Studying the Earth at Night from CubeSats

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Outline

• Introduction – CubeSats are beginning to study nighttime lights and related missions – 3 papers in last year’s SMALLSAT
  – New resources add to DMSP OLS, VIIRS DNB, ISS NightPod capabilities
  – Color, higher resolution, different orbits, different overpass times
  – Our past work demonstrated point-and-stare imaging and showed examples of several cities and regions at 130-100-m resolution

• AeroCube camera details, AC-4, AC-8 MFOV, AC-5, AC-8 NFOV

• New Nighttime Observations from CubeSats
  – Persian Gulf, Los Angeles – Detecting change in urban regions, lighting at urban/wildland interface
  – Texas Gulf Coast and Singapore - Lightning and weather observations
  – East China Sea, Sea of Japan - Ship lights from CubeSats
  – Rio de Janeiro - Imaging in the South Atlantic Anomaly

• Conclusions and Future Work

Acronyms: AeroCube (AC), Medium Field of View (MFOV), Narrow Field of View (NFOV), Visible Infrared Imaging Radiometer Suite (VIIRS), Day-night-band (DNB), International Space Station (ISS), Defense Meteorological Support Program (DMSP), Operational Line Scanner (OLS)

New work with cameras on Aerospace Corporation 1.5U CubeSats to image the Earth at Night and add to VIIRS and ISS photography results
Introduction - Nighttime Lights - a Potential CubeSat Mission

• The use of nighttime light signals for monitoring the global human footprint has been established by DMSP OLS and VIIRS DNB work
  – City lights, transportation grids, urban growth and change, light pollution, natural gas flaring, biomass burning
  – Work with ISS photography & CubeSats shows utility of higher resolution
  – Past work “The Nightsat Mission Concept” proposed mission requirements

• We are using existing Aerospace Corporation CubeSats with small on-board CMOS cameras to research nightlights imaging
  – Demonstrate capabilities of CMOS cameras on different AeroCubes
  – Determine if and how CubeSats complement the VIIRS DNB capability
    • Different orbits can sample early evening hours
    • Different spectral bands – (such as RGB color)
    • Higher resolution over a smaller field of view. We demonstrate point-and-stare imaging and show examples at 100-130-m resolution

Measuring nighttime lights is a promising CubeSat mission. 3 papers last year on this topic (two with data). Existing CubeSat cameras approach Nightsat study requirements
AeroCube Camera Details: Specifications

- 1600x1200 pixel 10-bit color RGB Bayer pattern CMOS arrays.
- Autoexposure was the only camera mode available for operations and images were downlinked using jpeg compression.
- The ON Semiconductor chips used are very compact, reasonably low-noise devices with decent low light sensitivity and have been reliably flown on many recent Aerospace Corporation CubeSats.

Cameras were not specially designed for nighttime measurements, but worked remarkably well. Other spacecraft details, including ACS, are documented in references.
AeroCube Camera Details: Techniques for Nighttime Ops.

• “Point-and-stare” nighttime imaging from the AC-5 and AC-8 NFOV and MFOV cameras (talk last year demonstrated technique)
  – Satellite is programmed to fly to a location, point and stay pointed while taking a number of camera frames, then after a delay, switch pointing to the next location and repeat. Must be done early in eclipse or use a rate gyro to maintain accurate Earth pointing
  – We show new examples using NFOV cameras to image the Persian Gulf, Los Angeles, and Brazil, and the Eastern Pacific Ocean using MFOV for wider area

• Multi-pixel aggregation modes are used to image weather and lightning
  – MFOV camera aggregated by 5x5 pixels to enable 7-8 minute collection of regional weather imagery. Examples shown from Texas and Singapore.

Examples were chosen to highlight utility of higher resolution and color for change detection in urban regions, and to demonstrate staring observations of lightning and weather.
Two Frames: Rumaila Gas Flares and Kuwait City

Two frames in a multi-point collection sequence 15 August 2016 22:26 UT using AC-5 NFOV camera
Kuwait City 2013 - 2016: Comparison of ISS and AC-5

Development of coastal neighborhood evident in the sequence of ISS and AC-5 data. Other subtle changes also appear.
Kuwait City 2016 – 2017: Color Changes Noted

A shift from blue/green (likely mercury vapor) to yellow (high pressure sodium) is noticeable in two regions. Elliptical orbit varies GSD and FOV.

