mapping satellite polygon footprints onto regular grids by tessellation

Seminar Lecture
9th GEMS Science Team Meeting
2 October 2018, Seoul

thomas p kurosu
jet propulsion laboratory, california institute of technology

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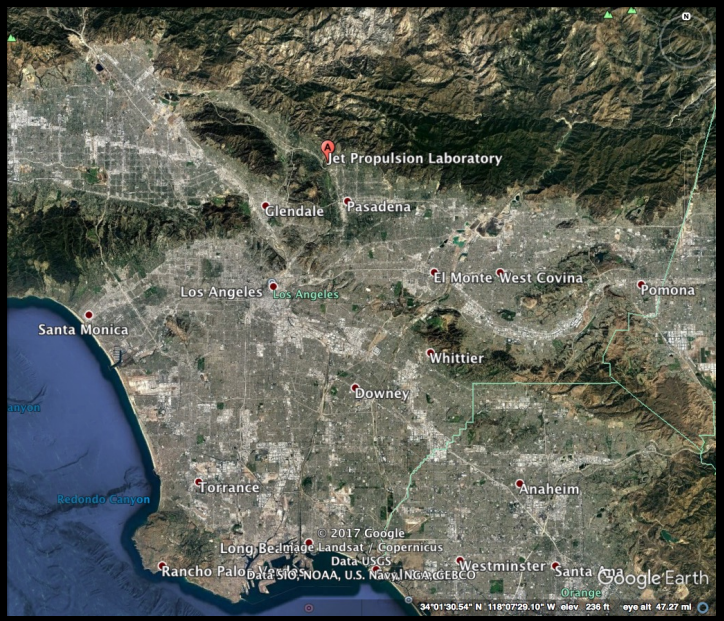
prelude – a bit about jpl



situated in pasadena, california, 20 minutes north of los angeles, in the foothills of the san gabriel mountains

planetary exploration
astronomy/astrophysics
earth sciences

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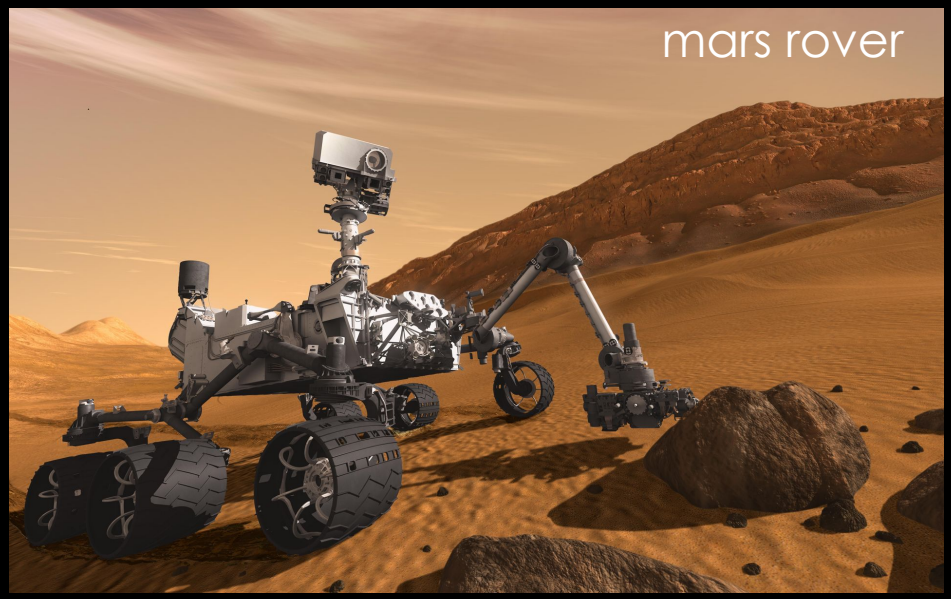
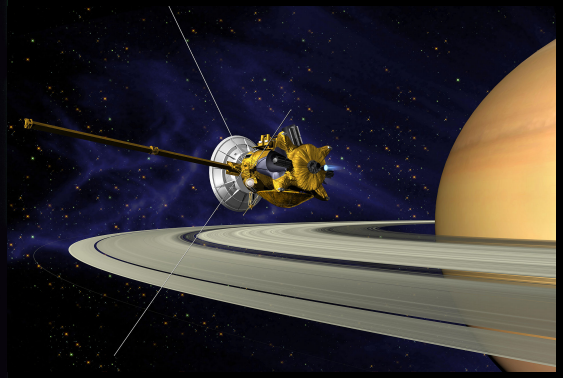
prelude – a bit about jpl





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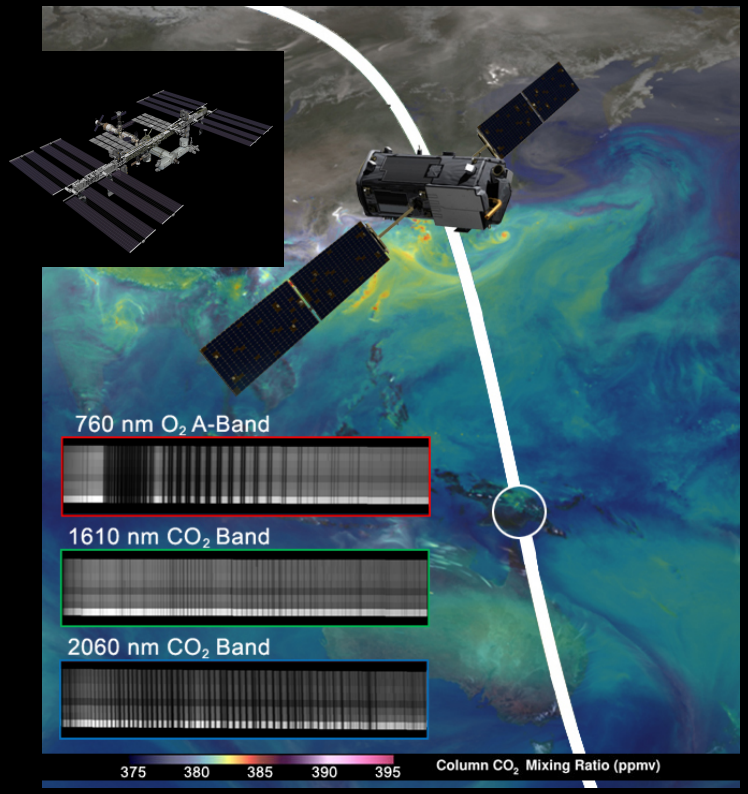
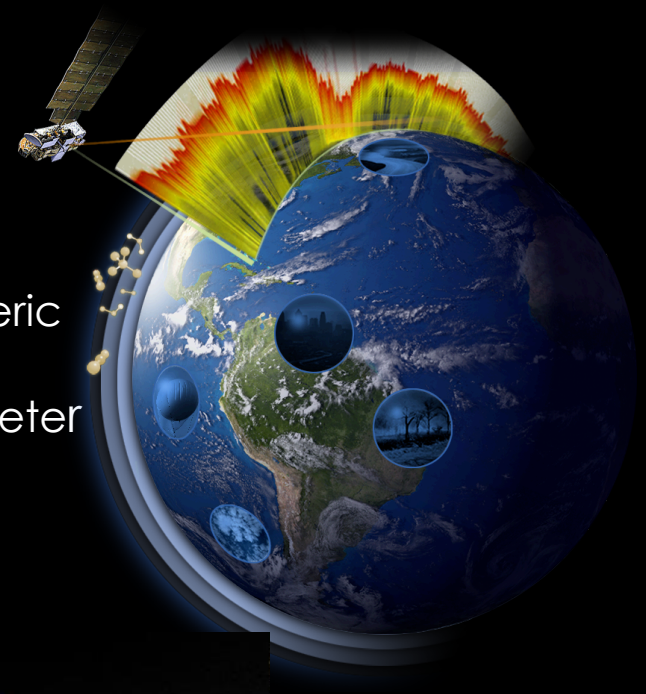
prelude – a bit about jpl

