Visible Infrared Imaging Radiometer Suite (VIIRS): improvements in imaging radiometry enabled by innovation driven by requirements

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Artwork Credit: NASA

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Outline

- VIIRS description
- Innovations that created VIIRS with resulting improvements

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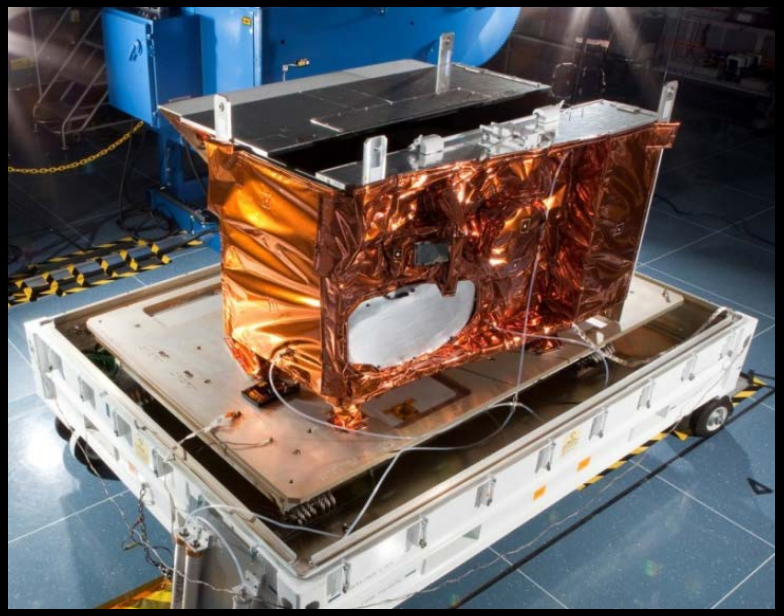
Visible Infrared Imaging Radiometer Suite (VIIRS) is the US operational environmental imager in polar orbit

- Flight Unit 1 onboard the Suomi NPP satellite is performing well, providing high-quality visible/infrared Earth observations since 2011
- Flight Unit 2 has been delivered and Flight Unit 3 is being built now in California
- VIIRS provides higher spatial resolution data across a wider area than previous instruments
  - More complete global coverage, higher quality and more complete data
- A highly sensitive day/night band is improving weather forecasting around the world and providing new ways to observe the Earth from space
- VIIRS replaces four legacy sensors with a single modular instrument
  - Facilitates incorporation of new technology and response to changing requirements



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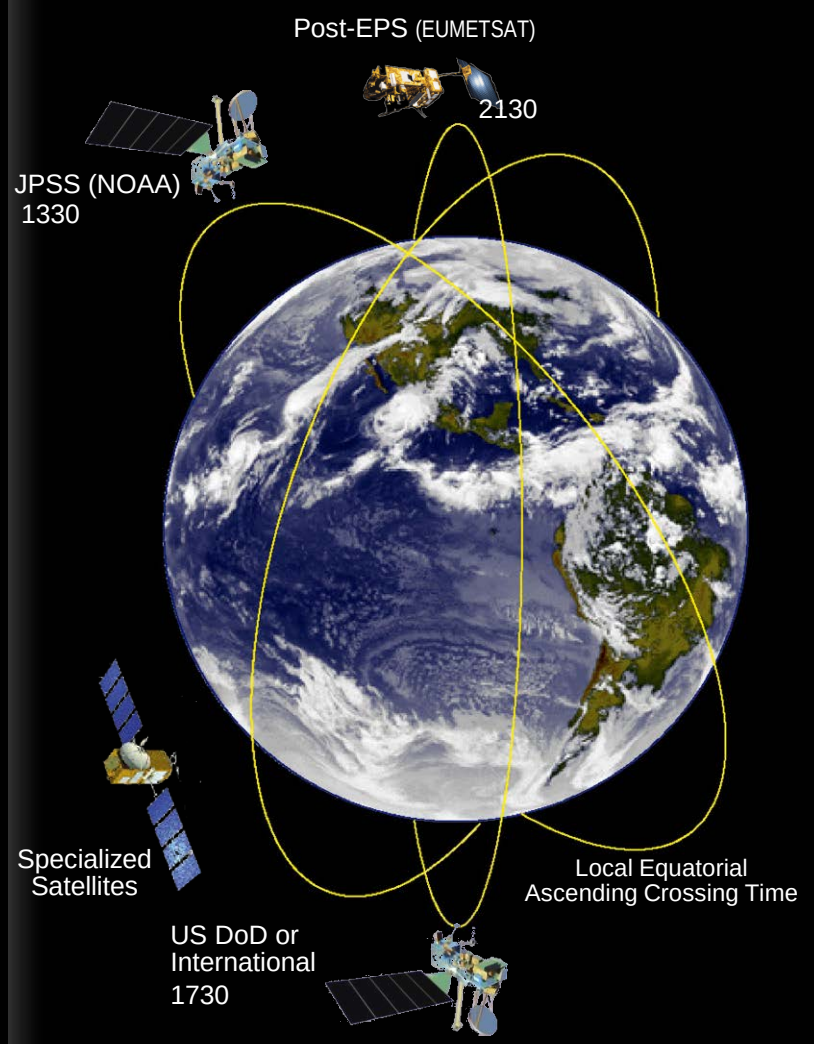
VIIRS is a key instrument in the Joint Polar Satellite System (JPSS)

- JPSS mission
  - Provide national, operational, polar-orbiting remote-sensing capability
  - Incorporate new technologies from NASA into operations
  - Encourage international cooperation
- VIIRS collects visible/ infrared imagery and radiometric data
- VIIRS contributes to more environmental data products than any other JPSS sensor
- VIIRS has been observing Earth from the Suomi NPP satellite, a precursor to JPSS, since late 2011



VIIRS has 22 spectral bands that address a wide variety of Environmental Data Records (EDRs)

		Band No.	Wave-length (μm)	Horiz Sample Interval (km Downtrack x Crosstrack)		Driving EDRs	Radi-ance Range	Ltyp or Ttyp
				Nadir	End of Scan			
VIS/NIR FPA	Silicon PIN Diodes	M1	0.412	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	44.9 155
		M2	0.445	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	40 146
		M3	0.488	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	32 123
		M4	0.555	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	21 90
		I1	0.640	0.371 x 0.387	0.80 x 0.789	Imagery	Single	22
		M5	0.672	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	10 68
		M6	0.746	0.742 x 0.776	1.60 x 1.58	Atmospheric Corr'n	Single	9.6
		I2	0.865	0.371 x 0.387	0.80 x 0.789	NDVI	Single	25
		M7	0.865	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	6.4 33.4
S/MWIR	PV HgCdTe (HCT)	M8	1.24	0.742 x 0.776	1.60 x 1.58	Cloud Particle Size	Single	5.4
		M9	1.378	0.742 x 0.776	1.60 x 1.58	Cirrus/Cloud Cover	Single	6
		I3	1.61	0.371 x 0.387	0.80 x 0.789	Binary Snow Map	Single	7.3
		M10	1.61	0.742 x 0.776	1.60 x 1.58	Snow Fraction	Single	7.3
		M11	2.25	0.742 x 0.776	1.60 x 1.58	Clouds	Single	0.12
		I4	3.74	0.371 x 0.387	0.80 x 0.789	Imagery Clouds	Single	270 K
		M12	3.70	0.742 x 0.776	1.60 x 1.58	SST	Single	270 K
		M13	4.05	0.742 x 0.259	1.60 x 1.58	SST Fires	Low High	300 K 380 K
LWIR	PV HCT	M14	8.55	0.742 x 0.776	1.60 x 1.58	Cloud Top Properties	Single	270 K
		M15	10.763	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K
		I5	11.450	0.371 x 0.387	0.80 x 0.789	Cloud Imagery	Single	210 K
		M16	12.013	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K

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VIIRS global monitoring improves decision making on crucial international priorities

