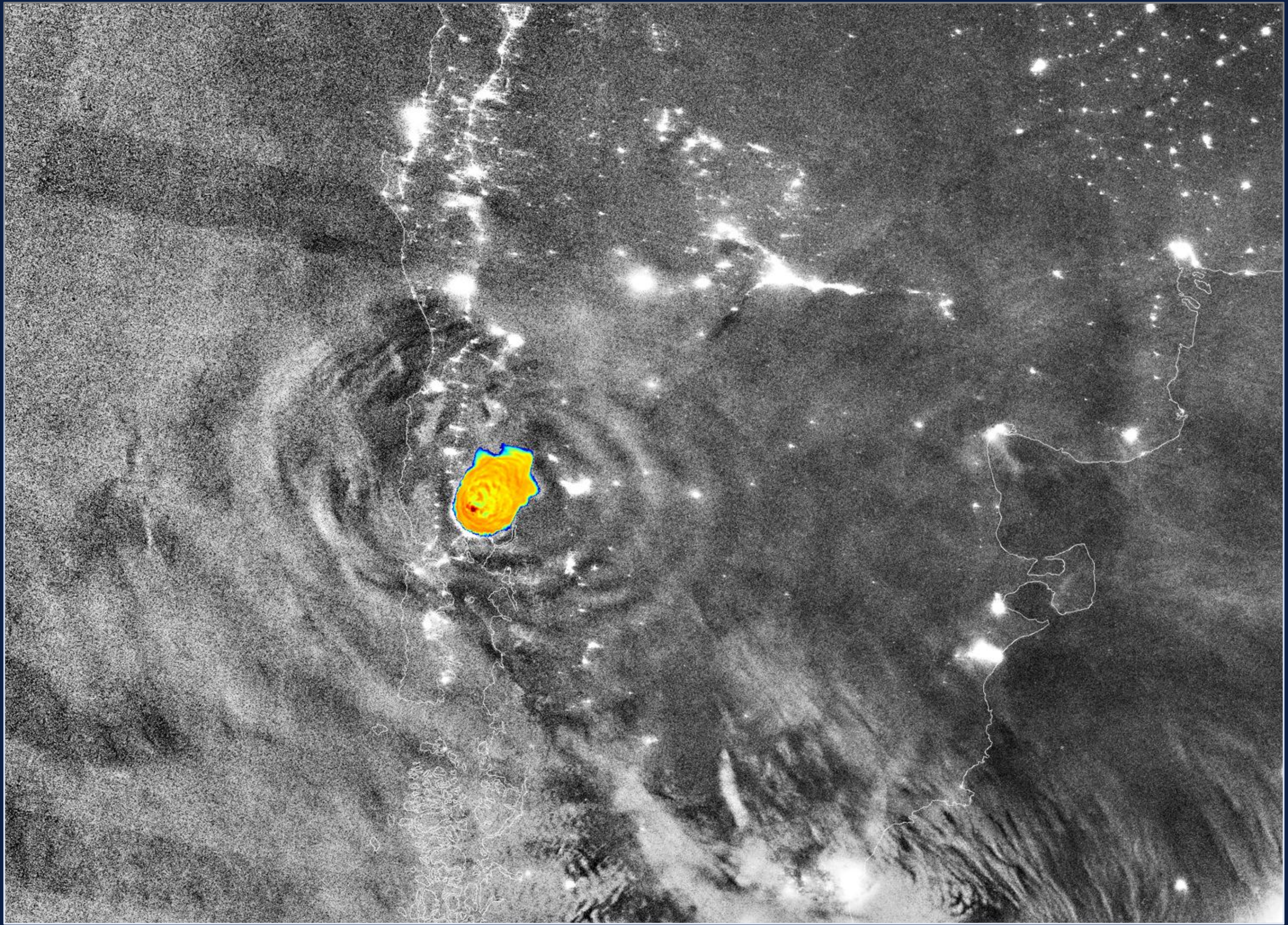
Southern Chile's Calbuco volcano unexpectedly erupted for the first time in more than 40 years on 22 April and then again early on 23 April 2015 (EUMETSAT)
http://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_2622165.html

