Satellite observed nighttime lights as an indicator of human induced stress on coral reefs

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Darksky 2008
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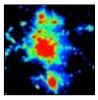
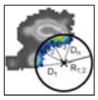
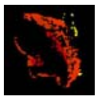
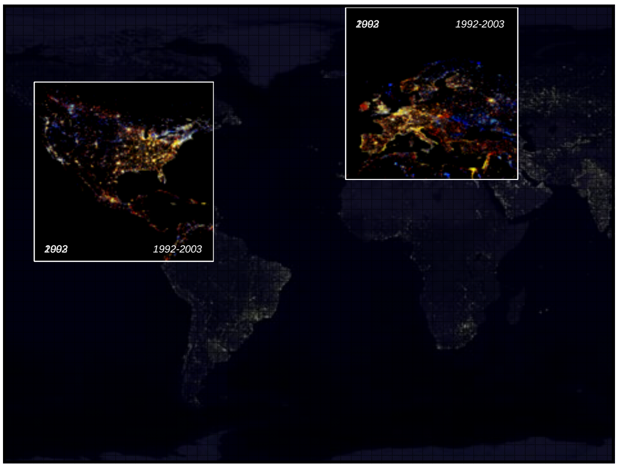
systems research
AUSTRIAN RESEARCH CENTERS

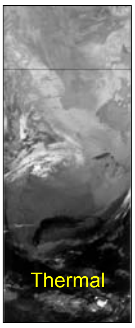
Outline

- Artificial night lighting as seen from space
  - NGDC - Defense Meteorological Satellite Program
- Applications based on DMSP data
  - Gas flaring
  - Population estimation
  - Light pollution …
- Impact of ANL on ecosystems
  - Coral reefs, sea turtles
- Lights Proximity Index
  - Methodology
  - Results for 2003
  - Temporal trends 1992-2003
- Conclusion and outlook



Artificial night lighting as seen from space



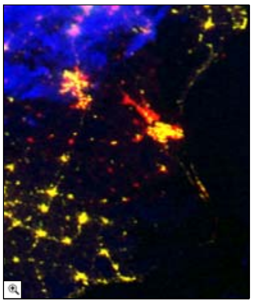
- The U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) has a unique capability to collect low-light imagery
  - Polar orbiting
  - 3000 km swath
  - Two spectral bands
    - Visible and thermal
  - Nightly global coverage
  - Flown since 1972
  - Will continue till ~2012

Applications based on DMSP nighttime lights

- Monitoring of gas flaring ▶
- Population estimation
  - Gridded population of the world
- Power outage detection following natural disasters ▶
- Light pollution
  - First Atlas of light pollution
- Impact of artificial night lighting on ecosystems
  - Potential risk of coral reefs

Power outage detection from hurricane Wilma

- Annual composite
  - Lights (visible band)
  - Cloud free
- Daily imagery
  - Lights (visible band)
  - Clouds (thermal band)
- RGB composite
  → Change detection
  - R
  - G
  - B



Elvidge, Aubrecht, Baugh, Tuttle, Howard (2007) *Satellite detection of power outages following earthquakes and other events*. International Geohazards Week. ESA/ESRIN, Frascati Rome, Italy.

Applications based on DMSP nighttime lights

- Monitoring of gas flaring
- Population estimation
  - Gridded population of the world
- Power outage detection following natural disasters
- Light pollution
  - First Atlas of light pollution
- Impact of artificial night lighting on ecosystems
  - Potential risk of coral reefs

Ecological impact of artificial night lighting

- Nocturnal lighting can have direct effects on ecosystems
  - Rich, C., T. Longcore (2006) *Ecological Consequences of Artificial Night Lighting*. Island Press, Washington DC.

Examples:
  - Effects of artificial night lighting on migrating birds
    - Gauthreaux Jr. and Belser in Rich and Longcore (2006)
  - Threatened sea turtle nesting sites
    - Salmon in Rich and Longcore (2006)
  - Fish response to artificial night lighting
    - Nightingale, Longcore and Simenstad in Rich and Longcore (2006)
  - …

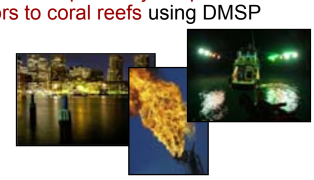
Coral reef related research

- Coral reefs are fragile and being damaged worldwide due to both physical and anthropogenic stressors
  - Physical stressors
    - Heat stress
  - Anthropogenic stressors
    - Development and agriculture resulting in water pollution
    - Overuse (recreation, fishing…)