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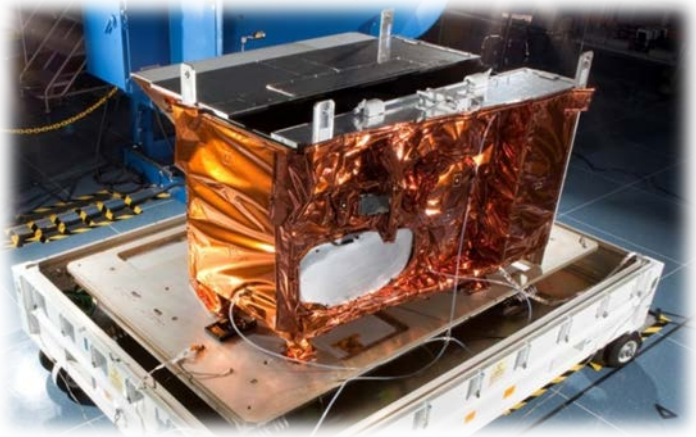
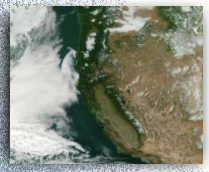
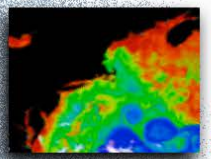
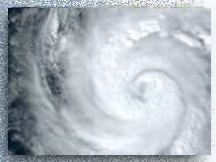
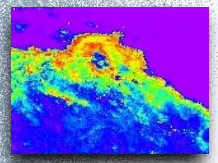
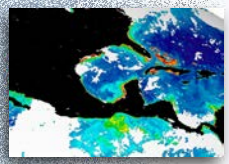
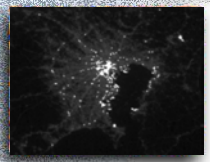
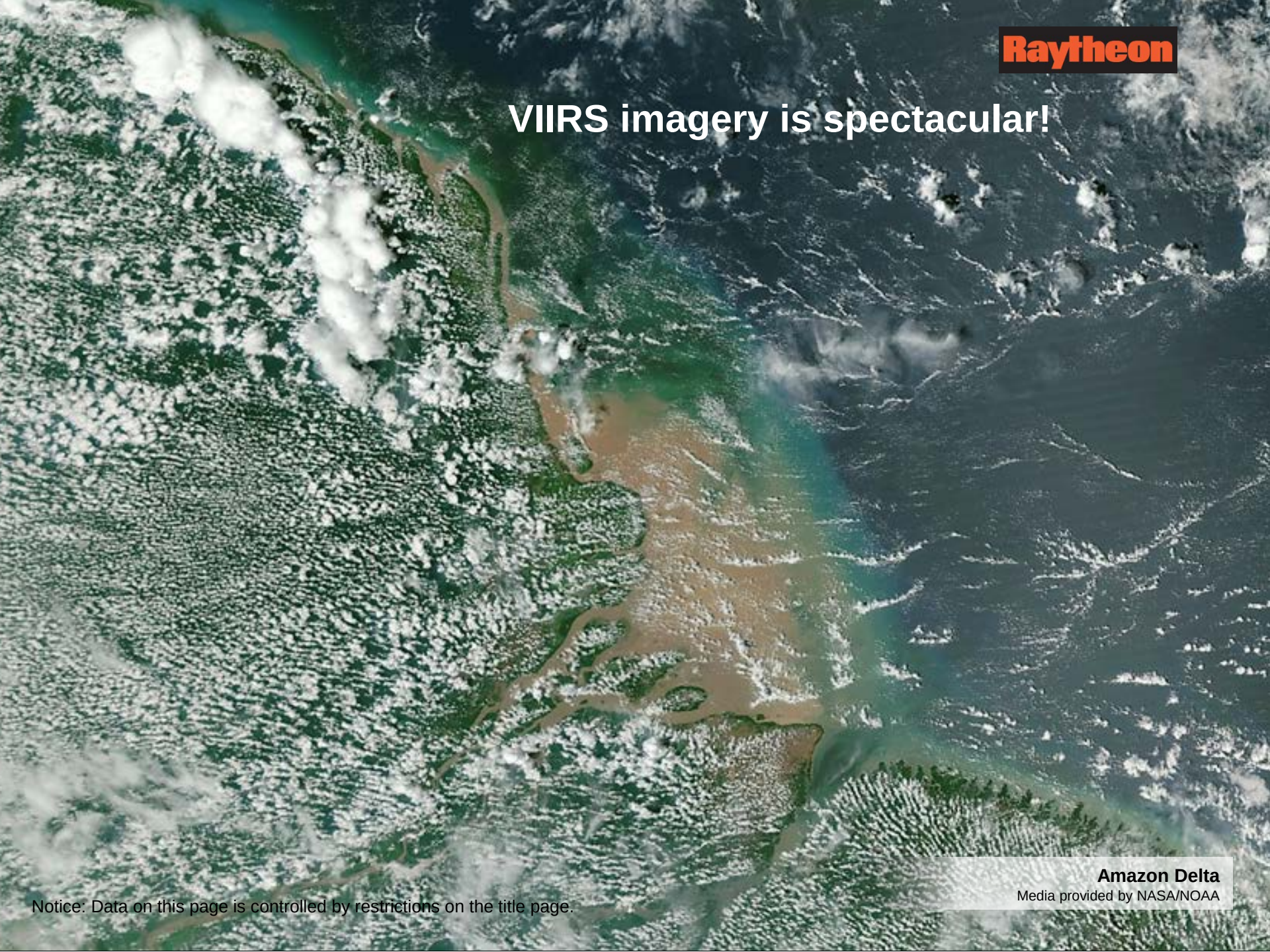


- **Breaks through limitations of previous operational systems with more complete spectral and spatial coverage, sharper imagery, better sensitivity and better accuracy**
- **Benefits from substantial US research investment in NASA/NOAA research systems to enable new operational weather forecasting and other environmental data products**
- **Enables new ways to view Earth from space using calibrated low light imaging band with 100x better sensitivity and 8x better spatial resolution than previous system**

Data Products	*Benefits for Decision Makers*
 *Imagery*	***Improved Environmental Monitoring and Forecasting for Weather and Ecosystems***
 *Sea Surface Temperature*	***Natural Disasters: Earlier Warning and Faster Response***
 *Clouds*	***Military Support: Sharper Imagery and Better Global Weather Forecasting for Mission Planning/Ops***
 *Aerosols*	
 *Ocean Color*	***Crucial Resources: Improved Ability to Protect Water Supply, Predict Electric Power Needs, Warn of Conditions Leading to Food Shortage***
 *Low Light Visible Imaging*	***Public Health: Early Warning of Health Hazards***

VIIRS imagery is spectacular!



Amazon Delta
Media provided by NASA/NOAA

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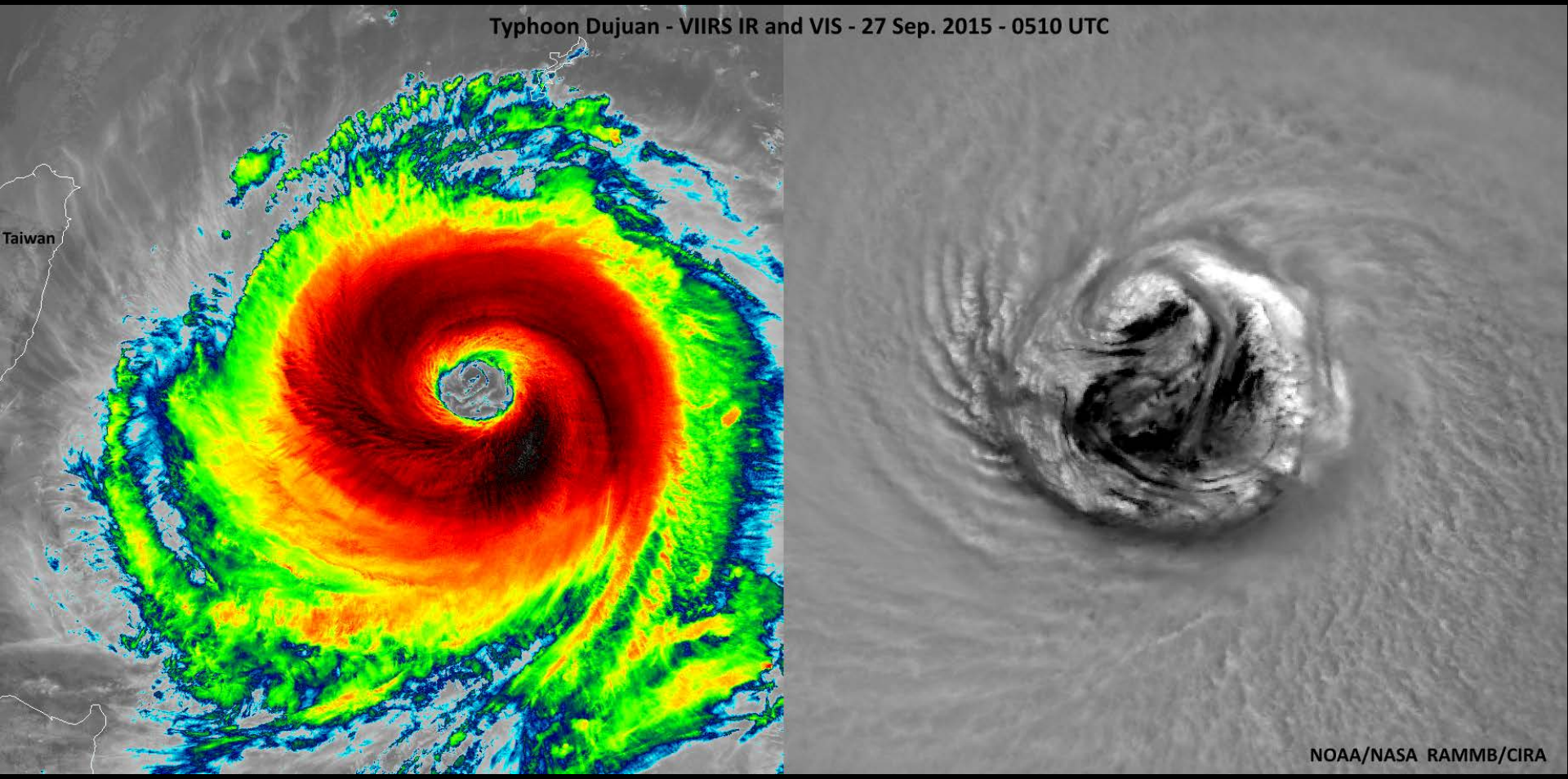
VIIRS' higher spatial resolution than other systems enables unprecedented insight into weather systems



Typhoon Dujuan approaching Taiwan on 2015 September 27
Credit: NOAA/NASA RAMMB/CIRA