Photo Credit: Marcelo Utreras

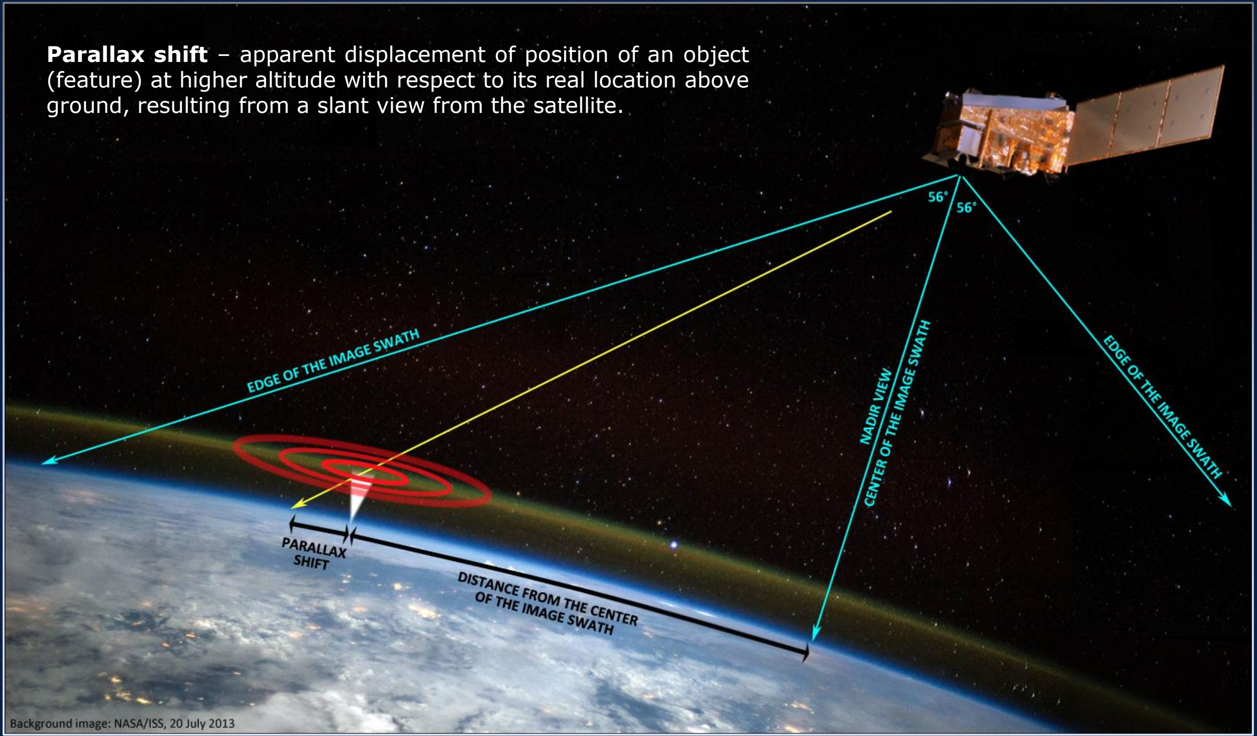
Photo Credit: imgur.com

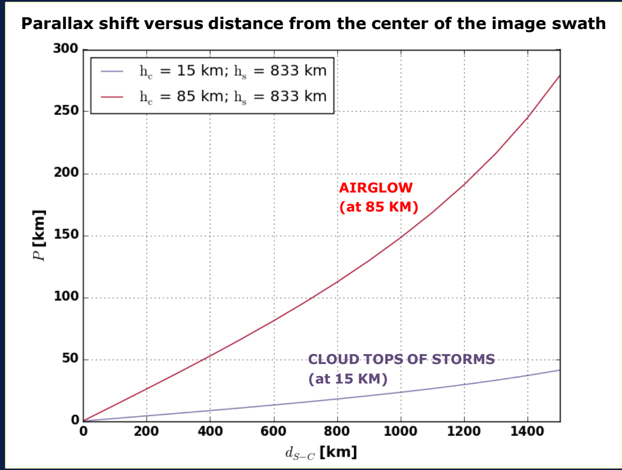
2015-04-23 05:12 UTC

DNB and M15 (190-240K)



Parallax shift of the airglow features in VIIRS DNB imagery





P [km]															
dS-C [km] / hC [km]	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
15	2.1	4.2	6.3	8.4	10.7	12.9	15.3	17.8	20.4	23.2	26.2	29.4	32.9	36.8	41.0
85	12.9	25.8	39.0	52.5	66.4	80.9	96.1	112.2	129.4	148.1	168.4	190.9	216.2	245.0	278.6

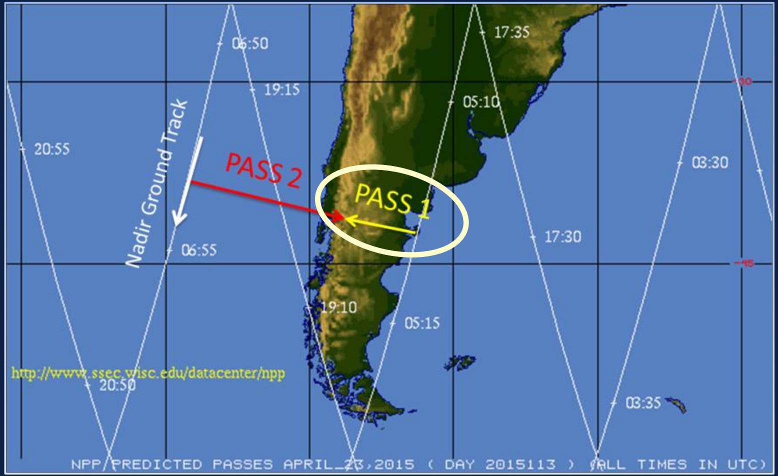
Parallax shift of airglow features in DNB imagery

Values of the parallax shift as related to distance from central line of the satellite data swath, computed for height 85 km and satellite orbit at 833 km.

Parallax shift values for cloud tops of convective storms at 15 km.

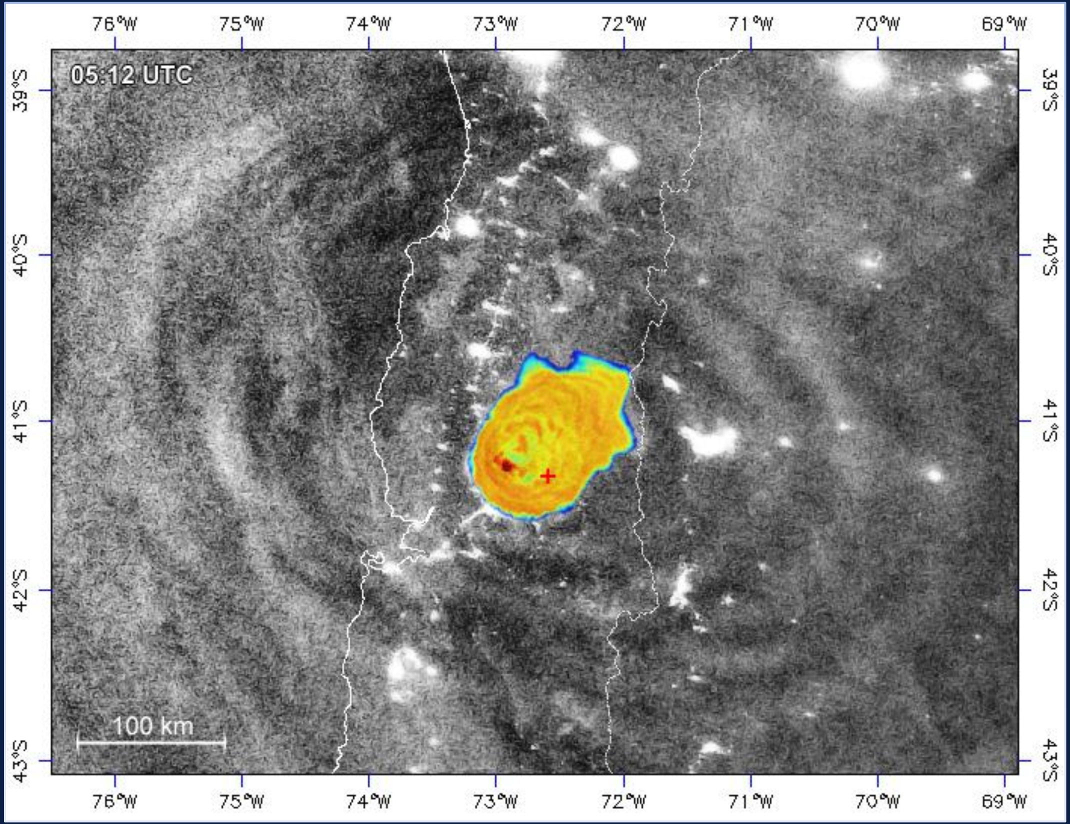
Plot above right and table:
Michaela Radová, michaela.radova@chmi.cz

Parallax shift of the airglow features in VIIRS DNB imagery – Calbuco Volcano, 23 April 2015



Pass 1 (orbit #18058), 05:12 UTC

The Calbuco volcano region was relatively close to the track (nadir line) of the pass, therefore the parallax shift was rather moderate here.