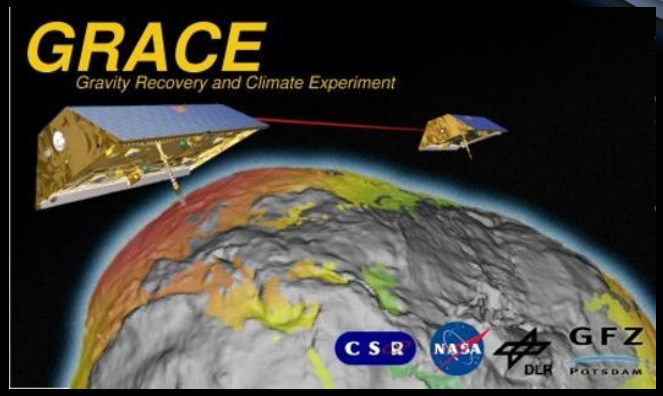
www.jpl.nasa.gov



orbiting carbon observatory 2/3



tropospheric emission spectrometer



gravity recovery and climate experiment

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mapping satellite polygon footprints onto regular grids by tessellation

note
this talk is not so much about science,
but rather about a tool to facilitate scientific investigations

also: the principle is really really simple!

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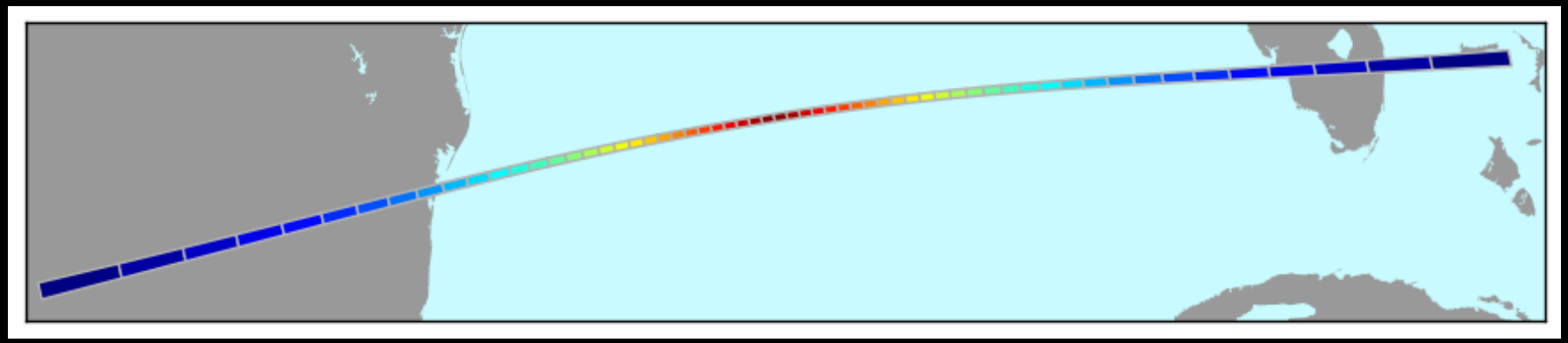
motivation #1

most applications that use satellite data require mapping of the (usually irregular) footprint polygons to rectangular grids, for subsequent averaging or comparison to other data

the commonly used "drop-in-the-box" approach either leads to significant loss of spatial coverage when the grid cells approach the size of the satellite footprint area, or jettisons spatial resolution of the sensor.



example of an OMI swath line
2,600 km swath divided into 60 cross-track pixels
range of pixel size: 340 km^2 (center) to 4,600 km^2 (edges)

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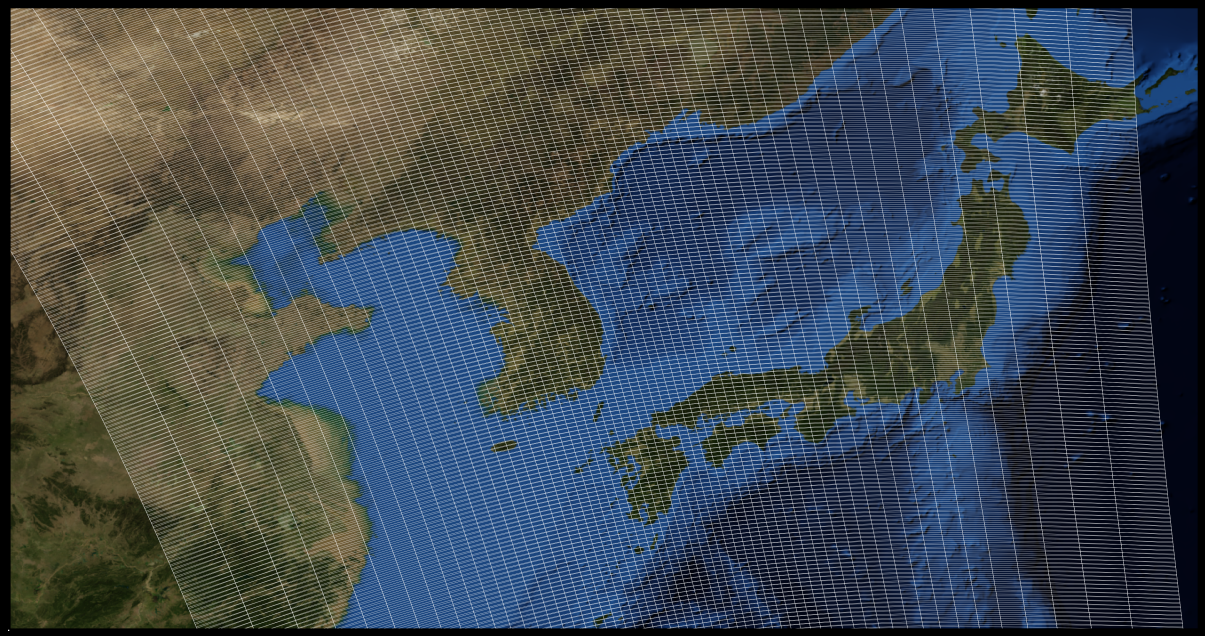
motivation #1