- Not much is known about interactions of the stressors

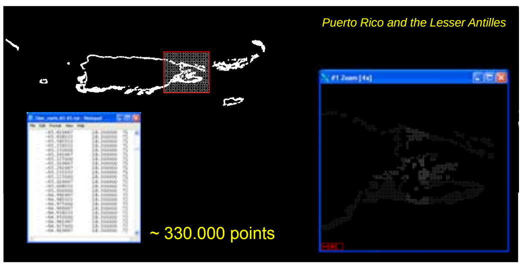
Coral reef related research

- NOAA has a global program to monitor SST (sea surface temperature) anomalies
- To date there has only been one single global survey of anthropogenic stress on coral reefs → 'Reefs at risk'
- The new research objective was to create a globally consistent assessment of the proximity of specific anthropogenic stressors to coral reefs using DMSP nighttime lights
  - Development
  - Gas flaring
  - Heavily lit fishing boats



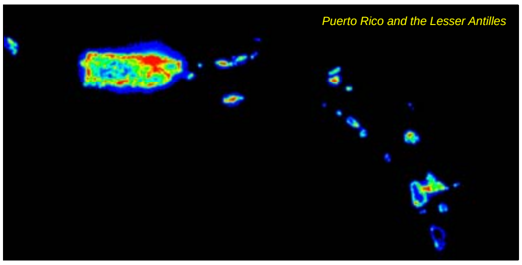
Coral reef related research – Data

- Global spatial compilation of coral reefs
  - Obtained from WRI (1998) – originates from UNEP, WCMC



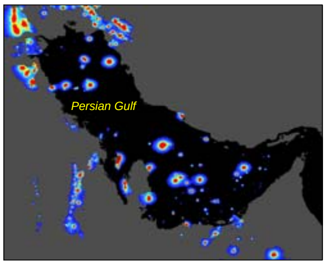
Coral reef related research – Data

- DMSP nighttime lights (2003)
  - Development



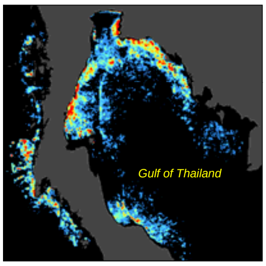
Coral reef related research – Data

- DMSP nighttime lights (2003)
  - Gas flaring



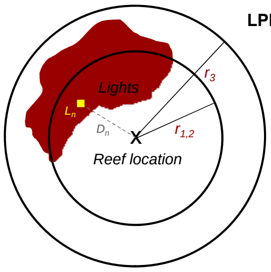
Coral reef related research – Data

- DMSP nighttime lights (2003)
  - Fishing boat activity



Coral reef related research – Methodology

- Lights Proximity Index (LPI)
  - 3 runs



$LPI_{r1,2,3} = \Sigma_{L1...n / D1...n}$

for $r_{1,2} \rightarrow D < 5km$
for $r_3 \rightarrow D < 25km$

$r_{1,2}$ Boats, Flares
5 km
r_3 Cities
25 km

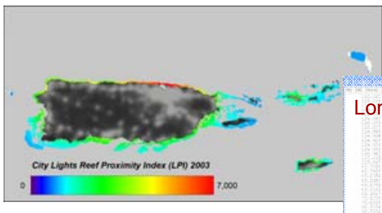
Coral reef related research – Results

- LPI values calculated for each reef point
  - Development
  - Gas flares
  - Heavily lit fishing boats
- Colorized images / maps
  - Rainbow color ramp
  - Standard deviation stretch
- Area ranking
  - By aggregated sum
  - Normalized

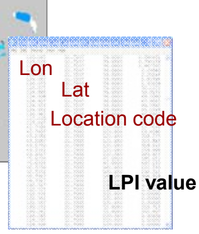
Aubrecht, Elvidge, Eakin (2008) *Earth Observation based assessment of anthropogenic stress to coral reefs – A global analysis.* IGARSS'08: International Geoscience and Remote Sensing Symposium. Boston, MA, USA.