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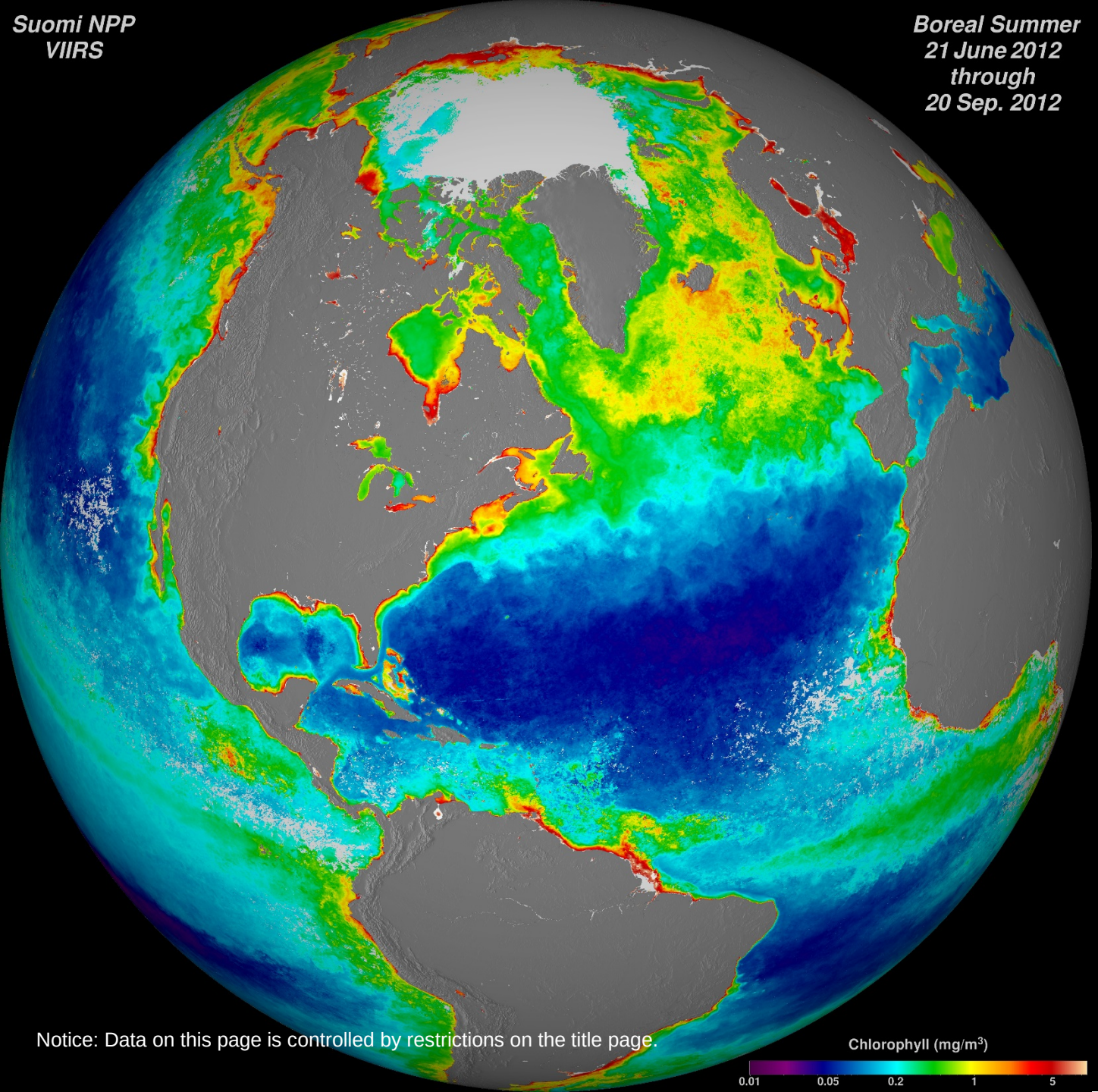

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VIIRS data is used to monitor worldwide health of ocean and coastal ecosystems

Credit: NASA

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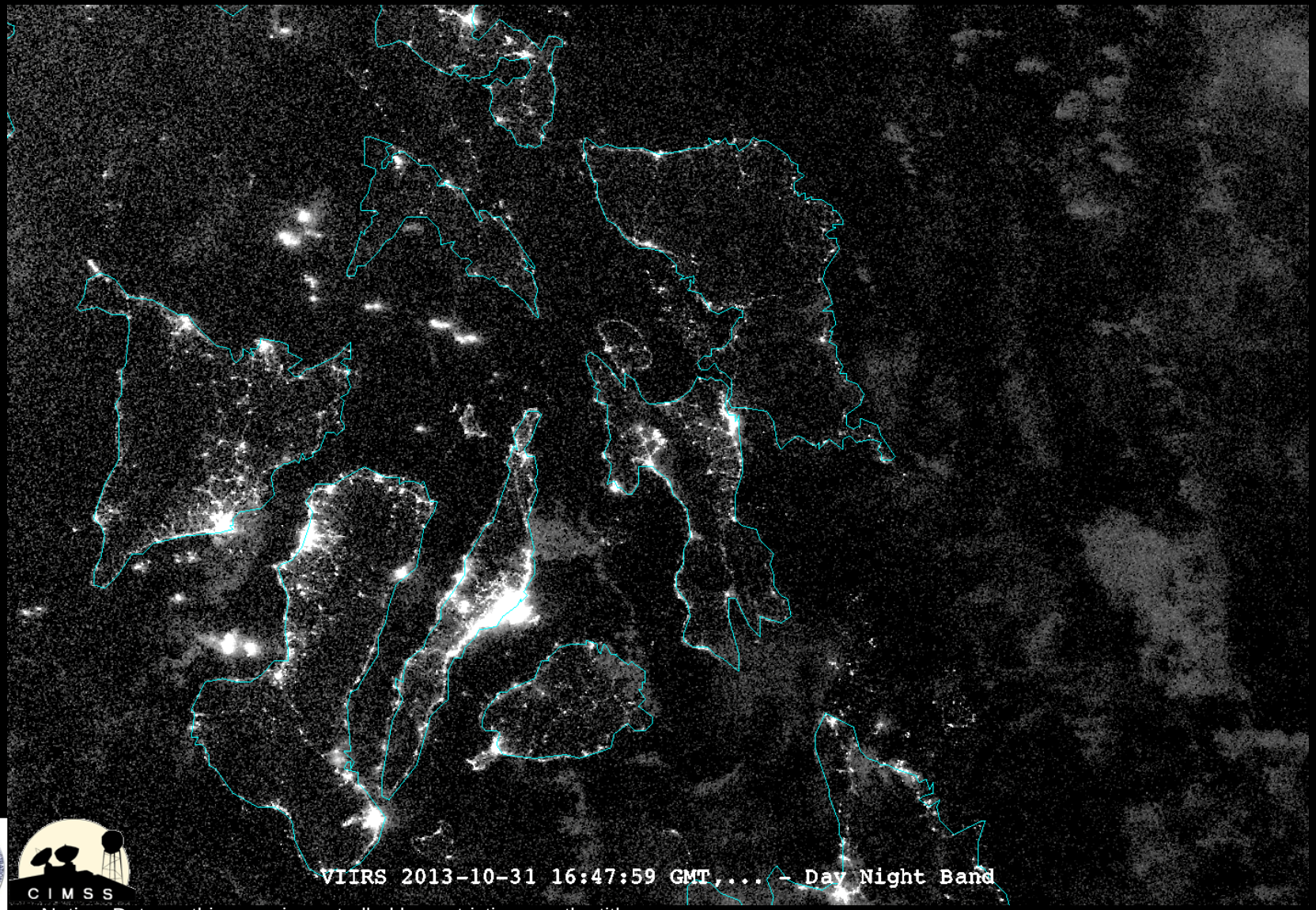
VIIRS helps mitigate natural disasters worldwide, as illustrated by this observation of power outages caused by Super Typhoon Haiyan