example : OMI orbit 75170 on 2018-09-02

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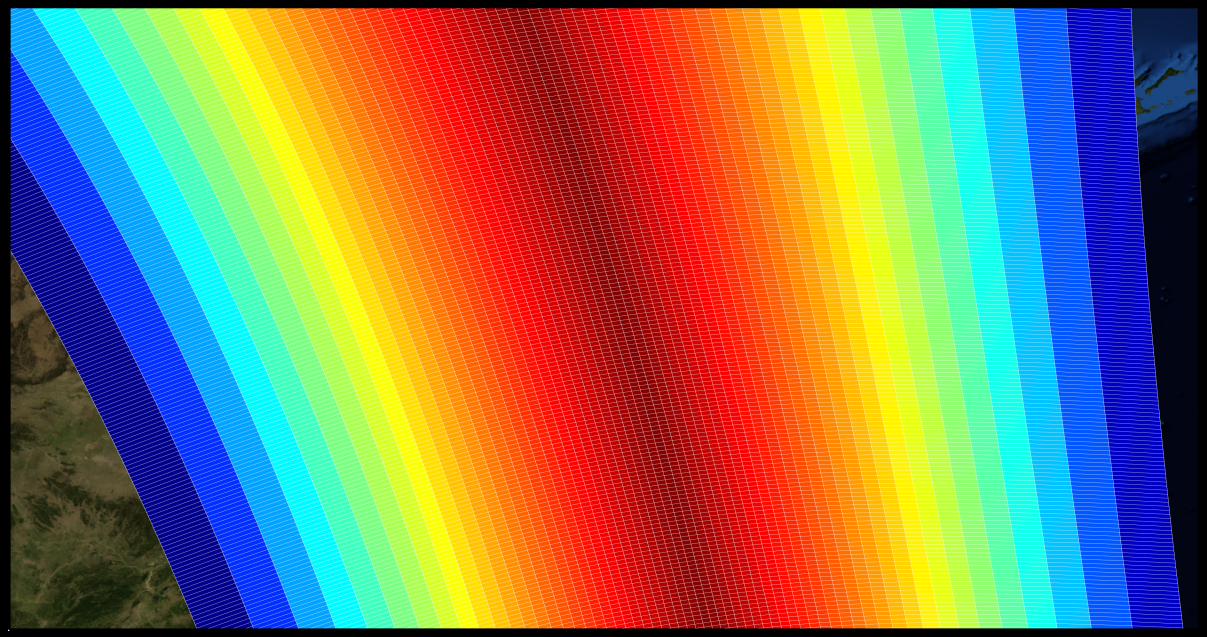
motivation #1



example : OMI orbit 75170 on 2018-09-02
color-coded by footprint area

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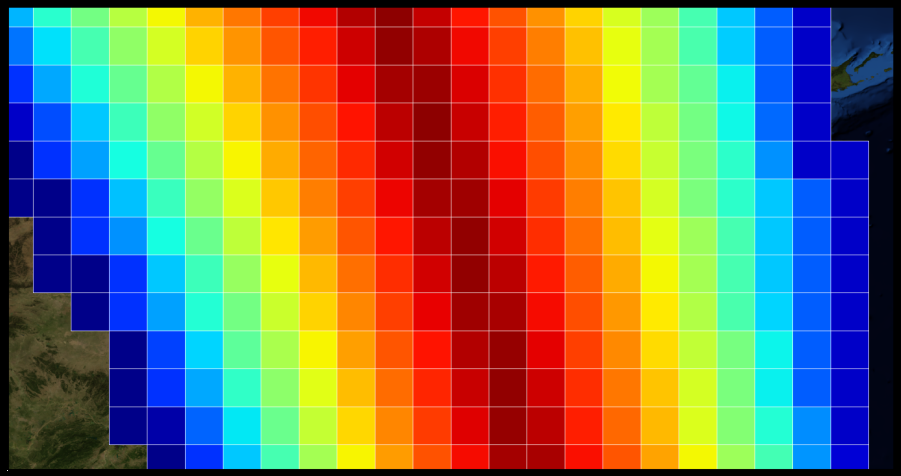
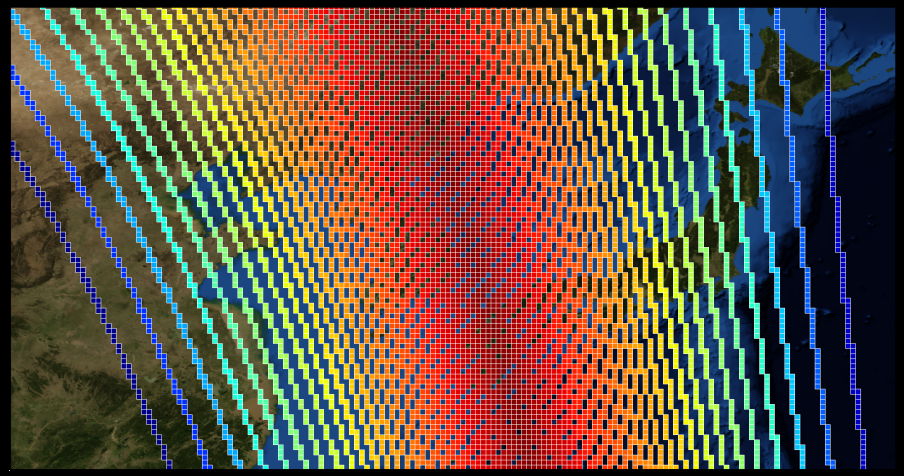
motivation #1

drop-in-the-box gridding



1.5°x1.5° grid
preserves spatial coverage



0.2°x0.2° grid
preserves highest spatial resolution

example : OMI orbit 75170 on 2018-09-02

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motivation #2

comparison/mapping of two or more independent data sets with significantly different spatial resolution on the same spatial grid

e.g.,
satellite vs. satellite
satellite vs. aircraft vs. ground

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motivation #2

GEMS, synthetic
(courtesy Heesung Chong)

OMI 2018-09-02
(OMPIXCOR, tiled)

TROPOMI 2018-09-02
(courtesy M. v. Roozendael)

three satellite data sets with significantly different spatial characteristics

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motivation #3

long-term averaging with high spatial oversampling
may expose features on sub-footprint scale

this depends on the nature of the observations – mainly the variation in the observation target and how the satellite footprints sample them