Coral reef related research – Results

- Analysis completed for 2003
  - Map of the coral reefs of Puerto Rico and the Virgin Islands



- Potential threat caused by human settlements



Coral reef related research – Results

- Analysis completed for 2003
  - Area ranking (development)
    - By aggregated sum

	A	B	C	D	E	F
1	Area_Code	Area_Name	Sum_Values	Num_Points	Avg	Lights
2	71	Puerto Rico	4131317.0	2626	1573.24	cities
3	17	Red Sea - Saudi Arabia & Yemen	3087648.3	7712	400.37	cities
4	20	Japan	2524594.3	3283	768.99	cities
5	161	Indonesia	2114366.7	54851	38.55	cities
6	10	Red Sea - Egypt	1904668.0	6018	316.50	cities
7	56	Philippines	1627927.2	31029	52.46	cities
8	70	Jamaica	1071520.0	1459	734.42	cities
9	27	Bahrain	982804.3	653	1505.06	cities
10	107	Martinique	952088.8	733	1298.89	cities
11	33	United Arab Emirates	926504.1	1367	677.76	cities
12	72	Virgin Islands	774166.3	1074	720.83	cities
13	42	India	725356.6	1906	380.56	cities
14	37	Taiwan	722606.1	1024	705.67	cities
15	35	Florida Keys	715185.9	1431	499.78	cities
16	15	Hawaii	658004.1	1302	505.38	cities

Coral reef related research – Results

- Analysis completed for 2003
  - Area ranking (development)
    - Normalized

	A	B	C	D	E	F	G
1	Area_Code	Area_Name	Sum_Values	Num_Points	Avg	Lights	Index_cities
2	175	Singapore	298613.0	61	4895.30	cities	100.0
3	11	Red Sea - Israel & Jordan	49665.9	16	3104.12	cities	63.4
4	115	Barbados	216102.8	124	1742.76	cities	35.6
5	71	Puerto Rico	4131317.0	2626	1573.24	cities	32.1
6	27	Bahrain	982804.3	653	1505.06	cities	30.7
7	75	St. Martin	150364.5	100	1503.65	cities	30.7
8	13	Kuwait	192345.8	128	1502.70	cities	30.7
9	124	Aruba	82273.4	57	1443.39	cities	29.5
10	113	Guam	340563.4	241	1413.13	cities	28.9
11	95	Guadeloupe	568311.4	425	1337.20	cities	27.3
12	107	Martinique	952088.8	733	1298.89	cities	26.5
13	237	Reunion	64480.9	51	1264.33	cities	25.8
14	108	Senegal	53538.4	45	1189.74	cities	24.3
15	90	Northern Mariana Islands	40416.8	37	1092.35	cities	22.3
16	16	Persian Gulf - Saudi Arabia	420661.2	474	887.47	cities	18.1

Normalization in order to account for the varying number of reef points per area

Coral reef related research – Results

- Analysis completed for 2003
  - Area ranking (fishing boat activities)
    - Normalized

	A	B	C	D	E	F	G
1	Area_Code	Area_Name	Sum_Values	Num_Points	Avg	Lights	Index_boats
2	131	Thailand - Gulf of Thailand	92099.1	1180	78.05	boats	100.0
3	117	Thailand West	24993.9	1126	22.20	boats	28.4
4	18	China	17789.8	1726	10.31	boats	13.2
5	52	Vietnam	3243.0	1098	2.95	boats	3.8
6	37	Taiwan	2580.9	1024	2.52	boats	3.2
7	120	Myanmar - Mergui Archipelago	1698.5	799	2.13	boats	2.7
8	56	Philippines	27923.9	31029	0.90	boats	1.2
9	162	Malaysia	1286.9	4061	0.32	boats	0.4
10	161	Indonesia	4489.2	47064	0.10	boats	0.1