+ – position of the Calbuco Volcano (from IR bands)

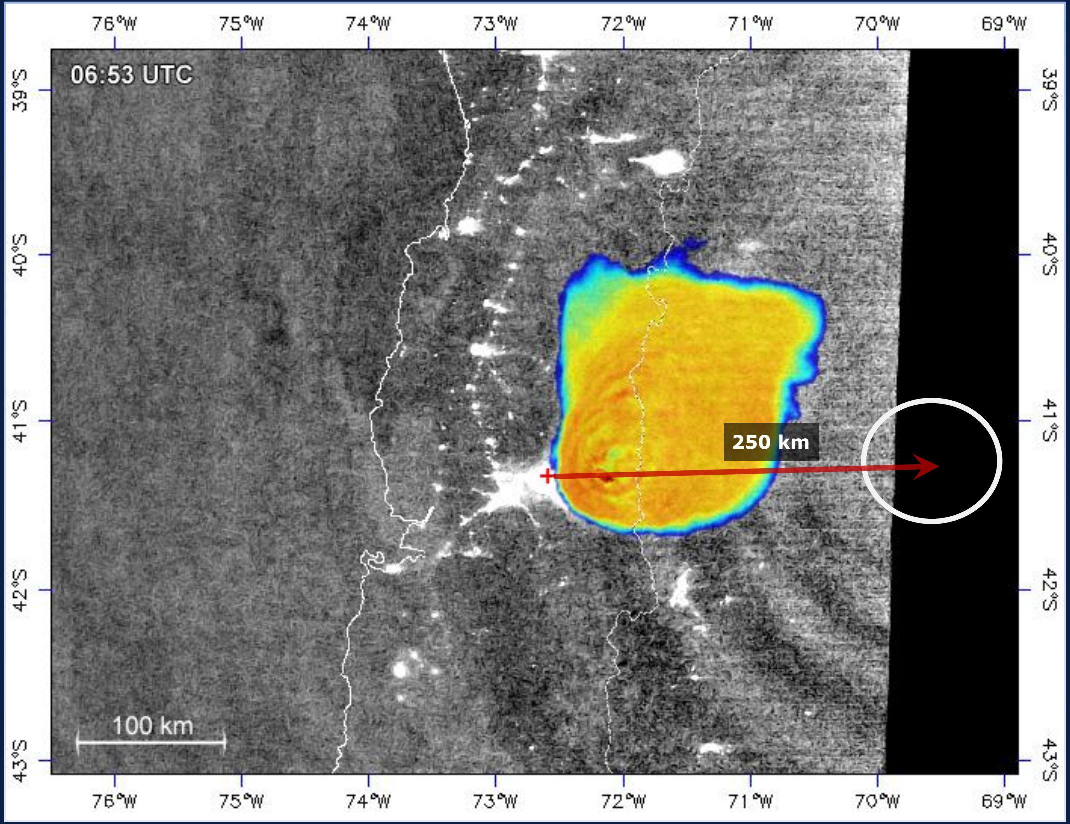
Martin Setvák (CHMI), Steven Miller (CIRA)

Parallax shift of the airglow features in VIIRS DNB imagery

Pass 2 (orbit #18059), 06:53 UTC

For this pass, the Calbuco volcano region was at the very edge of the image swath, therefore the parallax shift is substantial – for the center of the airglow waves about 250 km (in compliance with the calculated values).

Also, given the slant view from the west, the volcano itself can be seen in this pass – both in DNB (light emanated by the lava), and in IR bands (as a hot spot – not shown here).



\+ – position of the Calbuco Volcano (from IR bands)

Possible interpretation problems and ambiguities when correlating the concentric waves in airglow (in DNB) with tropospheric phenomena (in the IR bands):

- parallax shift of the airglow features in DNB with respect to the ground or lower atmospheric layers (e.g. cloud tops of convective storms)
- duration of vertical propagation of the gravity waves from their low-level sources up to the airglow layers – the source can move, weaken or even vanish before the gravity waves reach the airglow levels and modify them;
- persistence of the airglow waves after decay of the source (e.g. convective storm) which has evoked these, combined with possible advection of the airglow layers and displacement of the source itself (e.g. propagation of the storms).

Summary and concluding remarks

- The purpose of this study is to demonstrate the low-light capabilities of the DNB instrument, flown aboard the Suomi-NPP satellite, namely focusing at nightglow.

- The study has shown how to discriminate nightglow waves from clouds, using the imagery from other S-NPP VIIRS bands (IR M-bands). Also the MSG, GOES and MTSAT data were used to help identifying the meteorological mechanisms, responsible for the observed airglow waves.

- Airglow observations from the S-NPP (and the follow-up satellites, such as JPSS-1/2) can provide fine-scale information about waves in nightglow and their larger scale characteristics, but not about their heights or spectral wavelengths.

- No similar geostationary satellite-based instrument is available presently to follow the evolution of the waves in nightglow.

- The Suomi-NPP VIIRS Day/Night Band observations of airglow/nightglow can complement other ground-based or space-borne airglow observations, namely by its large spatial (global) coverage and possibility to resolve fine horizontal details.

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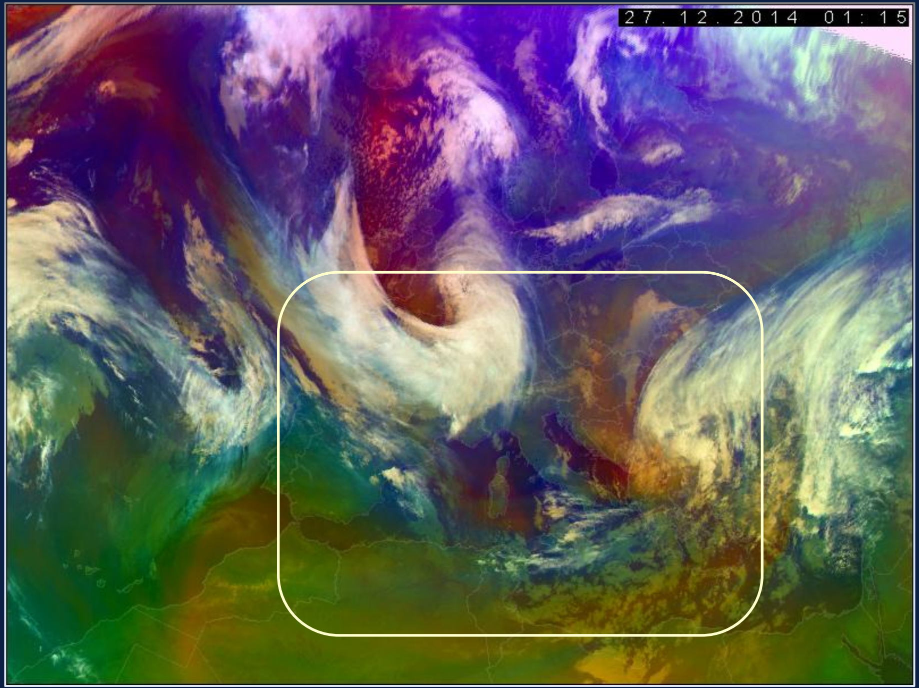
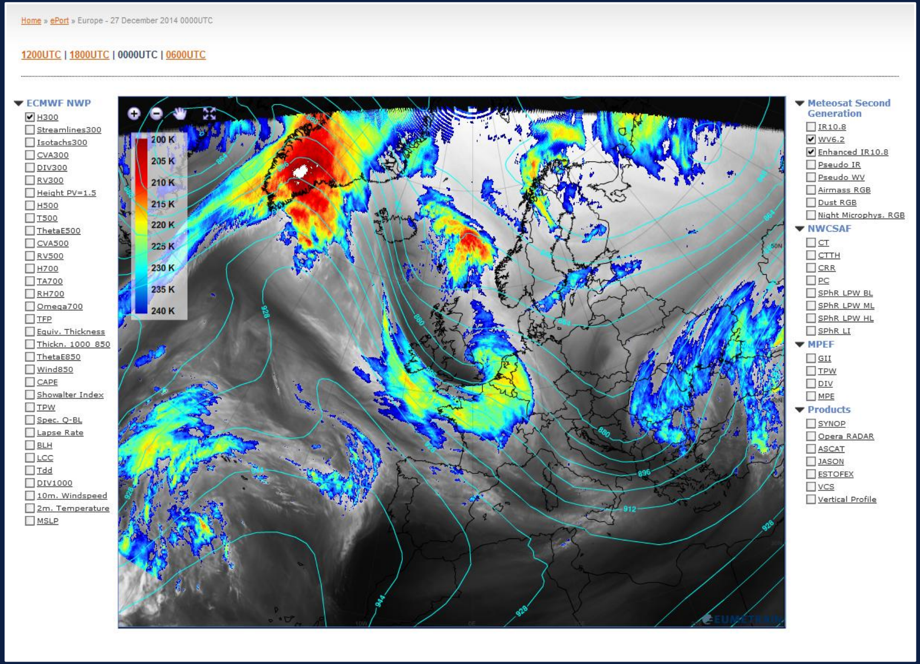
Additional backup slides