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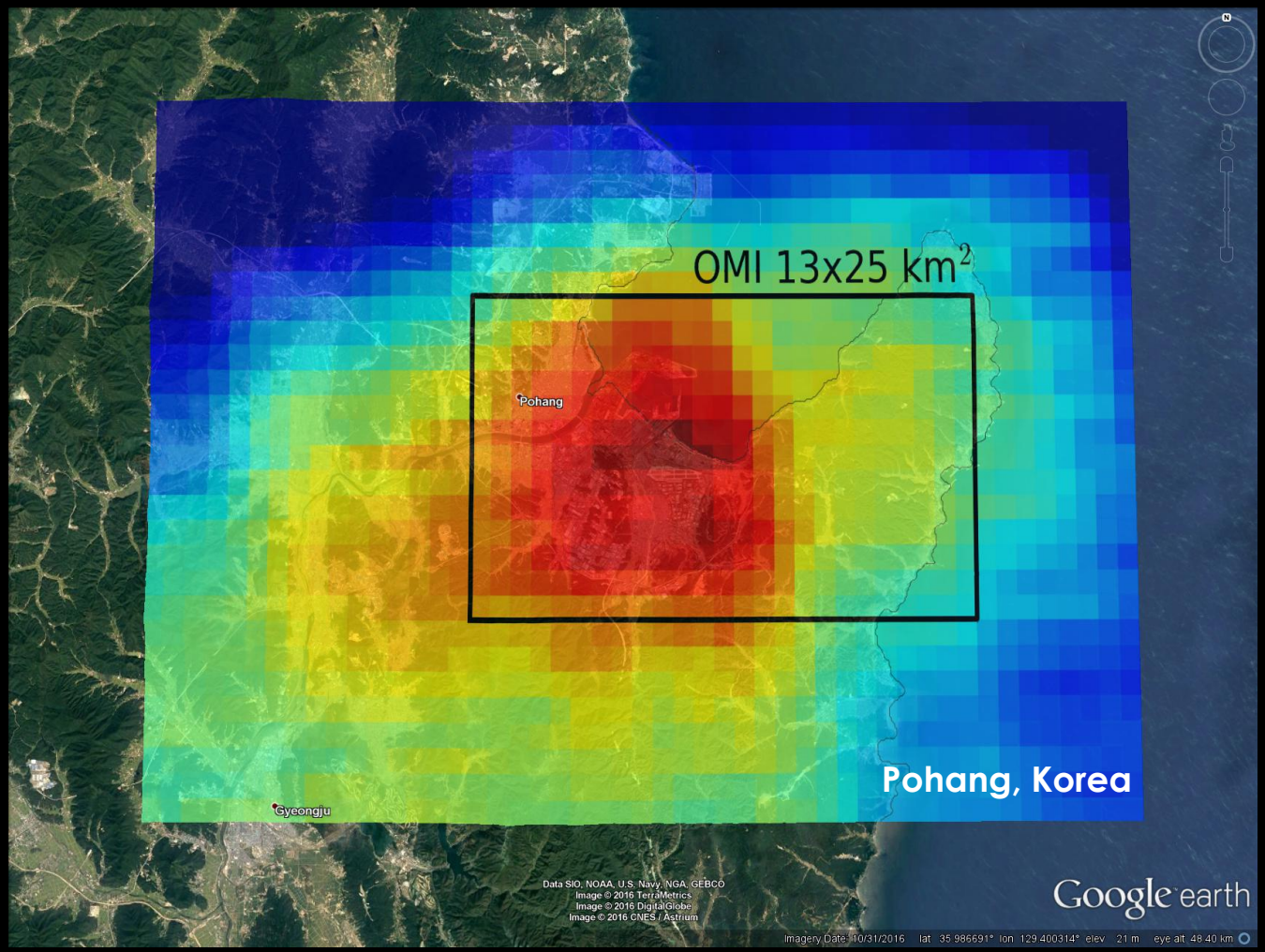
motivation #3



OMI tropospheric NO_2 – 2006, weighted tessellation to 0.01°x0.01°

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the goal

develop an algorithm to map the satellite footprint polygon to a rectangular grid of arbitrary latitude/longitude resolution, without loss of information on spatial coverage

method: tessellation

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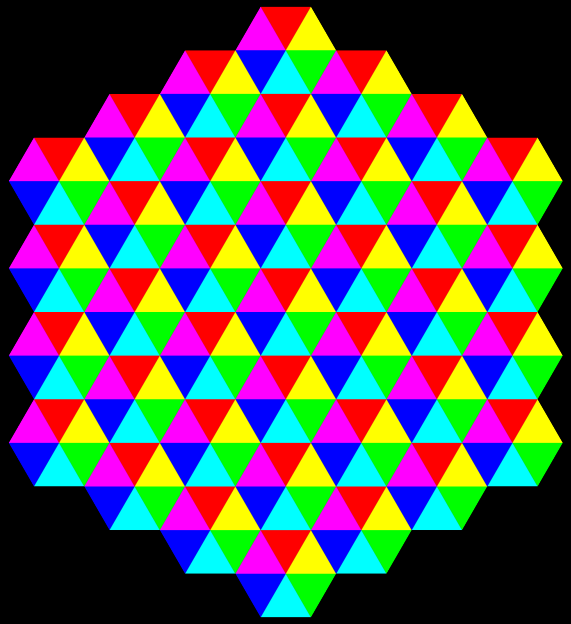
tessellation



tessellation of a flat surface is the tiling of a plane using one or more geometric shapes, called tiles, with no overlaps and no gaps.
(https://en.wikipedia.org/wiki/Tessellation)

(image from https://www.iconspng.com/image/1978/hexagonal-triangle-tessellation)

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the process – overview

1. define a rectangular grid onto which to map the data
2. for each satellite footprint:
    1. determine which grid cells it covers
    2. compute fractional coverage *f* of grid cells by the footprint
3. combine/average output with weights of your choice