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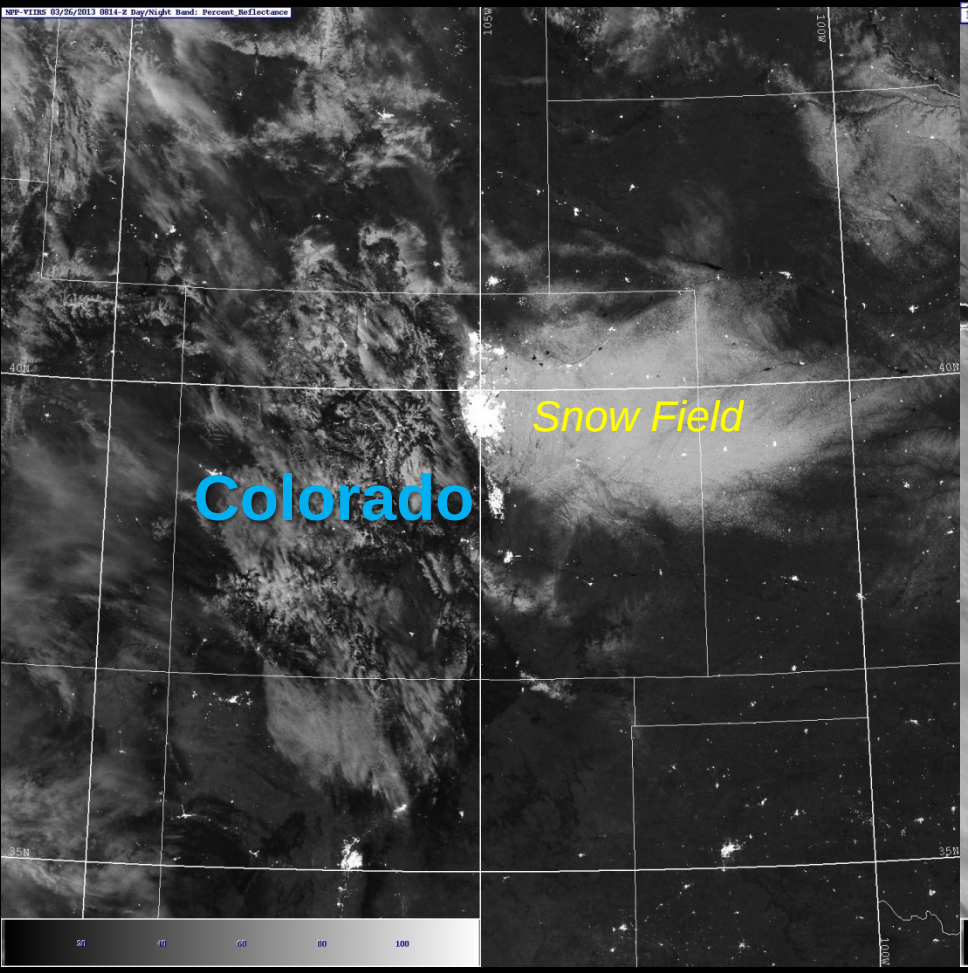
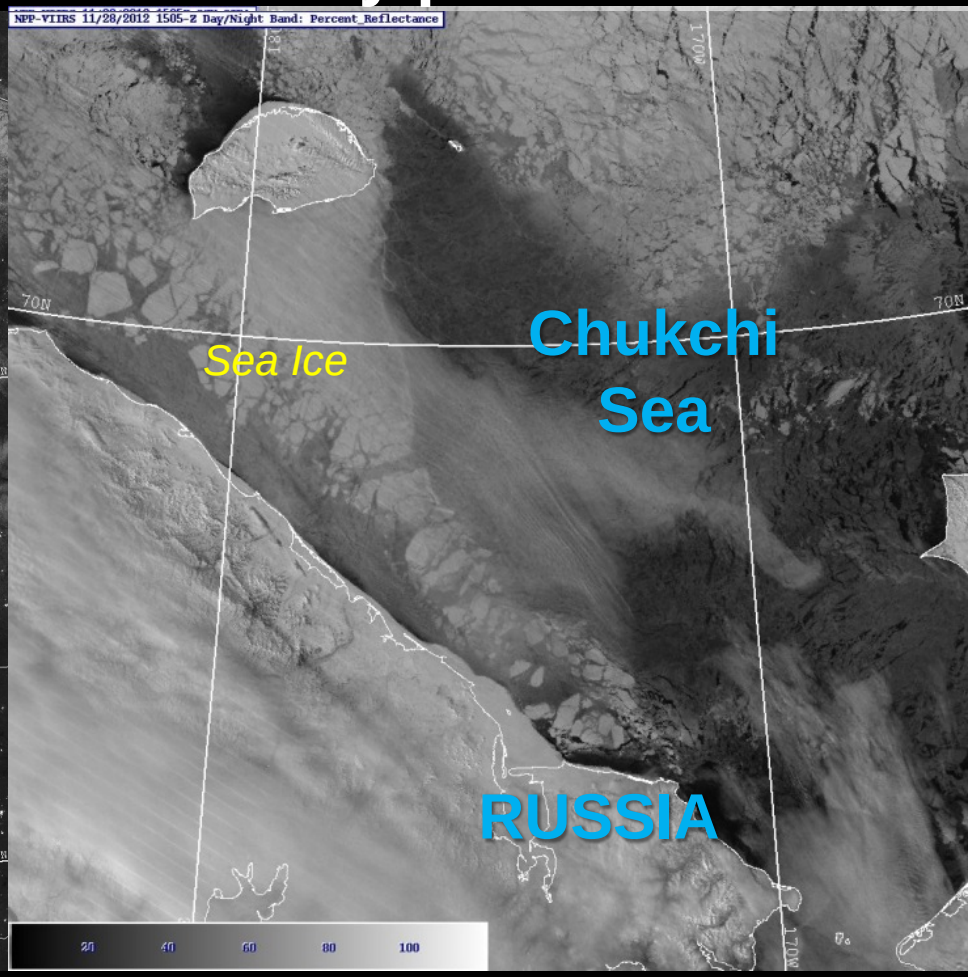
VIIRS DNB imagery improves insight into conditions in the Arctic and other wintry places





→ *Reveals features offering poor temperature contrast and/or obscured by optically thick (in the infrared) clouds*

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VIIRS was designed as an end-to-end system to meet NPOESS EDR requirements - system performance was verified with a testbed supported by hardware demos

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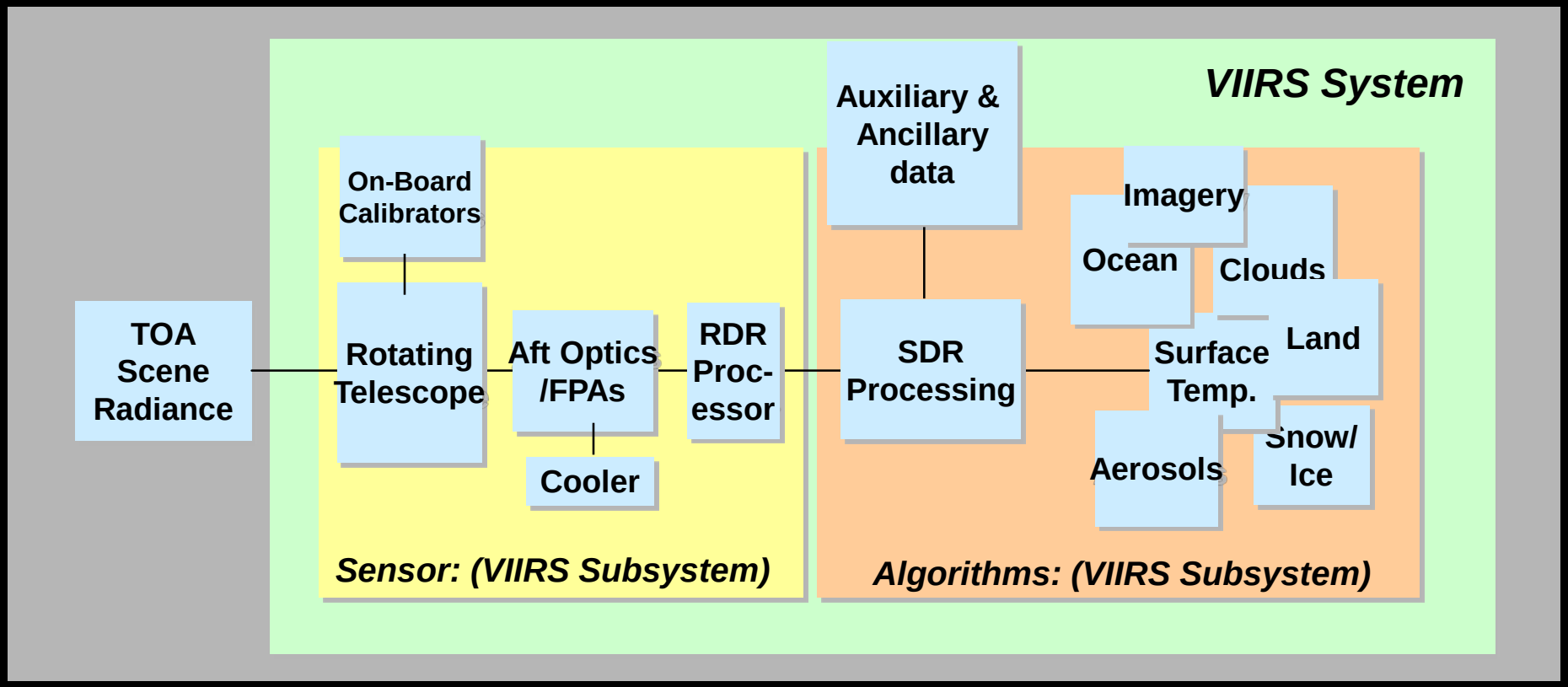

Closed the Loop!

- EDRs Drove Algorithm and RDR Requirements
- Sensor Specification derived from EDRs with testbed
- Sensor performance verified by PDR & Phase II Hardware Risk-Reduction Demonstrations and Analyses
- EDR performance verified by testbed with sensor model

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VIIRS responds successfully to enhanced performance requirements from previous operational and research sensors

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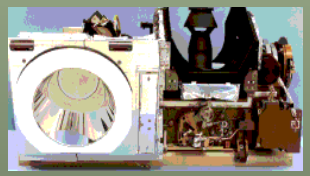
Operational Sensors

OLS



74 kg
2 bands

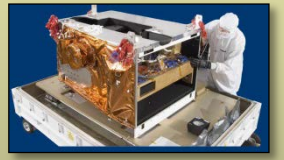
- High Spatial Resolution
- Day/Night Band
- Minimize Pixel Growth Across Scan

- Radiometric Accuracy
- SST Band Continuity

AVHRR

33 kg
5 bands

VIIRS



OMM

EM

270 kg
22 bands

Research Sensors

MODIS

220 kg
36 bands

- Band Selection/Continuity
- Thin Cirrus Band
- Solar Diffuser
- Calibration Lessons Learned

- Ocean Color Bands
- Rotating Telescope

SeaWiFS

45 kg
8 bands

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Three retired Raytheon engineers and two program managers were key VIIRS innovators

- Carl Schueler – first VIIRS Technical Director and inventor of spatial sampling approach to minimize cross scan pixel growth
- Ed Clement – Chief Engineer from first proposal through Flight Unit 1 delivery – still with the program as NASA support contractor
- Phil Ardanuy – led early trade studies to optimize VIIRS spectral sampling and other design characteristics
- Rod Durham – first VIIRS program manager
- Marty Greenfield (deceased) – VIIRS capture manager

Many others in the Customer communities inspired and contributed to VIIRS innovations

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VIIRS combines technology developed in MODIS and SeaWiFS with innovation to meet enhanced performance requirements demanded by NPOESS