Other forms of gravity waves in nightglow as observed by Suomi-NPP in its VIIRS DNB imagery

Waves in nightglow above Mediterranean Sea and Adriatic Sea – 26/27 December 2014

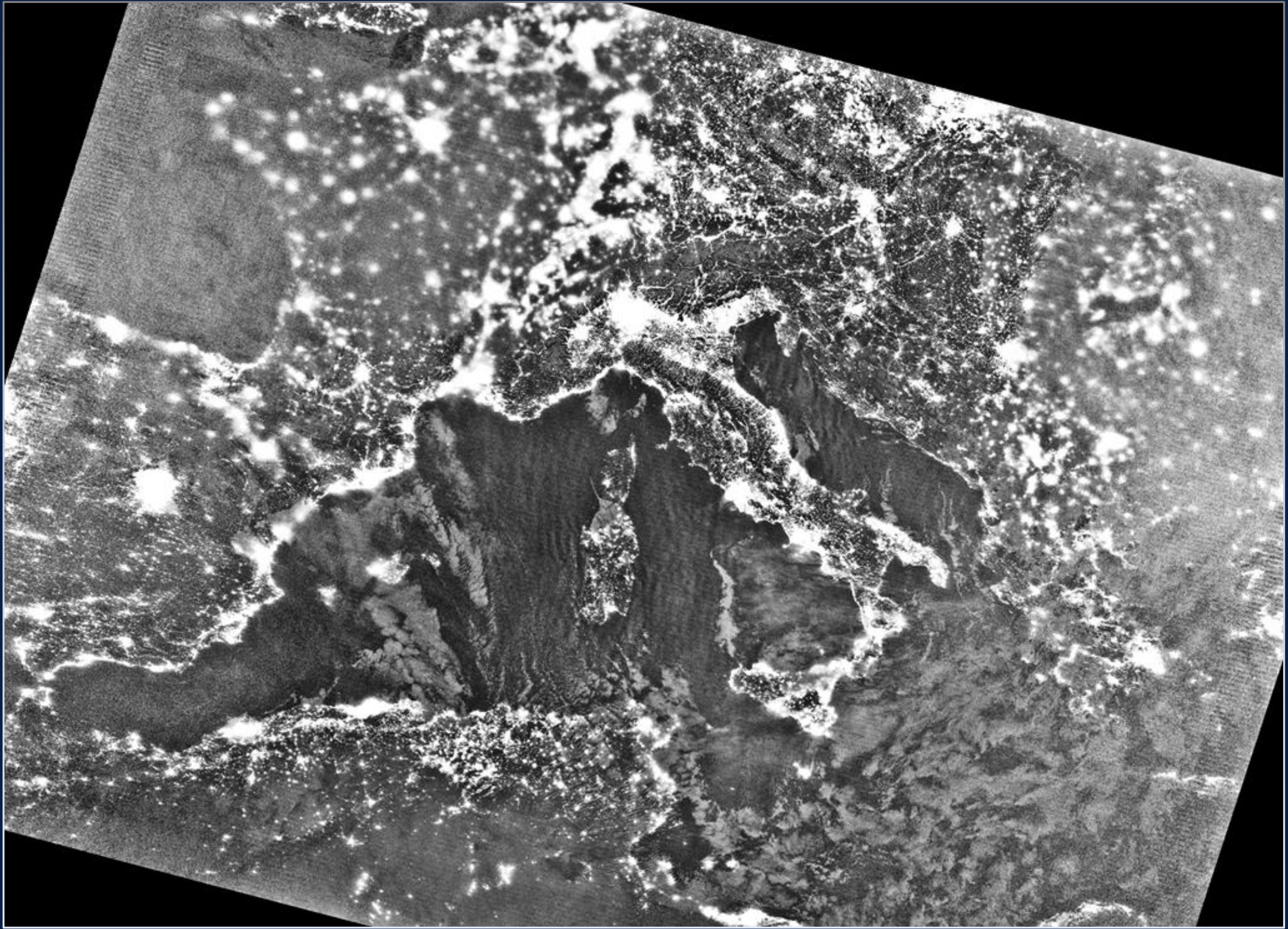


Meteosat-10 Airmass RGB product



300 hPa + MSG WV6.2 source: EUMeTrain ePort