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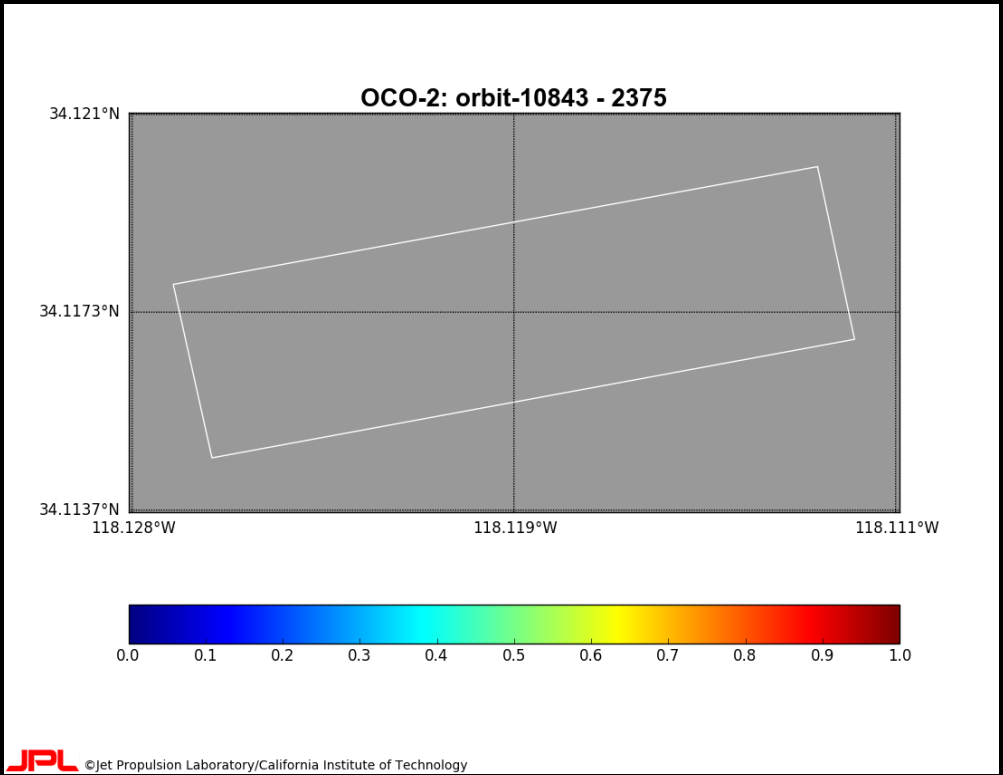
the tessellation process

start with a satellite ground pixel (*e.g.*, OCO-2 target data, ~1x1 km^2)



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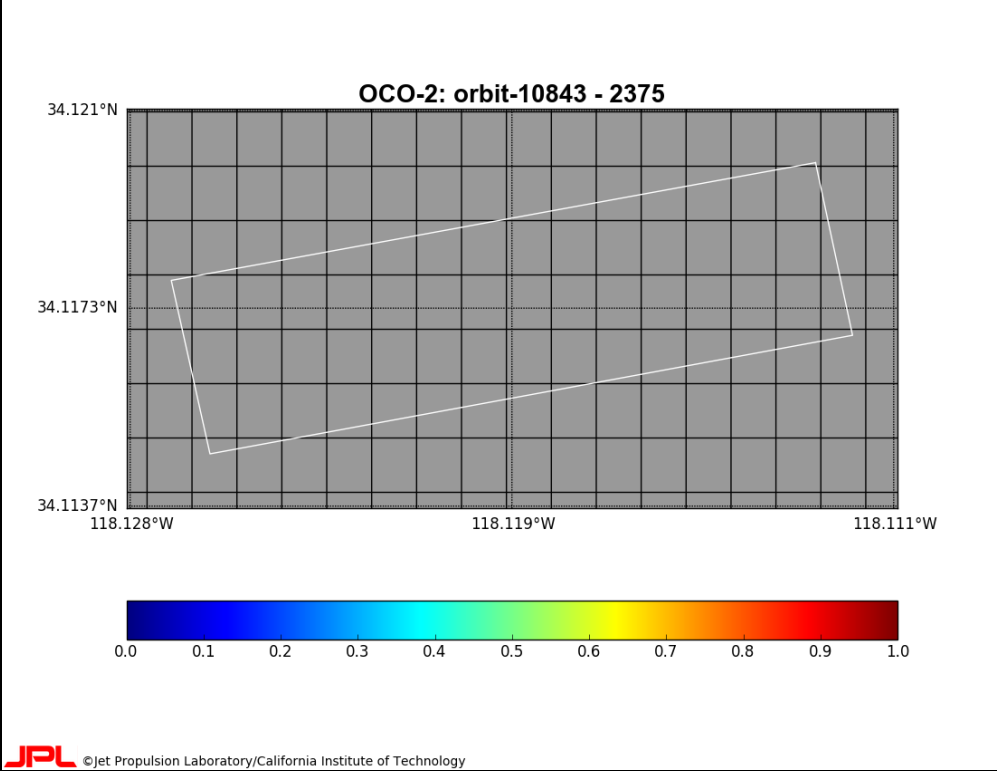
the tessellation process

1. define a rectangular grid, *e.g.*, 0.001°x0.001° resolution (~100 m)



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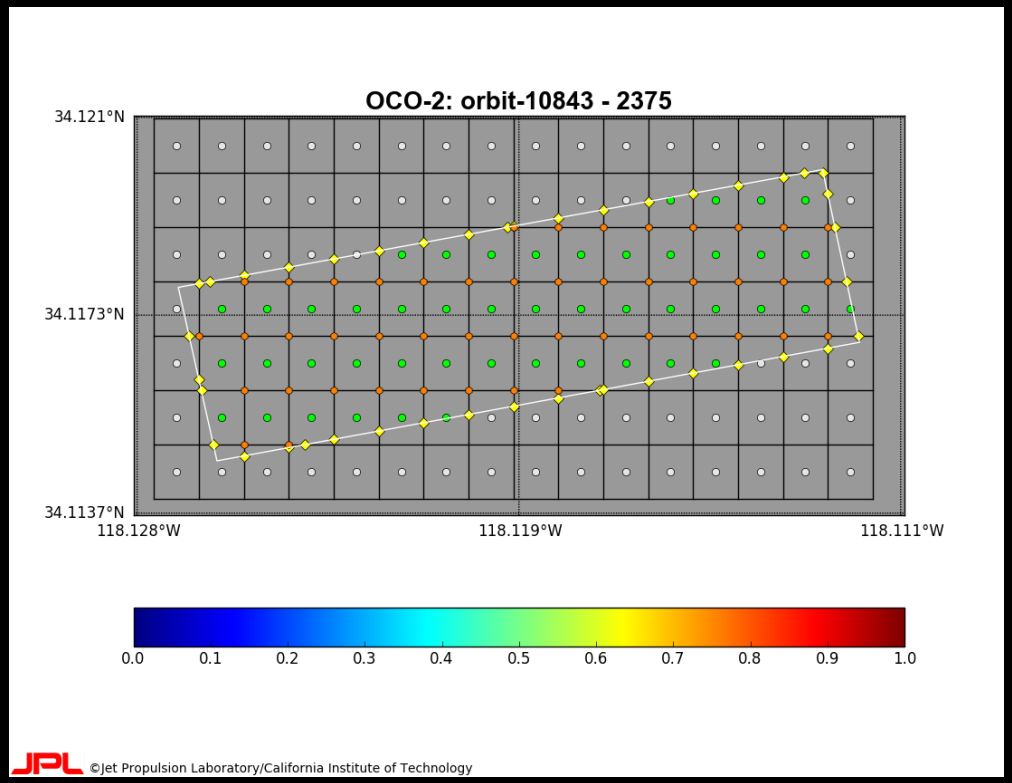
the tessellation process

2.1 calculate intersects of footprint and grid cell boundaries



- line intersects
- grid cell centers inside footprint
- grid cell corners inside footprint