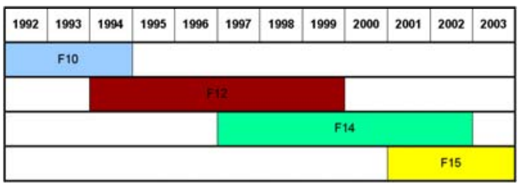
Coral reef related research – Results

- Analysis completed for 2003
  - Area ranking (gas flaring)
    - Normalized

	A	B	C	D	E	F	G
1	Area_Code	Area_Name	Sum_Values	Num_Points	Avg	Lights	Index_flares
2	27	Bahrain	229565.4	653	351.55	flares	100.0
3	8	Iran - Persian Gulf	183261.0	599	305.94	flares	87.0
4	28	Oman	3590.3	12	299.19	flares	85.1
5	31	Qatar	61449.4	808	76.05	flares	21.6
6	10	Red Sea - Egypt	235219.5	3229	72.85	flares	20.7
7	168	Brunei	9515.4	223	42.67	flares	12.1
8	33	United Arab Emirates	57036.4	1352	42.19	flares	12.0
9	16	Persian Gulf - Saudi Arabia	4225.6	474	8.91	flares	2.5
10	199	Australia	7229.6	960	7.53	flares	2.1
11	162	Malaysia	6709.0	2083	3.22	flares	0.9
12	39	Mexico Gulf	81.6	27	3.02	flares	0.9
13	56	Philippines	20733.0	8132	2.55	flares	0.7
14	161	Indonesia	8682.3	3946	2.20	flares	0.6
15	19	Flower Garden Banks	5.4	10	0.54	flares	0.2
16	13	Kuwait	2.4	128	0.02	flares	0.0

Coral reef related research – Time series

- Analysis completed for 2003
- Next step
  - Compilation of a time series 1992-2003
  - Change detection
- DMSP archive



Coral reef related research – Time series

- Analysis completed for 2003
- Next step
  - Compilation of a time series 1992-2003
  - Change detection
- Inter-calibration essential for comparability
  - F121999 → 'brightest' year
- Stable lights used for development and gas flares
  - Noise had been removed
- Raw data used for boats
  - Noise was removed individually for each year and satellite in order to not lose any lights of fishing boat activity

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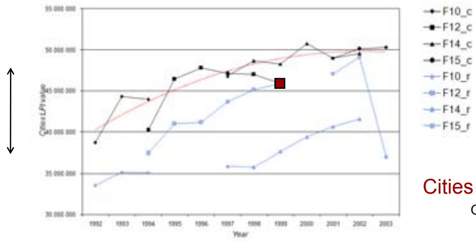
Coral reef related research – Time series

- Analysis completed for 2003
- Compilation of a time series 1992-2003
  - Inter-calibration: F121999



Cities LPI
Global

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systems research

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Coral reef related research – Time series

- Analysis completed for 2003
- Compilation of a time series 1992-2003
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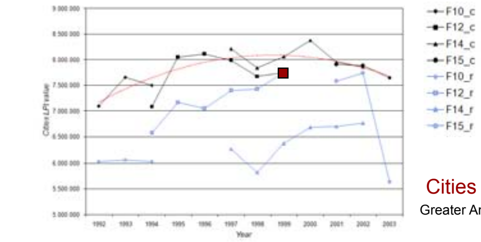

Cities LPI
Greater Antilles

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Coral reef related research – Time series

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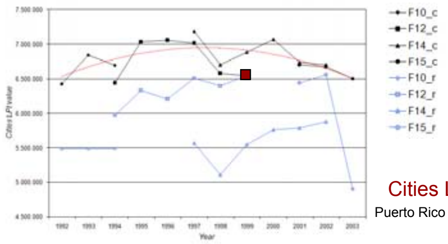

Cities LPI
Puerto Rico & VI

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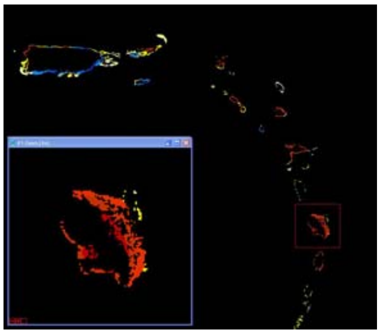
Coral reef related research – Time series



- Visualization of change (1992-2003) in potential stress to coral reefs
  - Blue → Improvement
  - Red → Decline

Cities LPI
Puerto Rico &
Lesser Antilles

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Coral reef related research – Time series

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- Compilation of a time series 1992-2003
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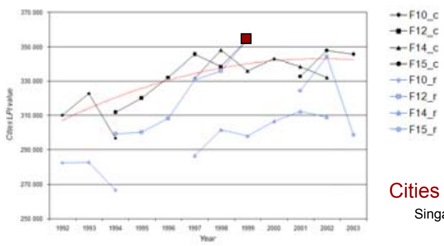

Cities LPI
Singapore

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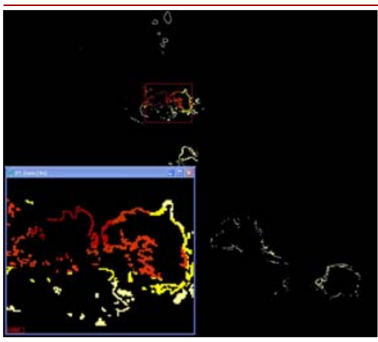
Coral reef related research – Time series