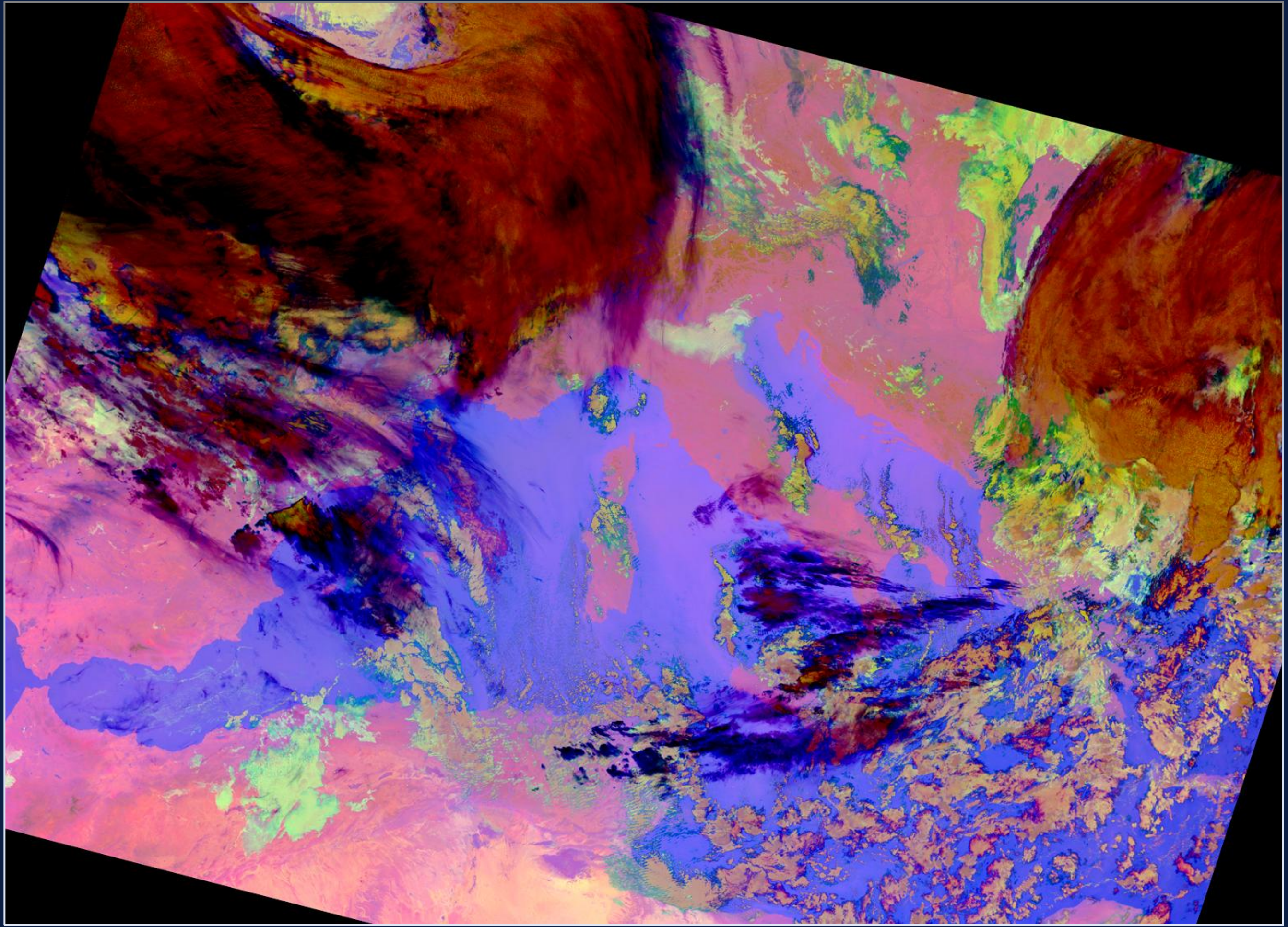
Waves in nightglow above Mediterranean Sea and Adriatic Sea



2014-12-27 01:20 UTC

DNB – strongly enhanced

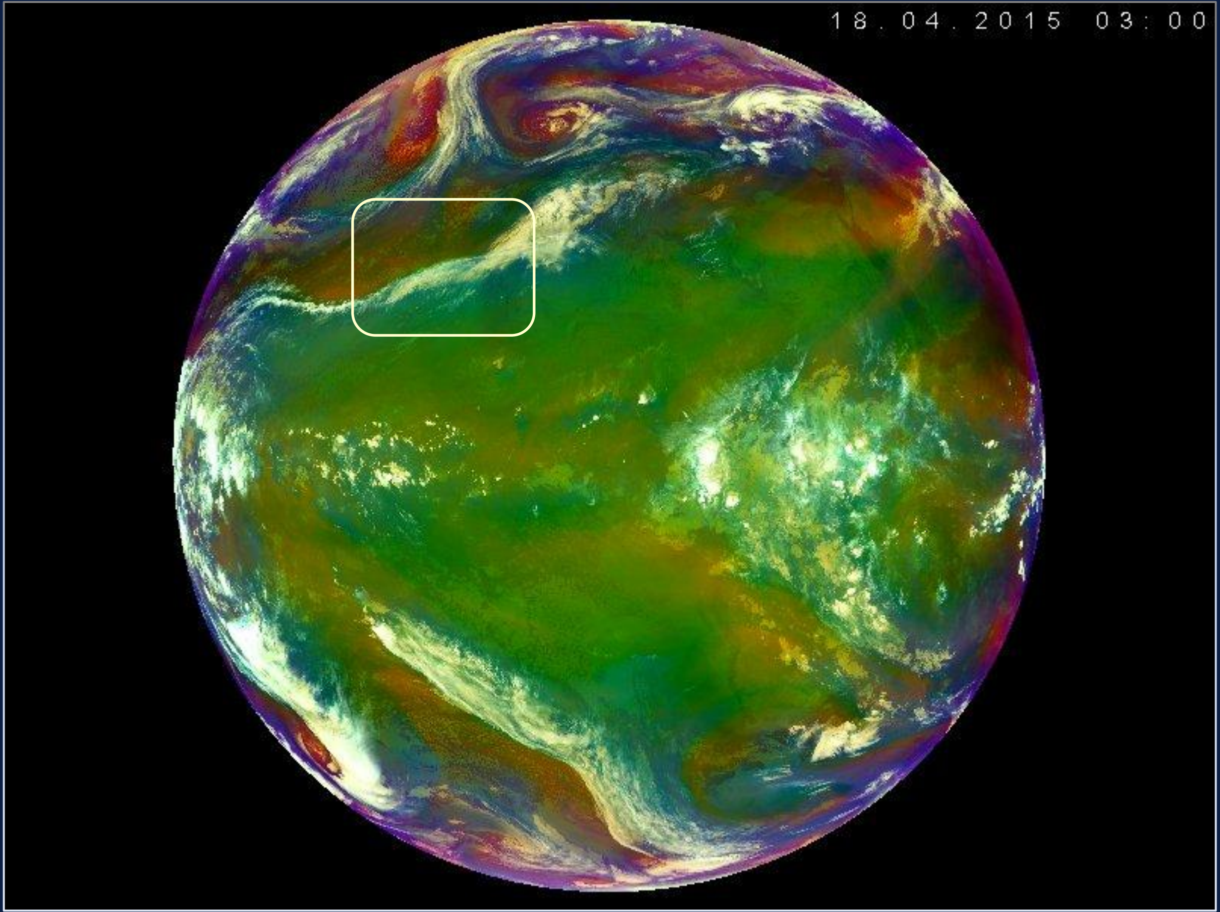
Waves in nightglow above Mediterranean Sea and Adriatic Sea