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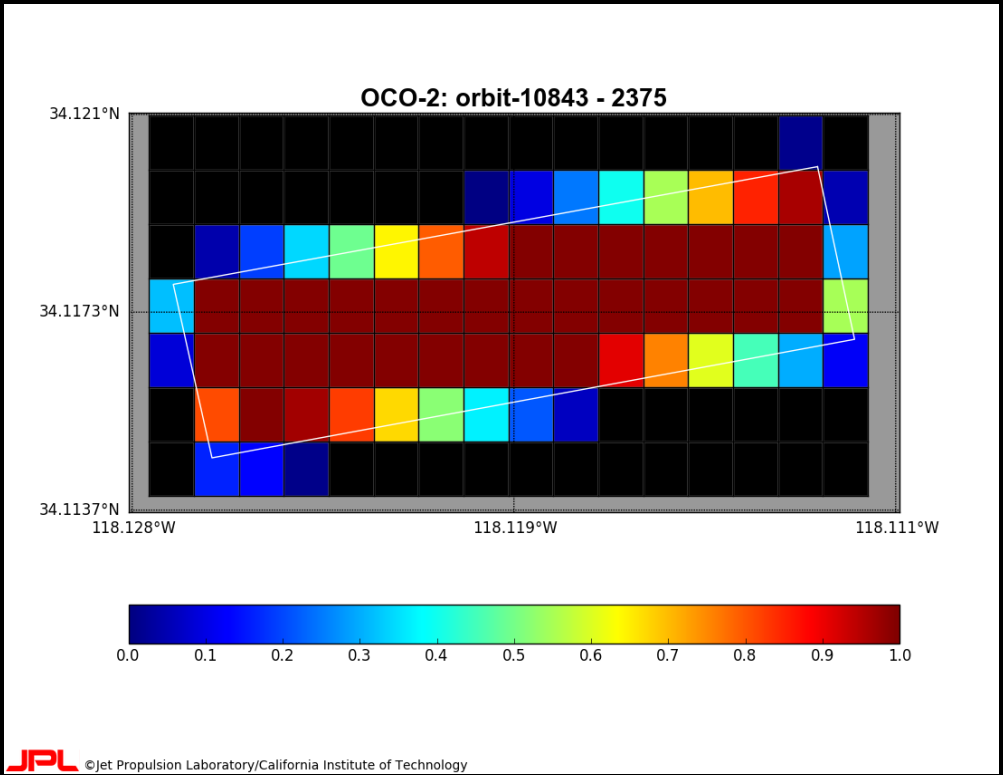
the tessellation process

2.2 Calculate covered cell area by built-in rules (triangles and rectangles)



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the tessellation process

3 Update grid cell values and create (weighted) average

for all footprints *k* that overlap grid cell *i,j*:

$$A_{ij} = A_{ij} + f_{k,ij}$$
$$W_{ij} = W_{ij} + f_{k,ij} \cdot w_k$$
$$V_{ij} = V_{ij} + v_k \cdot f_{k,ij} \cdot w_k$$

final averaging:

$$\bar{V}_{ij} = V_{ij} \,/\, W_{ij}$$

v_k	value of observation *k*
w_k	weight association with observation *k*
$f_{k,ij}$	fractional overlap of footprint *k* with grid cell *i,j*
A_{ij}	cumulative coverage of grid cell *i,j*
W_{ij}	cumulative weight of grid cell *i,j*
V_{ij}	cumulative (weighted) observation of grid cell *i,j*

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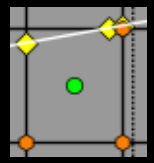
tessellation – built-in rules

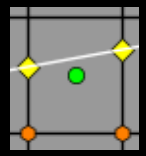
trivial cases:

- grid cell is completely outside footprint: $f = 0$
- grid cell is completely inside footprint: $f = 1$

simple cases:

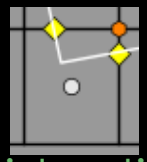
- footprint boundary goes across a cell corner: f is a triangle
- footprint boundary slices cell east-west or north-south: f is a combination of a triangle and a rectangle





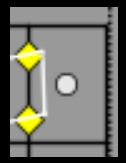
less simple case:

- a single footprint corner inside the grid cell: f is a combination of several triangles and rectangles



anything more complicated: "divide and conquer"

- recursive zoom processing: sub-divide cell with finer grid until built-in rules apply or we run up against the recursion limit



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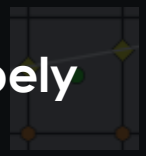


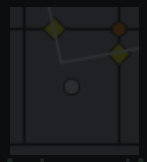
alternatively:

use methods from python polygon packages like **shapely**

(currently under evaluation)

less simple case:

- a single footprint corner inside the grid cell: f is a combination of several triangles and rectangles



anything more complicated: "divide and conquer"

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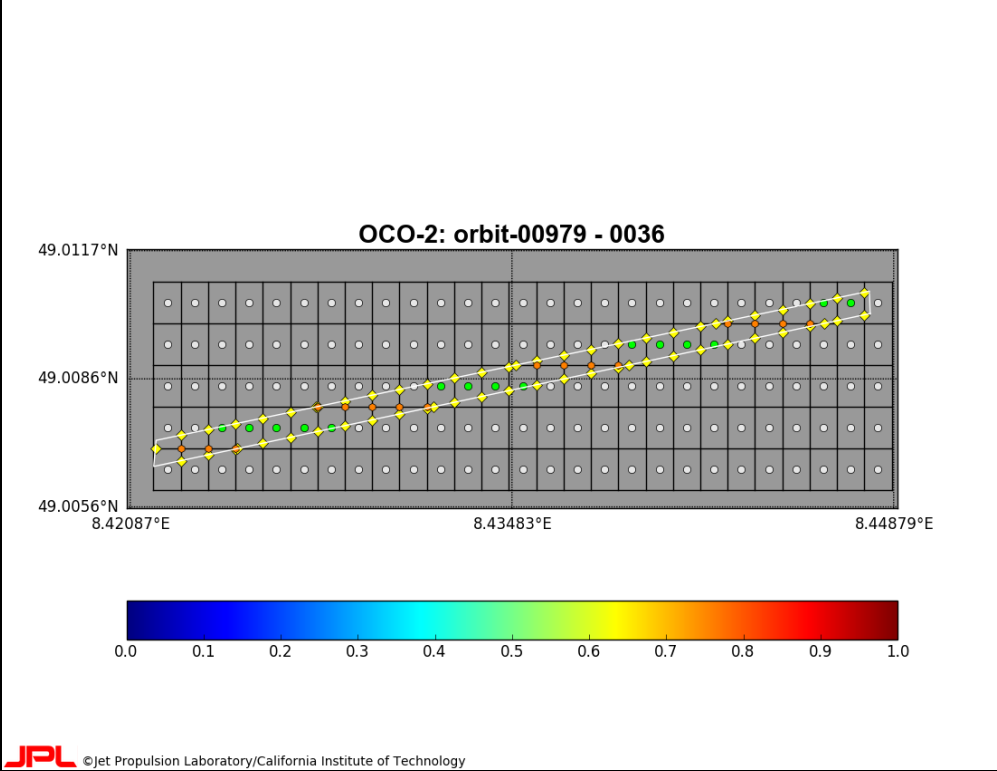
the tessellation zoom process