AeroCube-5 NFOV camera
~ 130m GSD 15 Aug 2016 red arrows mark blue/green neighborhood lighting

AeroCube-5 NFOV Camera (low altitude pass)
~ 90m GSD 18 May 2017 red arrows mark blue/green to yellow change

A shift from blue/green (likely mercury vapor) to yellow (high pressure sodium) is noticeable in two regions. Elliptical orbit varies GSD and FOV.
Kuwait City 2016 – 2017: Color Changes- Detail

AeroCube-5 NFOV camera
~ 130m GSD 15 Aug 2016 red circles mark blue/green neighborhood lighting

AeroCube-5 NFOV Camera (low altitude pass)
~ 90m GSD 18 May 2017 red circles mark blue/green to yellow change

A shift from green (likely mercury vapor) to yellow (high pressure sodium) is noticeable in two regions. Elliptical orbit varies GSD and FOV.
Los Angeles – Santa Monica Mountains Region

AC-5 19 Sept. 2015 – Exceedingly bright light source spotted near Oxnard. This turned out to be a seasonal greenhouse operation.

AC-5 22 August 2016 – Evolution from yellow sodium lights to blue-green LED lightning is one of many changes in LA lighting since 2010 ISS data.

ISS photography 30 November 2010

Easily tasked CubeSat data provide more regional coverage than ISS, but at lower resolution - add color and improved resolution compared to VIIRS.
Texas Flyby – Severe Weather Near Houston

Imaging Lightning from a CubeSat
129 Frames MFOV Camera 5x5 Pixel Aggregation Mode

AC8C 27 March 2017 16:29:41UT Frame 1-129 New Moon
AC8-C 27 March 2017 16:29:41 UT. Four frames from a 129-frame sequence that images lightning activity from thunderstorms running northeast from Houston, TX.
Singapore Flyby – Imaging Clouds and Lightning Over the Strait

Nighttime Cloud Cover Observation from a CubeSat
160 Frames MFOV Camera 5x5 Pixel Aggregation Mode

AC8C 12 April 2017 16:06:44UT Frame 1-160 Full Moon
AC8-C 12 April 2017 16:06:44 UT. Four frames from a 160-frame sequence imaging the Indonesian archipelago, Singapore, the Strait of Malacca and the Malay peninsula.
Korea Flyby – Maritime Domain Awareness from a CubeSat

AC-8D 29 April 2017 13:36:01 UT. 27-frame sequence covering the East China Sea traveling north over the Korean peninsula. 14% Moon had set.
AC-8D MFOV camera full-resolution 29 April 2017 13:36:01 UT. Four frames from 27-frame sequence covering the East China Sea traveling north over the Korean peninsula
Imaging Rio in the South Atlantic Anomaly
Future Sensors (near term)

<table>
<thead>
<tr>
<th>Satellite Camera</th>
<th>Lens F#</th>
<th>Lens FL (mm)</th>
<th>Pixel Pitch (µm)</th>
<th>Nominal Altitude (km)</th>
<th>GSD (m)</th>
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<tr>
<td>AC-7 (high res)</td>
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- New camera payloads will add to our ability to research the Earth at night from CubeSat platforms.
- 2 NASA Optical Communication and Sensor Demonstration CubeSats (aka AC-7)
- CUMULOS (the CUbesat MULTispectral Observation System) which is hosted on the NASA ISARA (Integrated Solar Array and Reflectarray Antenna) CubeSat
- These were originally scheduled to launch on a Falcon-9 v1.1 rocket along with Formosat-5 and a number of other CubeSat payloads.
- The AC-7 satellites and ISARA are now scheduled to launch 11 October, 2017. After 6 weeks at the ISS they will be boosted to a 500 km orbit and deployed.

Coming next – a higher resolution color camera on AC-7 B, C and CUMULOS, a 3-camera VIS/SWIR/LWIR sensor
References

References (continued)

• All photographs taken from the International Space Station and their meta data are available at “The Gateway to Astronaut Photography of Earth”, which is run by NASA: [http://eol.jsc.nasa.gov](http://eol.jsc.nasa.gov).

• Longcore et al., unpublished analysis of VIIRS data.


Acknowledgments

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Extra Slides
Persian Gulf Flyby – Lights, Clouds, Lightning, Flares

Nighttime Cloud Cover from a CubeSat
174 Frames 5x5 Pixel Aggregation Mode

AC8C 7 May 2017 04:39:57 UT Frame 1-174
Pearl River Delta Flyby – Lightning Over the South China Sea

Demonstration of LEO Lightning Flash Rate Measurement
142 Frames 5x5 Pixel Aggregation Mode

Click movie

AC8C 21 April 2017 18:19:17 UT Frames 1-142
Moscow

Greenhouse Complex is brightest source