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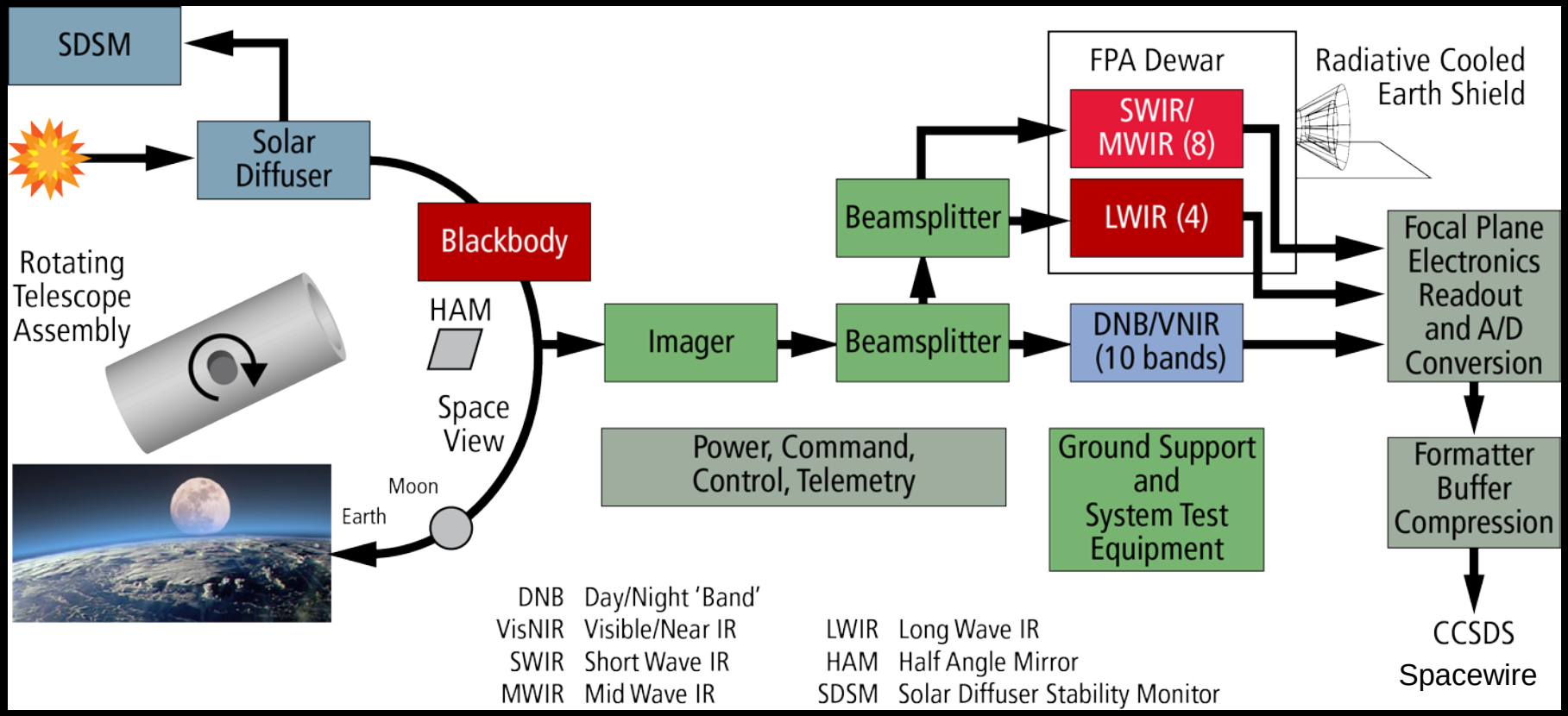
Dimensions:	137 x 149 x 89 cm^3
Mass:	270 kg
Power:	184 W
Data Rate:	11.4 peak/9.1avg Mbps



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VIIRS improvements are enabled by design and engineering innovations driven by requirements

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Innovations	*Resulting Improvements*
▪ Oversampling and variable aggregation of detector samples	▪ Greatly reduced pixel growth at edge of scan
▪ PV HgCdTe detector technology for LWIR to improve sensitivity	▪ 375-m resolution thermal infrared imagery
▪ MODIS flight proven calibration technology brought to operational practice	▪ Well calibrated bands across full spectral range
▪ Rotating telescope scanner to minimize straylight	▪ High sensitivity calibrated Day Night Band (DNB) with nearly constant pixel size across the swath
▪ High sensitivity CCD detector technology with Time Delay and Integration (TDI) to improve SNR and oversampling with 32 aggregation modes	

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VIIRS detector sample sizes were selected to meet requirements at end of scan

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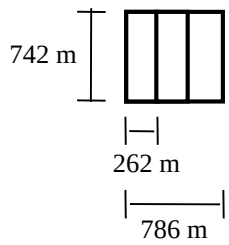
On-board aggregation of detector samples into pixels reduces downlink data rate

Radiometric "Moderate-Resolution " M-Bands

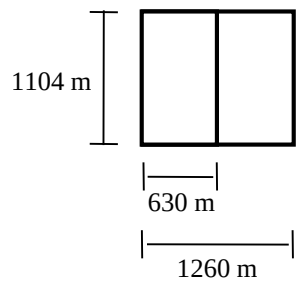
At nadir

- Aggregate 3 samples



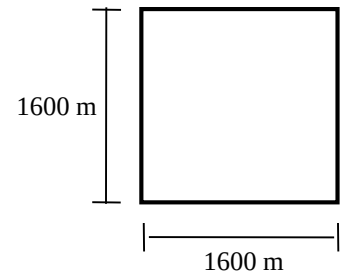
~ 850km from nadir

- Aggregate 2 samples



~1500km from nadir

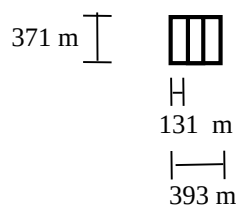
- No aggregation



Imaging "High-Resolution" I-Bands

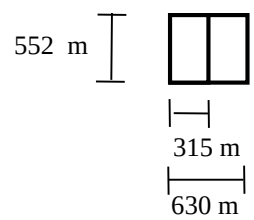
At nadir

- Aggregate 3 samples



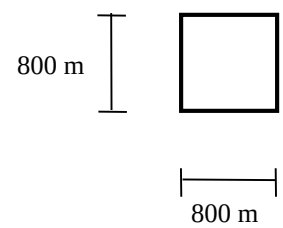
~ 850km from nadir

- Aggregate 2 samples



~1500km from nadir

- No aggregation



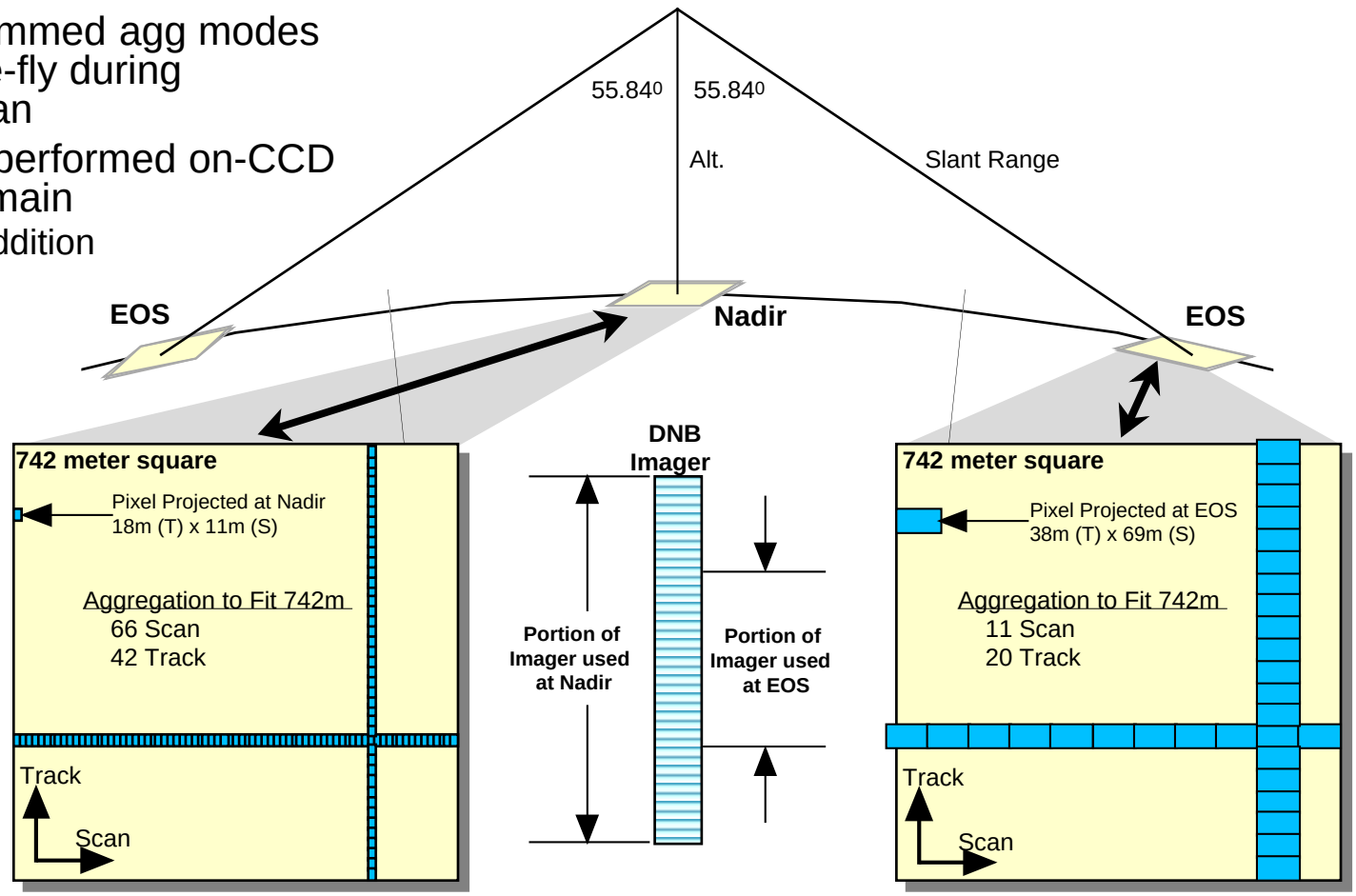
Exact sample size in the scan direction varies by spectral band. Values shown here are typical.