built-in rules for cell area computations don't cover all geometric cases



in the above case …

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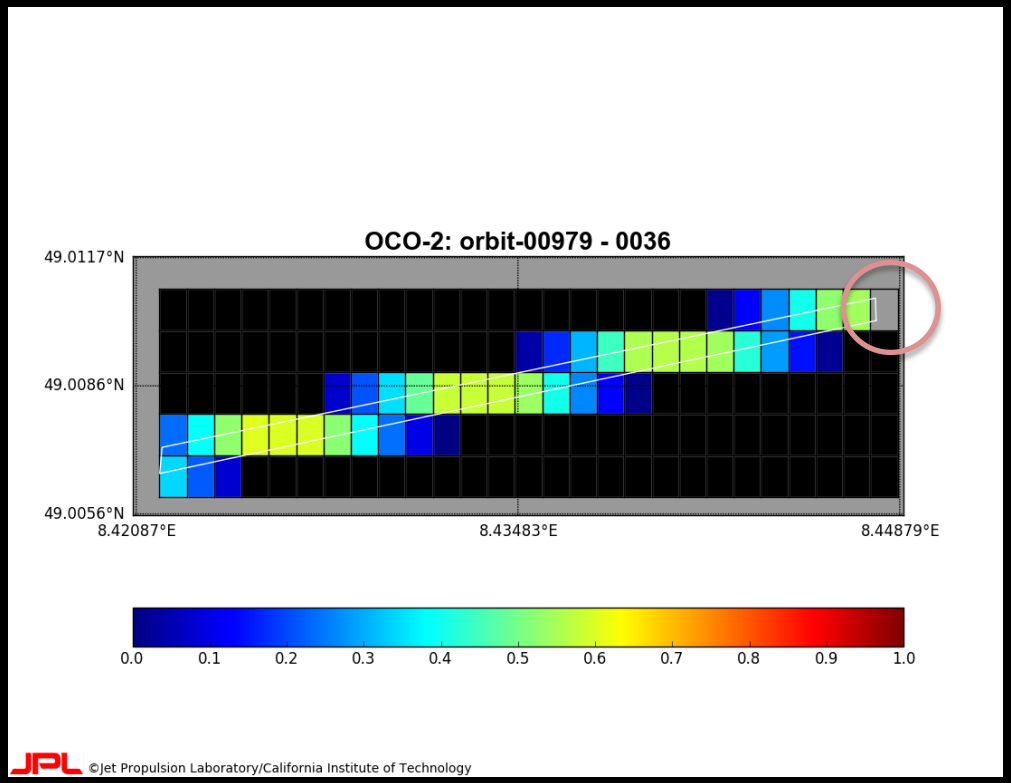
the tessellation zoom process

… the eastern-most grid cell can't be quanfied



all such unquantifiable grid cells enter zoom processing

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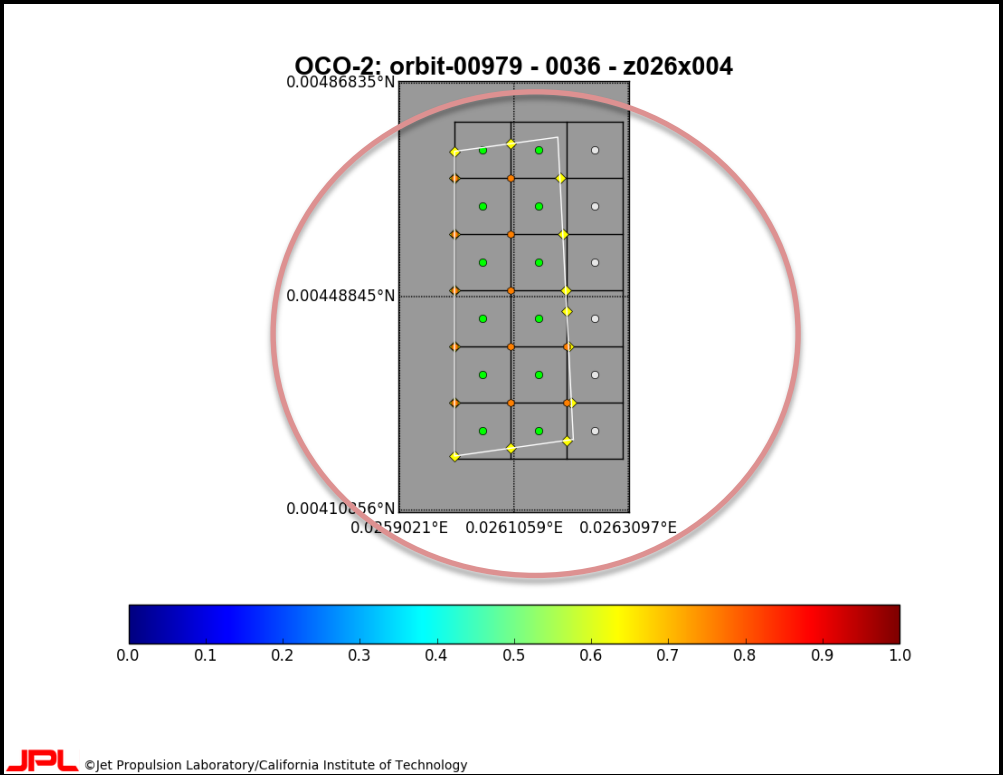
the tessellation zoom process

the grid cell is divided by a sub-grid and processed like the original footprint ...



... in the hope that this defines the coverage area.