2014-12-27 01:20 UTC

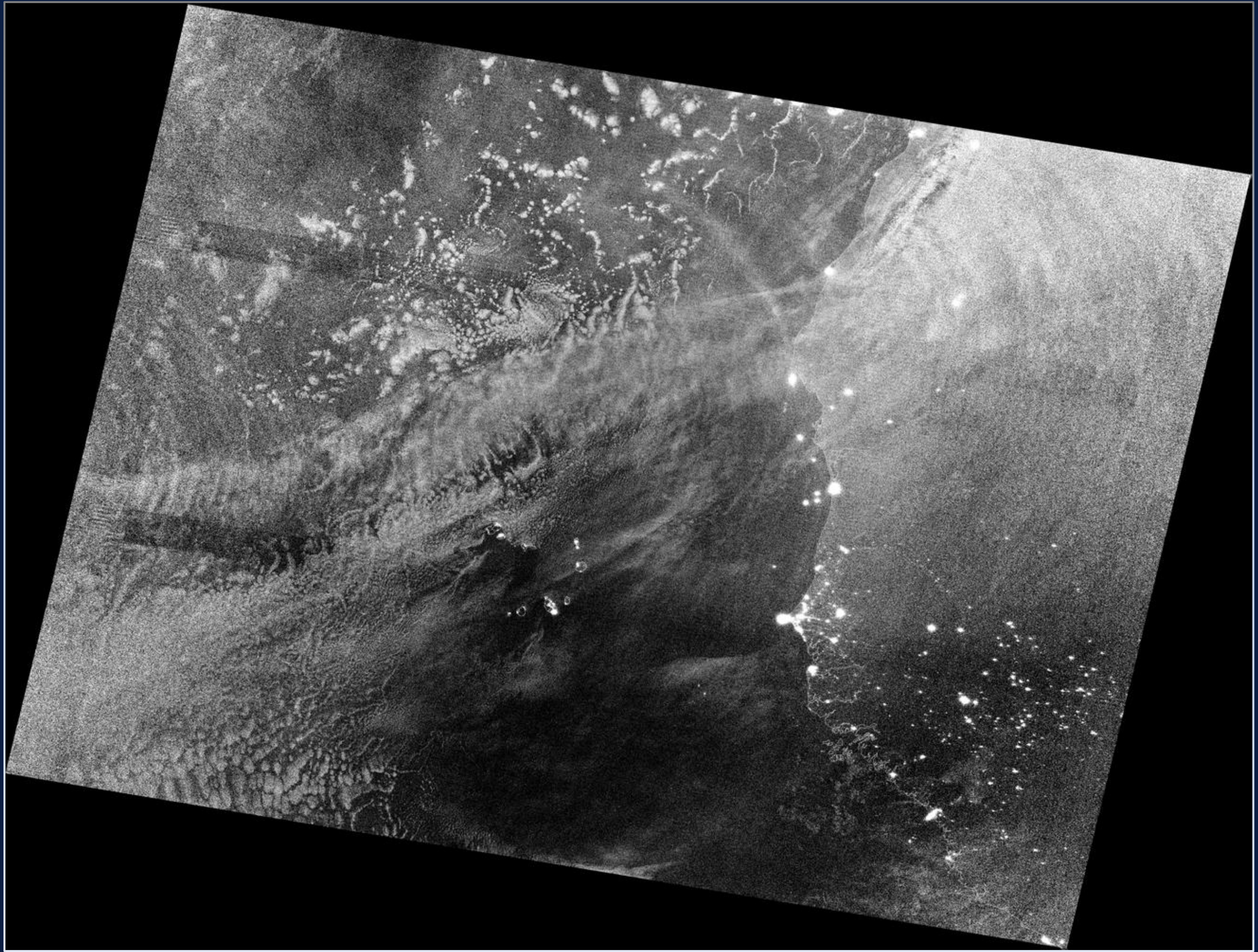
M12, M14 and M15
Night microphysical RGB

Bow-shaped waves in nightglow above jet stream, east Atlantic and west Africa



Meteosat-10 Airmass RGB product

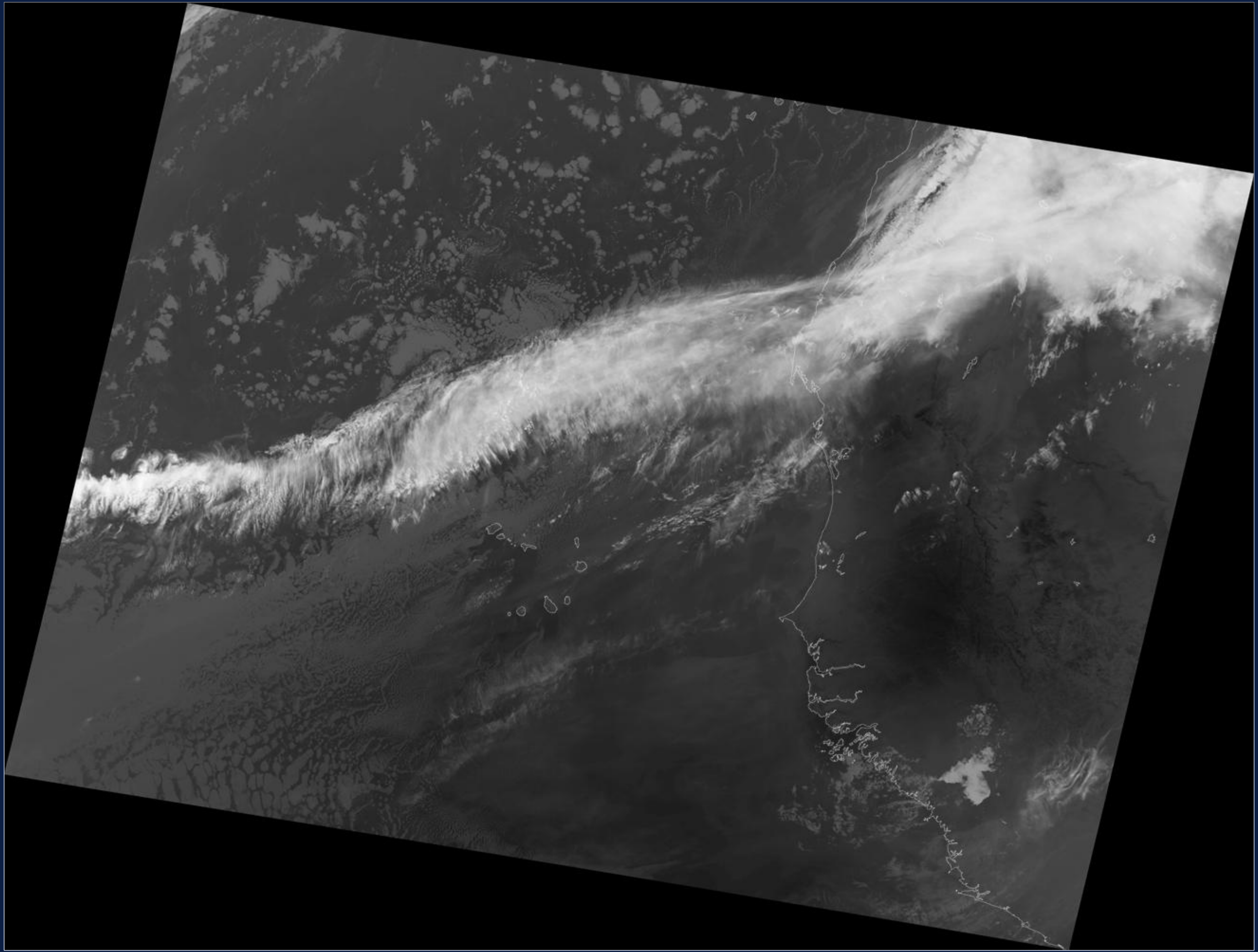
Bow-shaped waves in nightglow above jet stream, east Atlantic and west Africa