*Schueler, C. 1997, "Dual-use Sensor Design for Enhanced Spatioradiometric Performance," US Patent 5,682,034

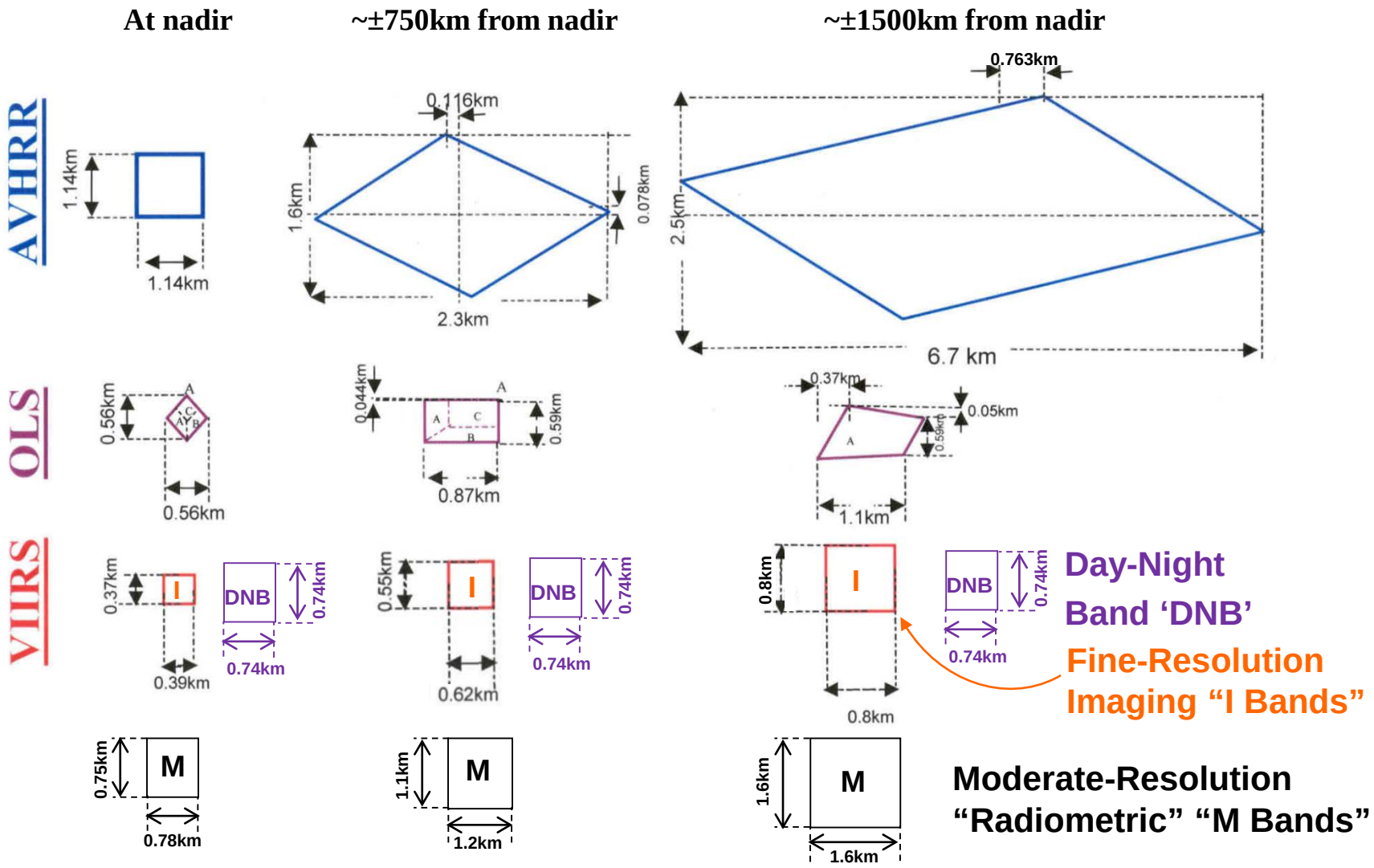
VIIRS DNB uses variable aggregation across scan to improve SNR and maintain nearly constant pixel size

- Variable aggregation provides near-constant HSI throughout scan
  - 32 preprogrammed agg modes cycled on-the-fly during earthview scan
  - Aggregation performed on-CCD in charge domain
    - Noiseless addition

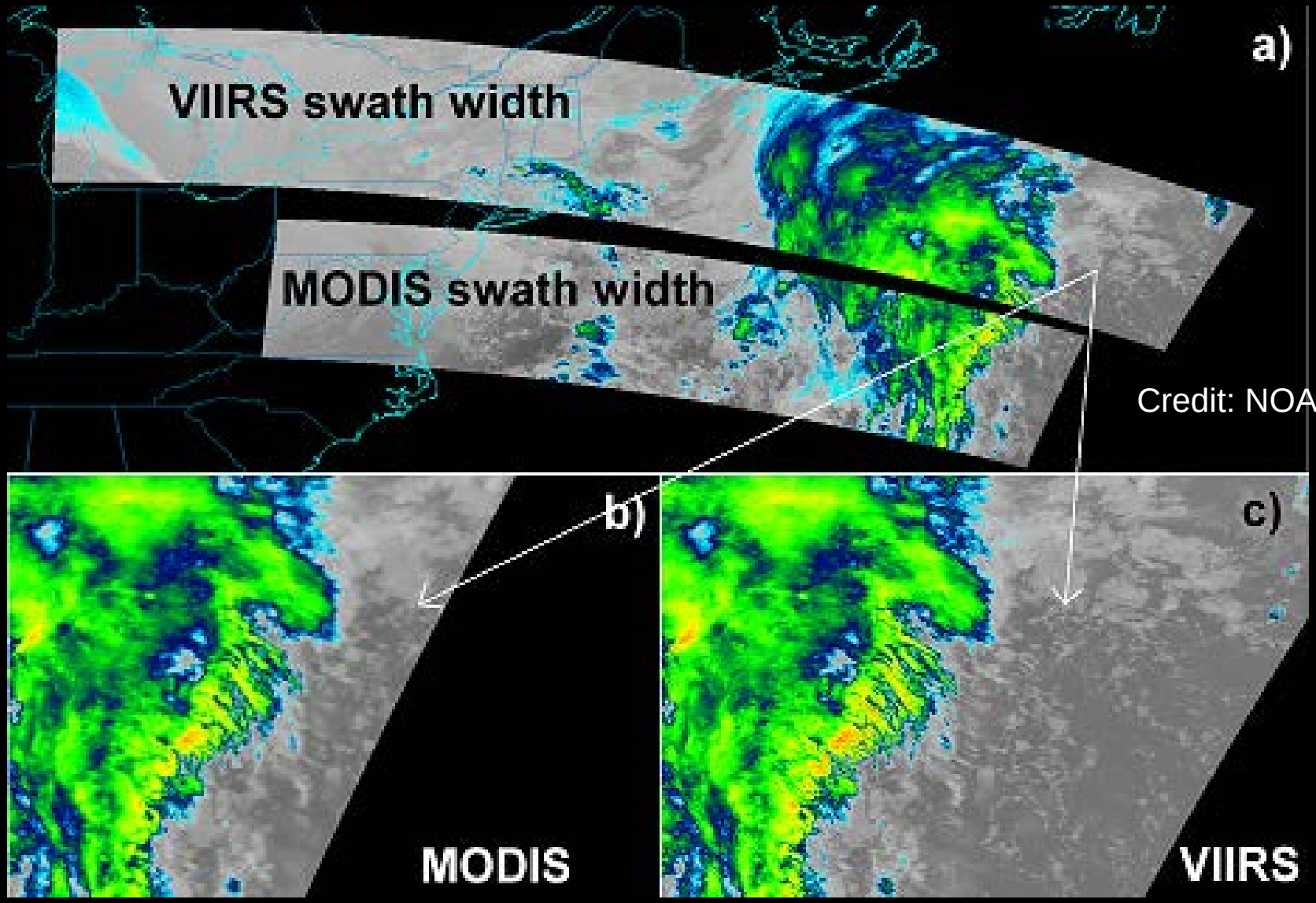
Source: Jacobson, et al., 2010, AMS 6th Annual Symposium on Future National Operational Environmental Satellite Systems, 349