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Singapore

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Coral reef related research – Time series

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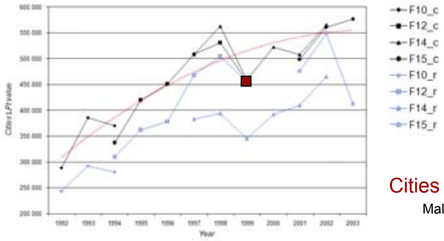

Cities LPI
Malaysia

Coral reef related research – Time series

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- Compilation of a time series 1992-2003
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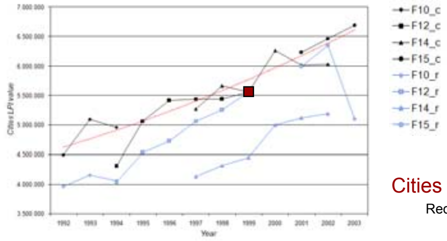
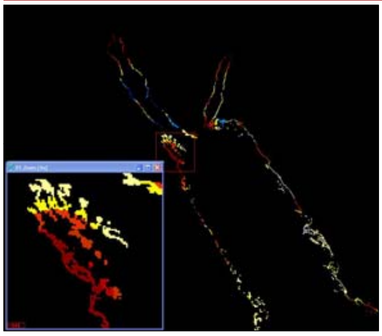


Cities LPI
Red Sea

Coral reef related research – Time series



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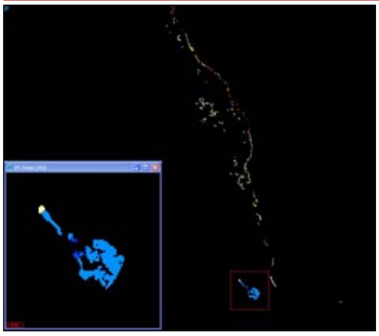
Cities LPI
Red Sea

Coral reef related research – Time series



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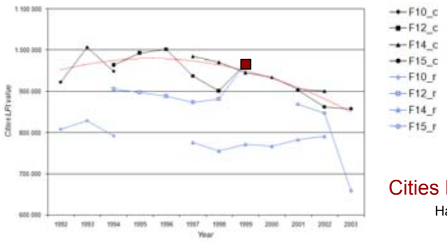
Cities LPI
Red Sea

Coral reef related research – Time series

- Analysis completed for 2003
- Compilation of a time series 1992-2003
  - Inter-calibration: F121999



Cities LPI
Hawaii

Coral reef related research – Time series

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Cities LPI
Hawaii

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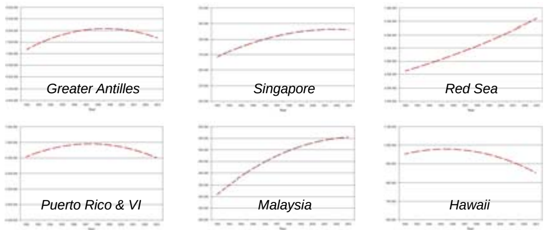
Coral reef related research – Time series

- Analysis completed for 2003
- Compilation of a time series 1992-2003
  - Inter-calibration: F121999

Cities LPI
Examples



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Coral reef related research – Time series

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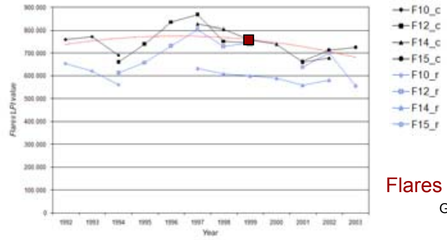

Flares LPI
Global

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Coral reef related research – Time series

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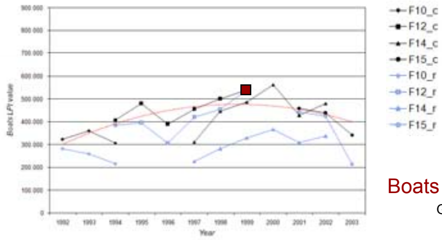

Boats LPI
Global

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Coral reef related research – Time series

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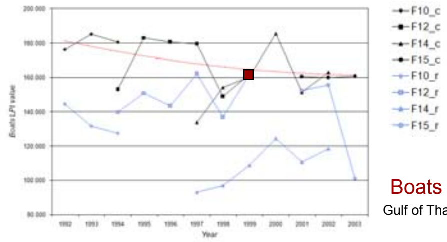