2015-04-18 03:05 UTC

DNB

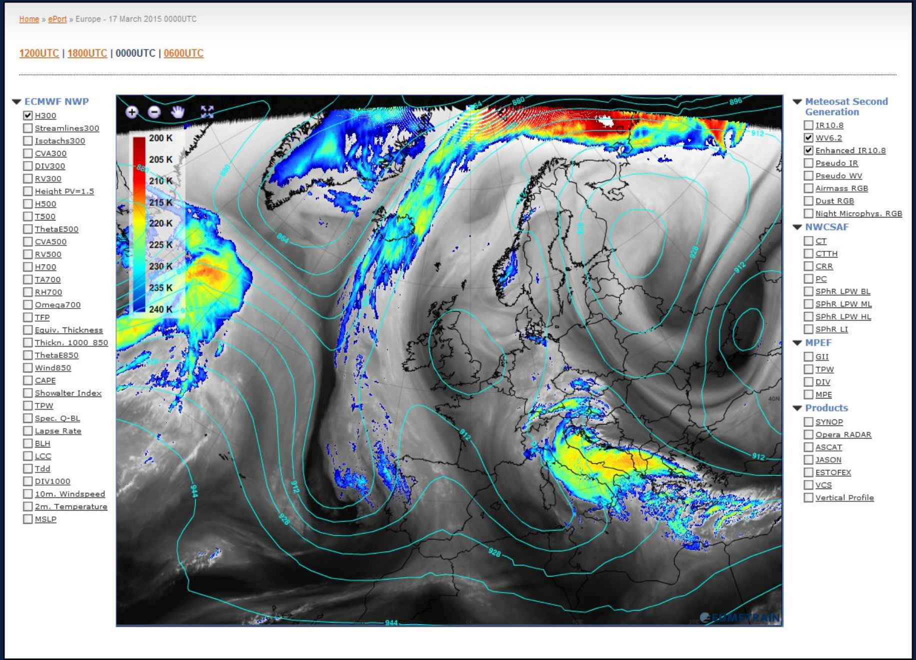
Bow-shaped waves in nightglow above jet stream, east Atlantic and west Africa