VIIRS spatial sampling approach greatly reduces pixel growth at edge of scan



VIIRS offers wider swath and higher spatial resolution than MODIS



Credit: NOAA

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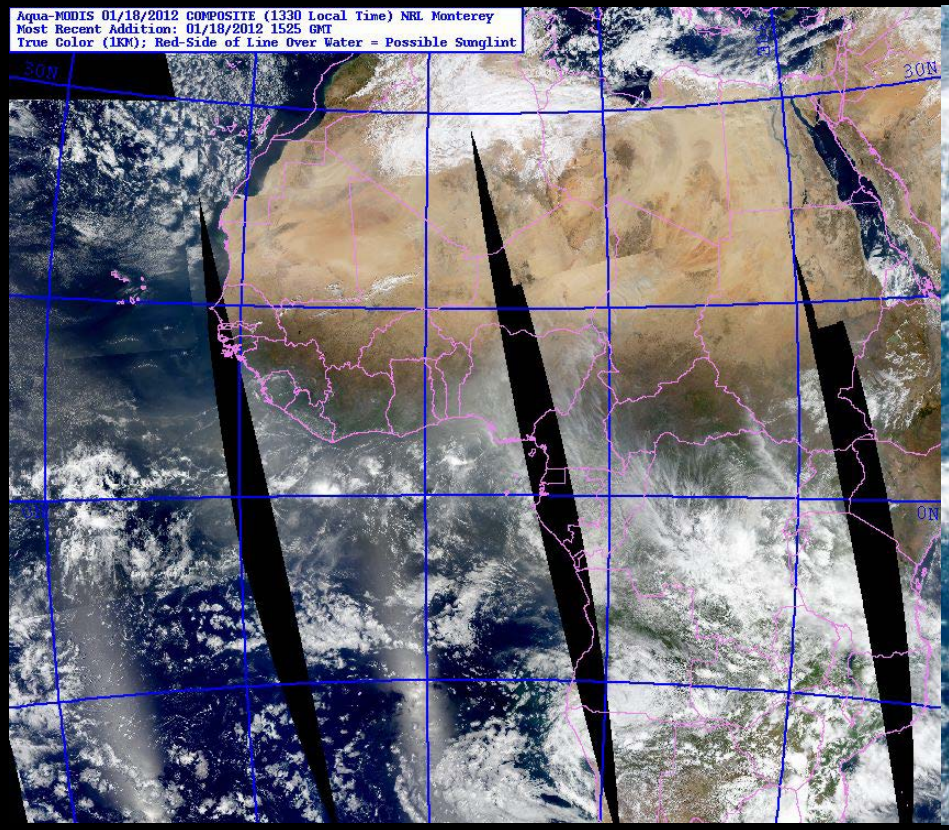
VIIRS has no coverage gaps between passes over equatorial regions!



MODIS

VIIRS

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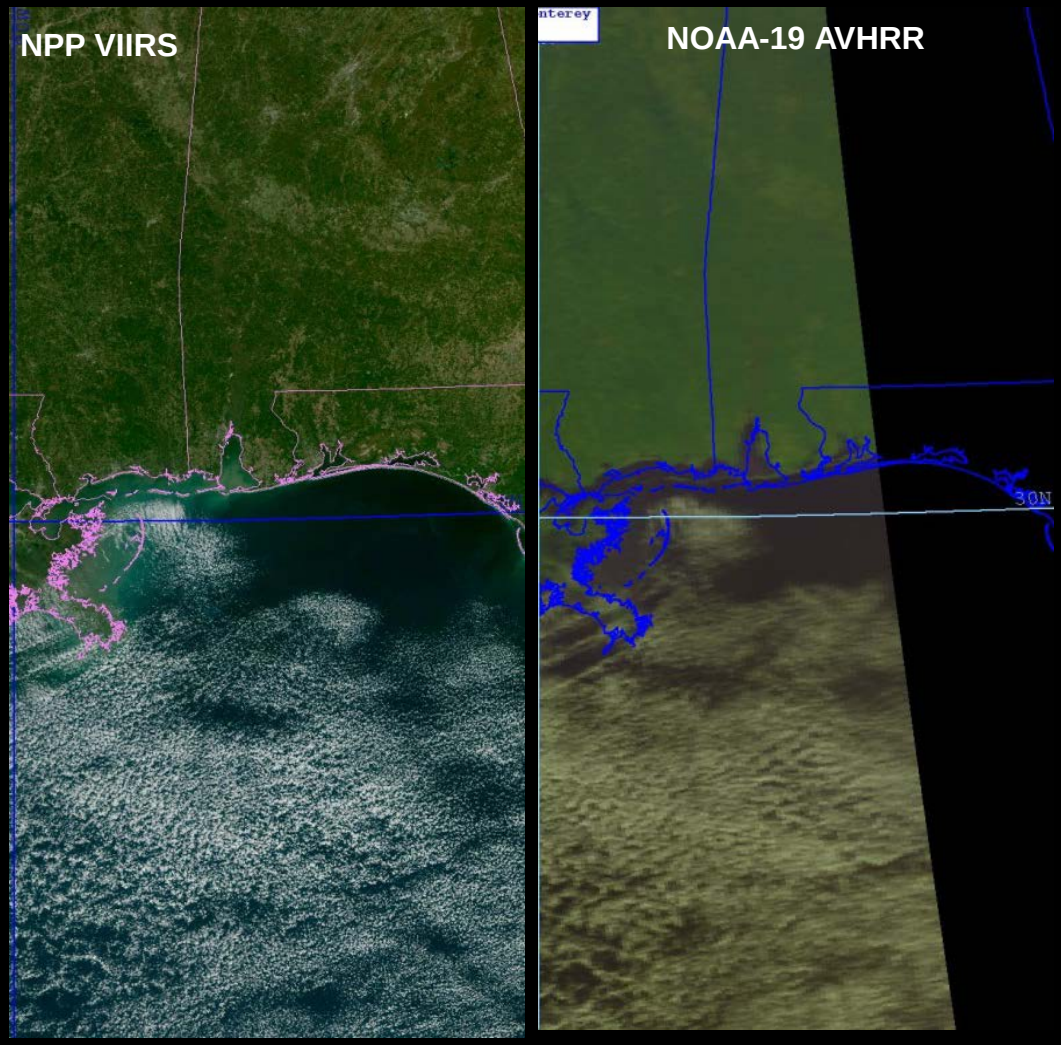
Credit: NRL-Monterey and NASA

VIIRS spectral coverage and spatial resolution are much better than AVHRR, enabling remarkably superior data products



Credit: NRL-Monterey and NOAA

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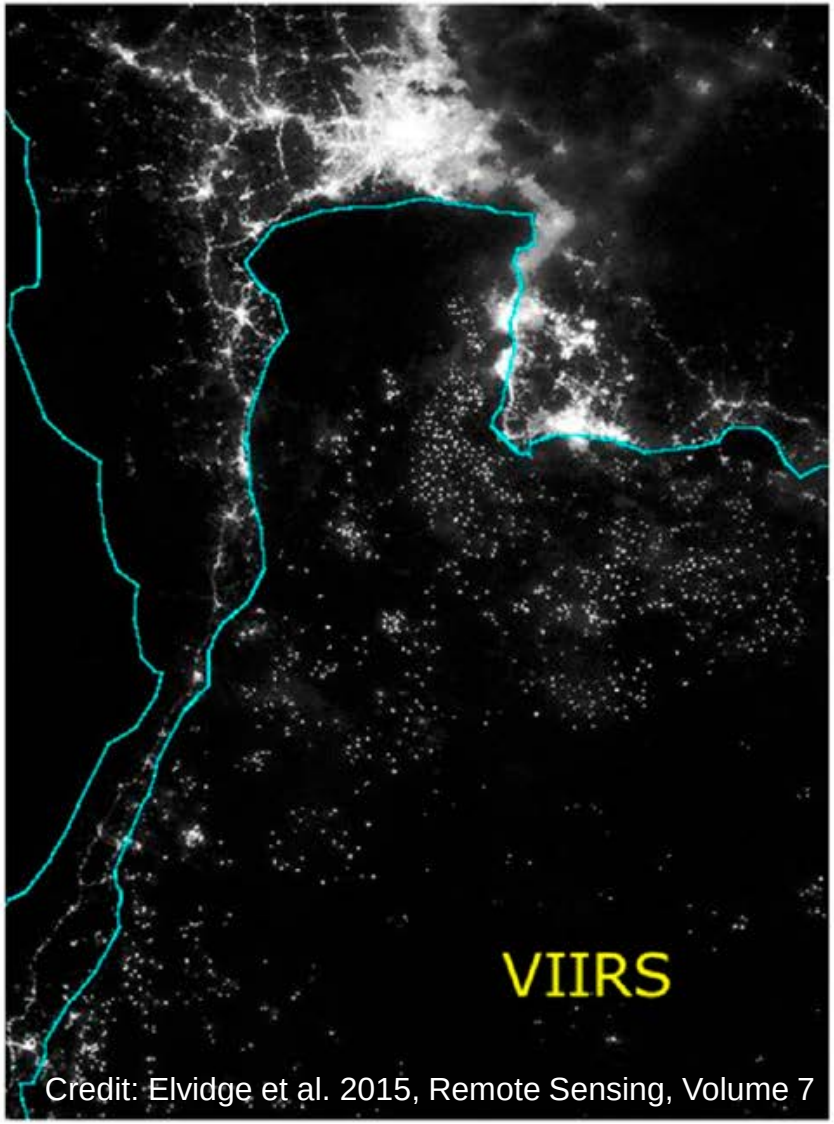
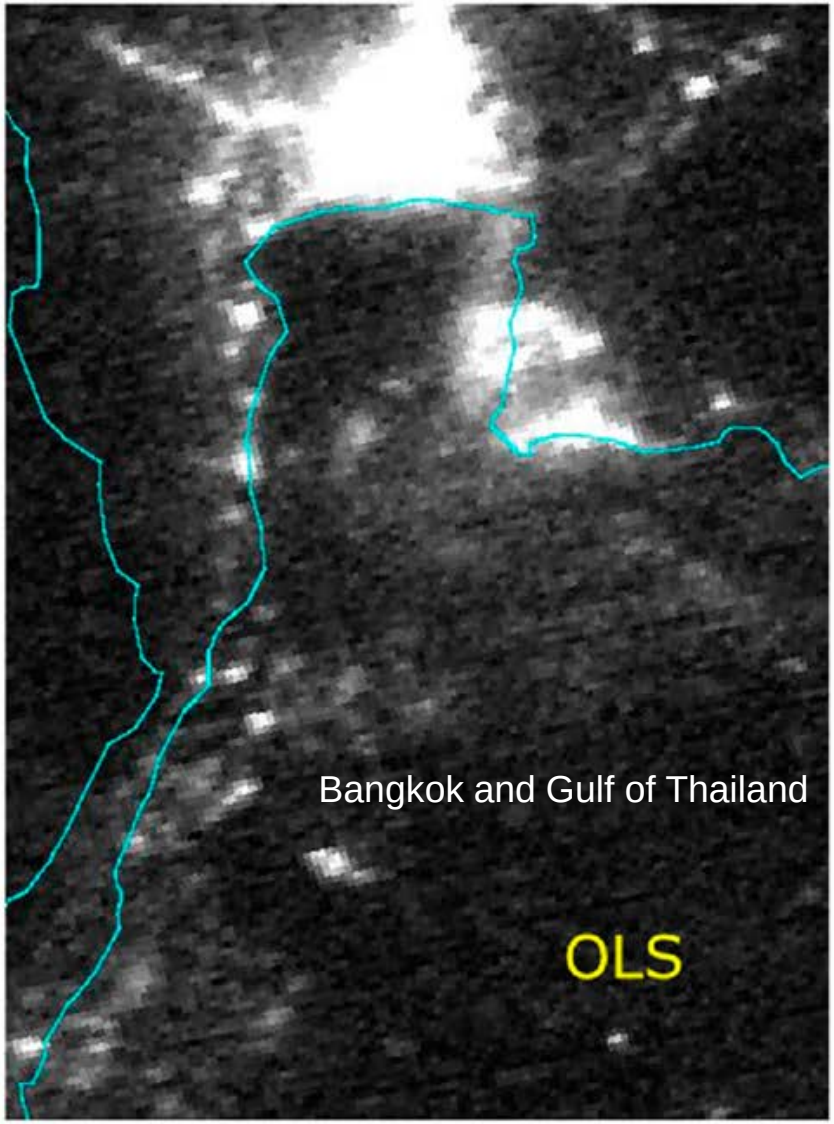
VIIRS DNB offers much better sensitivity and spatial resolution than DMSP OLS