Boats LPI
Gulf of Thailand

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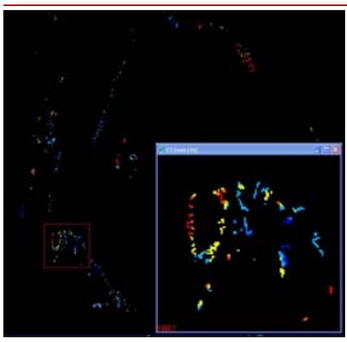
Coral reef related research – Time series



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Boats LPI
Gulf of Thailand

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Coral reef related research – Time series

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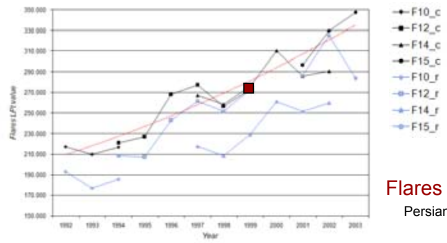

Flares LPI
Persian Gulf

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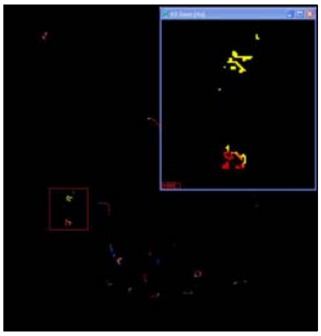
Coral reef related research – Time series



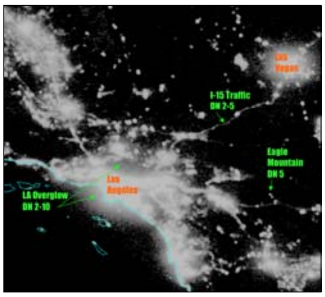
- Visualization of change (1992-2003) in potential stress to coral reefs
  - Blue → Improvement
  - Red → Decline

Flares LPI

Persian Gulf

Conclusion and outlook

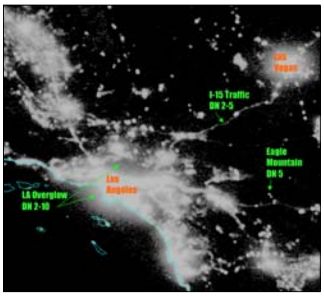
- Shortcomings of DMSP lights



- Coarse spatial resolution
  - 2,5 km GSD
- OLS lights are larger than sources on the ground → 'Overglow' surrounds bright sources
- No visible band calibration
- 6 bit quantification

Conclusion and outlook

- Shortcomings of DMSP lights



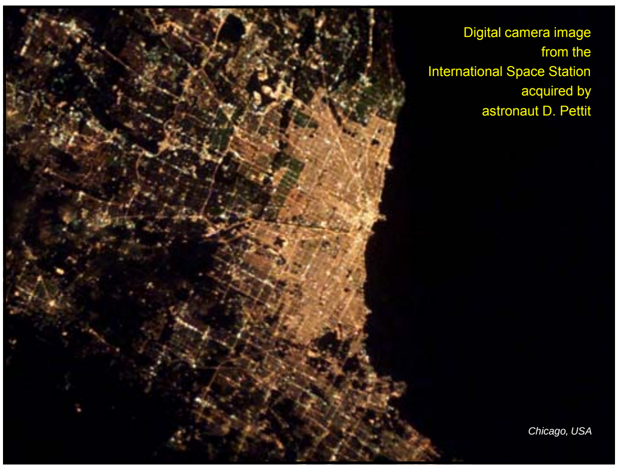
- Urban centers saturate in operational data
- No spectral information on the type of the lighting or changes in lighting type

Conclusion and outlook

- Future possibilities
  - The NPOESS Visible Infrared Imaging Radiometer Suite (VIIRS) will provide improved nighttime lights over the OLS → First launch in 2009-10.
  - NPOESS will fly VIIRS in 6 a.m. / 6 p.m. plus 1 p.m. / 1 a.m. orbits. Metop is considering adding a low light imaging sensors for flights planned a decade+ from now.
  - NOAA had planned a low light imager for GOES-R but this was dropped due to cost considerations.

Higher spatial resolution / multispectral nighttime lights?

- The Nightsat Mission concept

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Thank you for your attention!

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