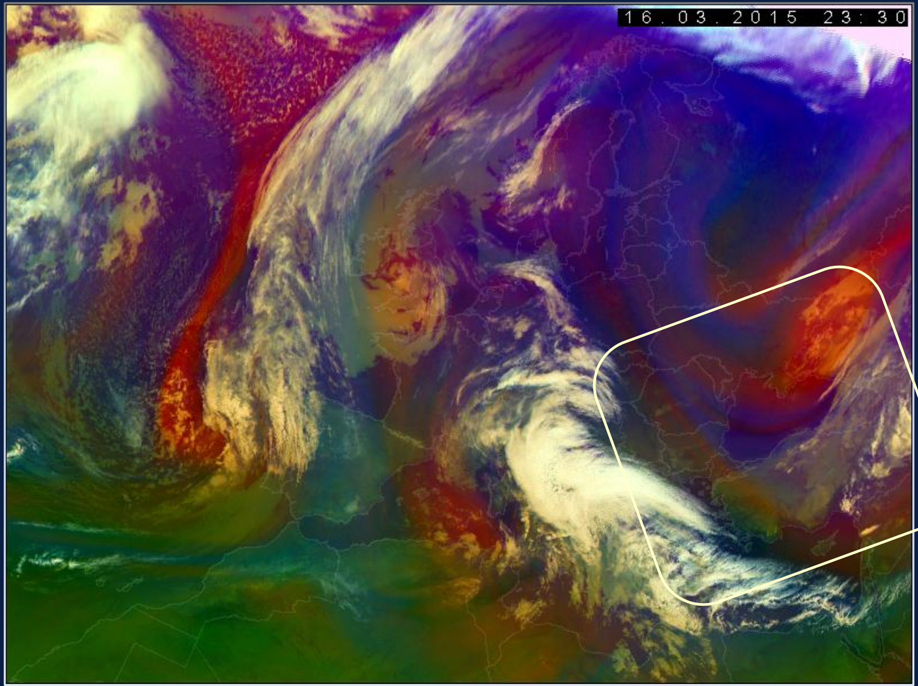
2015-04-18 03:05 UTC

M15 band

Waves in nightglow above Black Sea (jet stream exit) – 16/17 March 2015

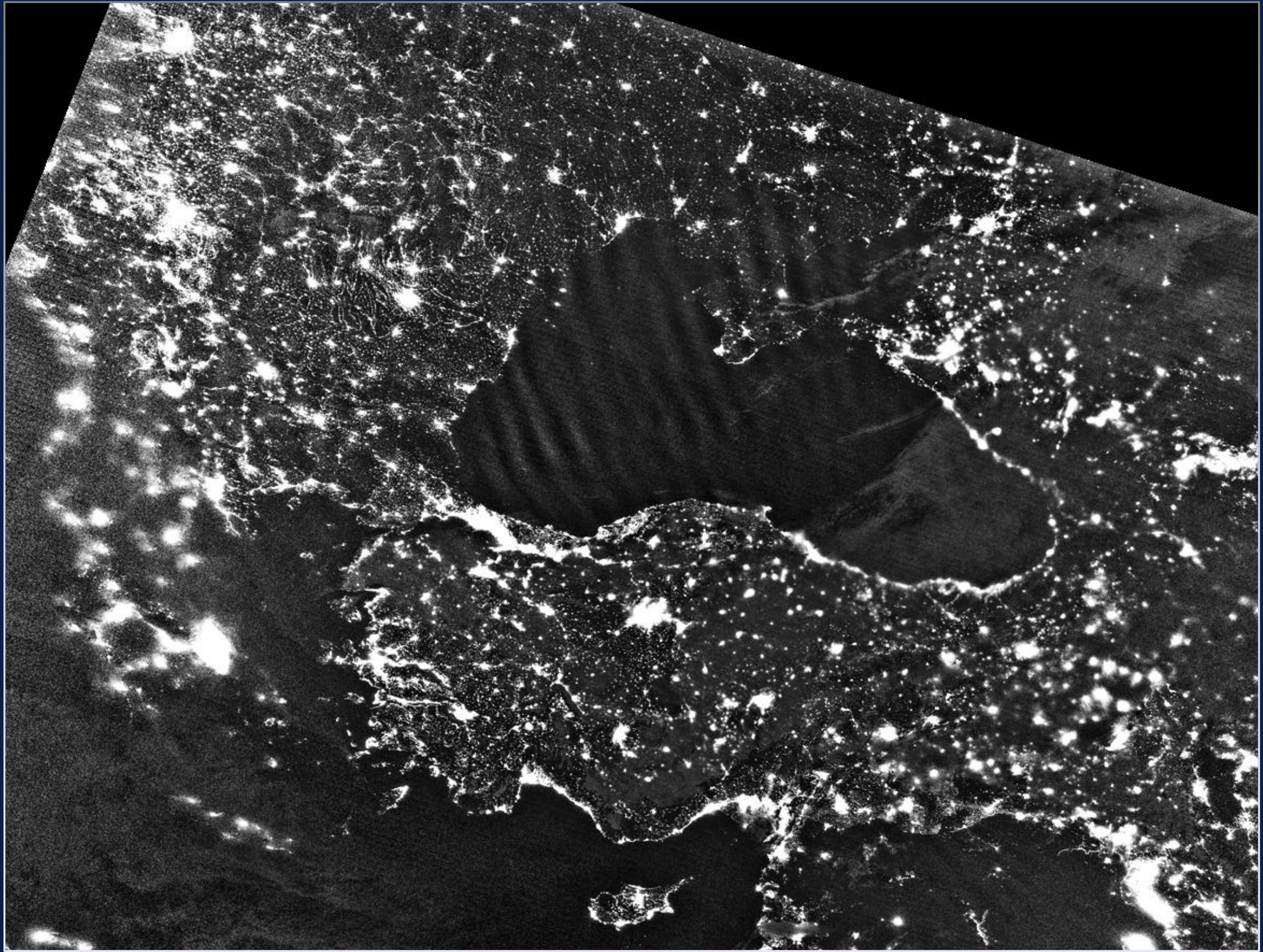


300 hPa + MSG WV6.2 source: EUMeTrain ePort



Meteosat-10 Airmass RGB product

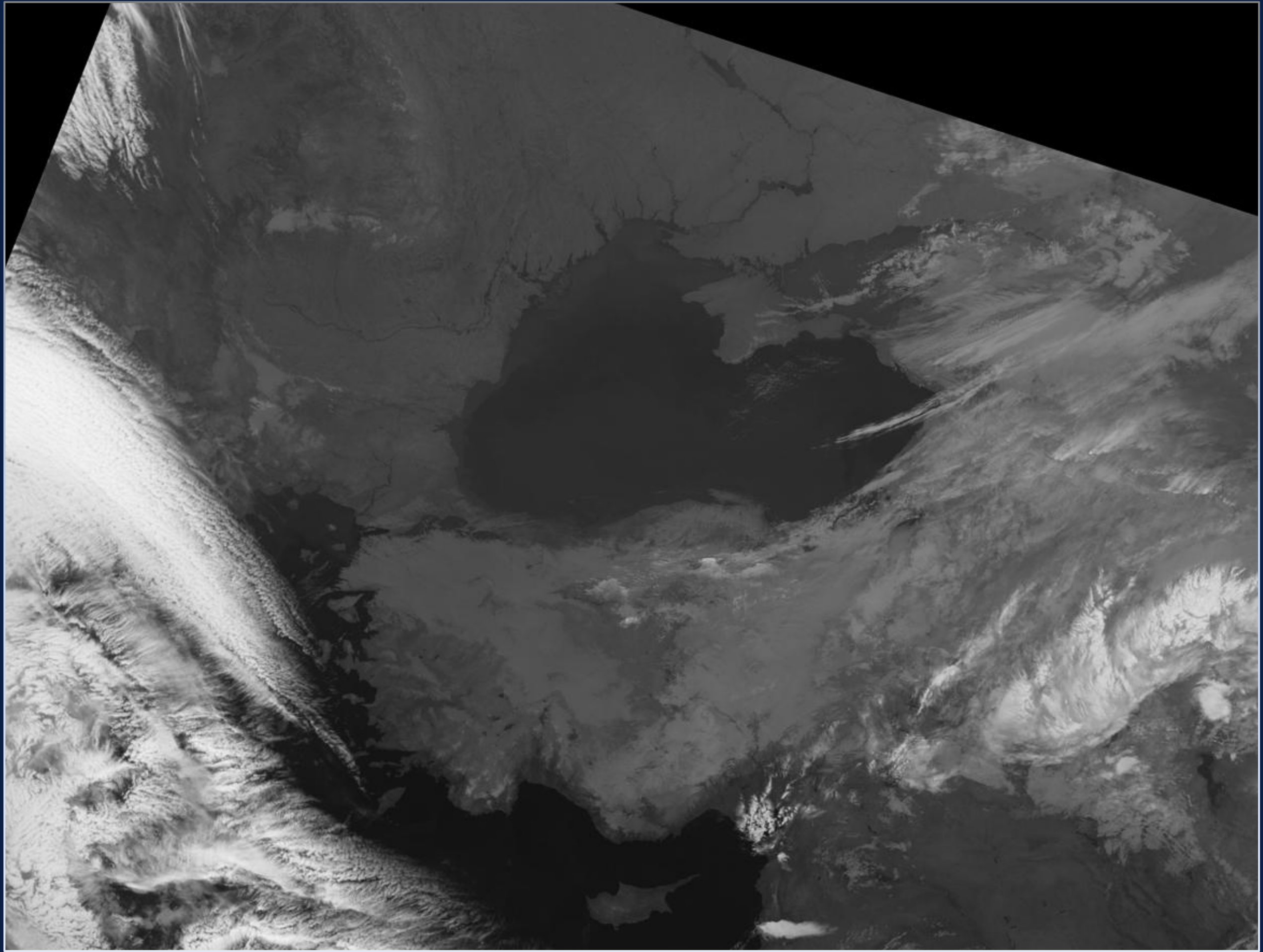
Waves in nightglow above Black Sea (jet stream exit)



2015-03-16 23:40 UTC

DNB

Waves in nightglow above Black Sea (jet stream exit)



2015-03-16 23:40 UTC

M15 band