Credit: Elvidge et al. 2015, Remote Sensing, Volume 7



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The best is yet to come! Innovations in the user community will increase the value of VIIRS immeasurably! One example is new applications of the VIIRS DNB, with much of that work being led by Dr. Steve Miller at Colorado State's Cooperative Institute for Research in the Atmosphere (CIRA)

Artwork Credit: NASA/NOAA

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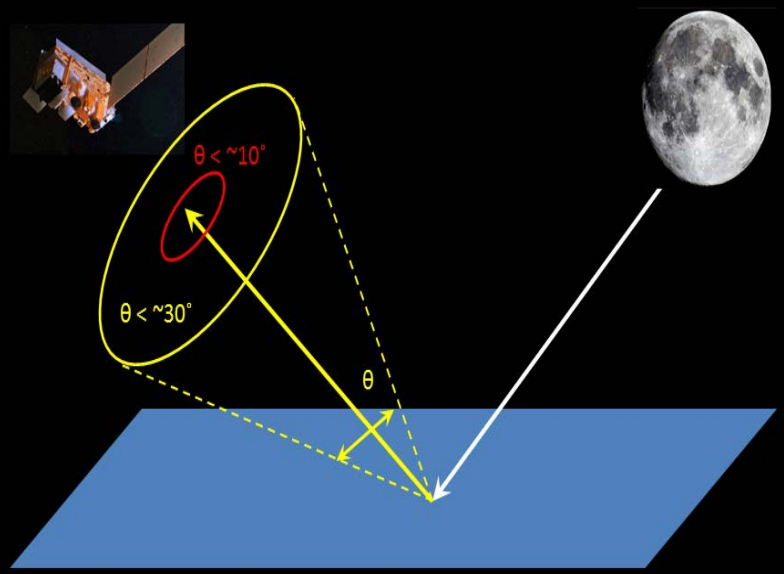
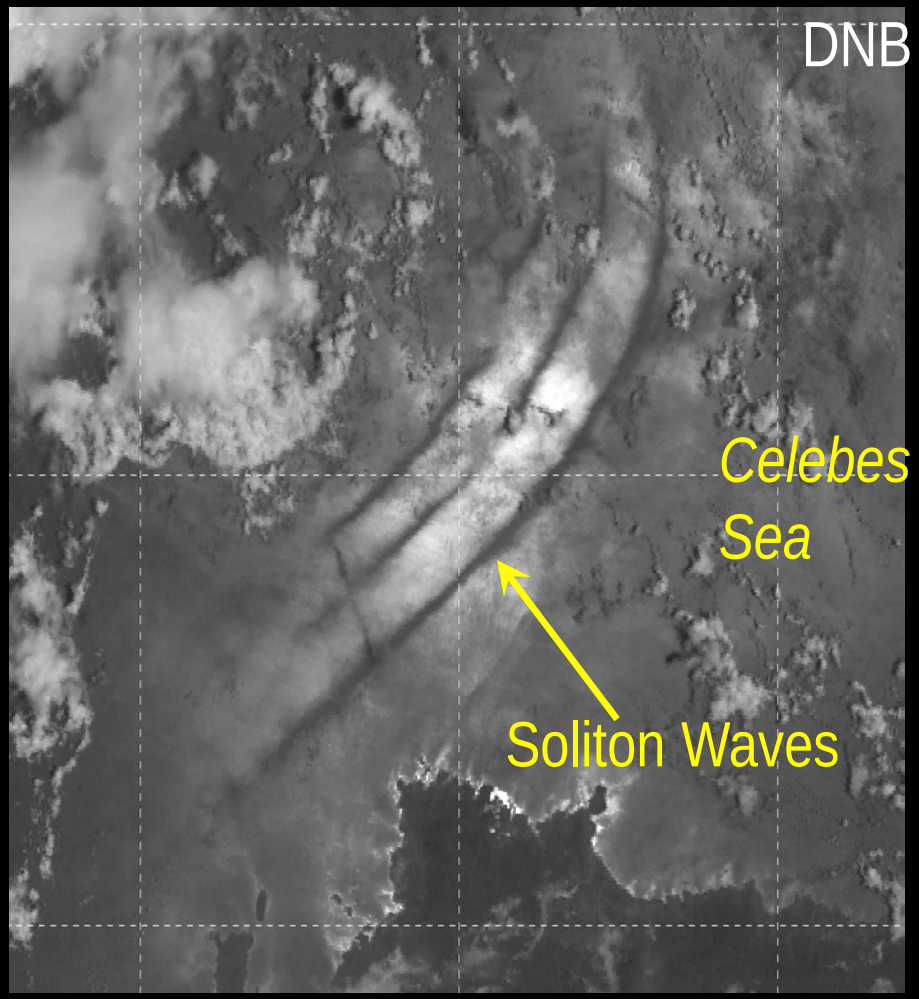
Moon Glint



→ Near mirror reflection geometry reveals information about surface properties.

Uses: ocean surface properties (currents, boundaries, winds, slicks, ship wakes), and cloud heights via lunar shadows



Credit: CIRA

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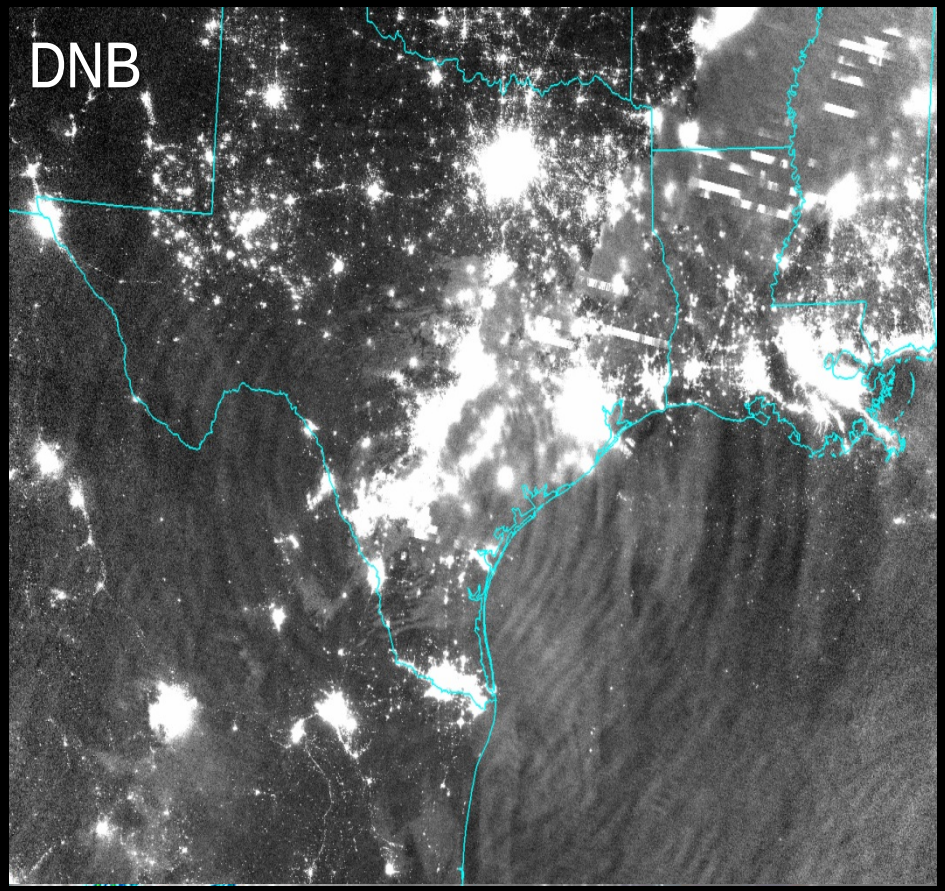
Gravity Waves in Nightglow



→ *Unprecedented perspective on the global distribution and high-resolution structure of gravity waves near the mesopause.*

→ *Offers new insight on the coupling of the lower and upper atmosphere.*

Credit: CIRA

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Innovation continues! Thanks for your kind attention!

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