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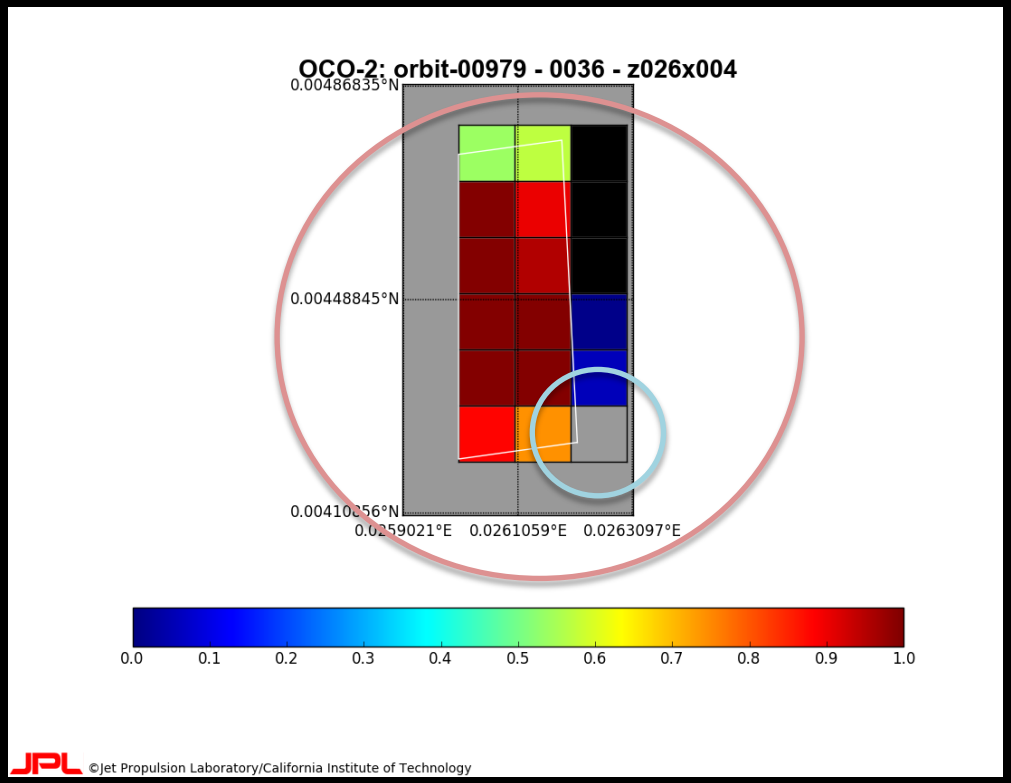
the tessellation zoom process

if this doesn't resolve the sub-cell, the process is continued recursively



… in the hope that THIS defines the coverage area.

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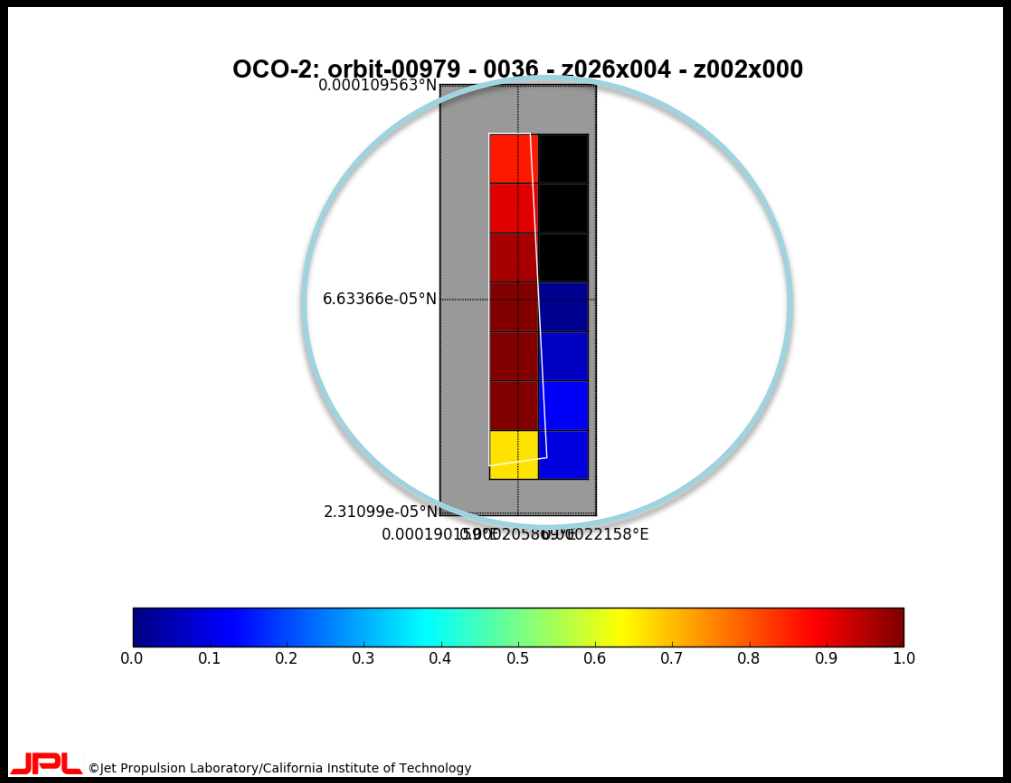
the tessellation zoom process

the recursive iteration stops either if the sub-sub(-sub…) cell is quantified …



or until the limits of the recursion process are reached.

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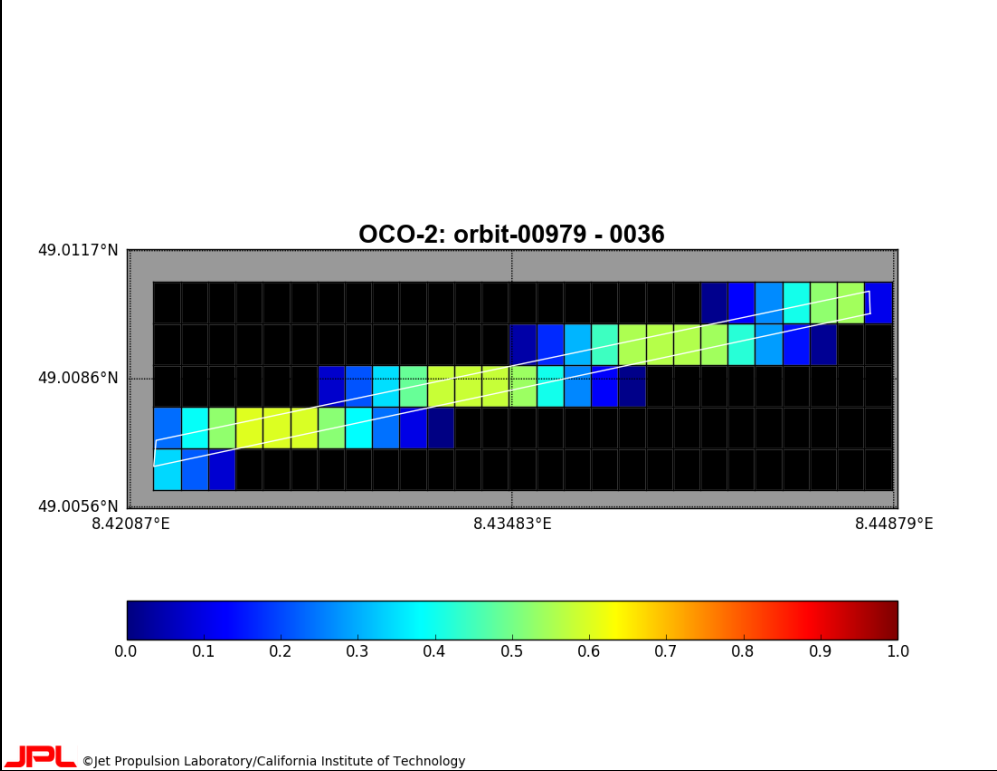
the tessellation zoom process

in this case, two iterative zoom processes resolved the grid cell.



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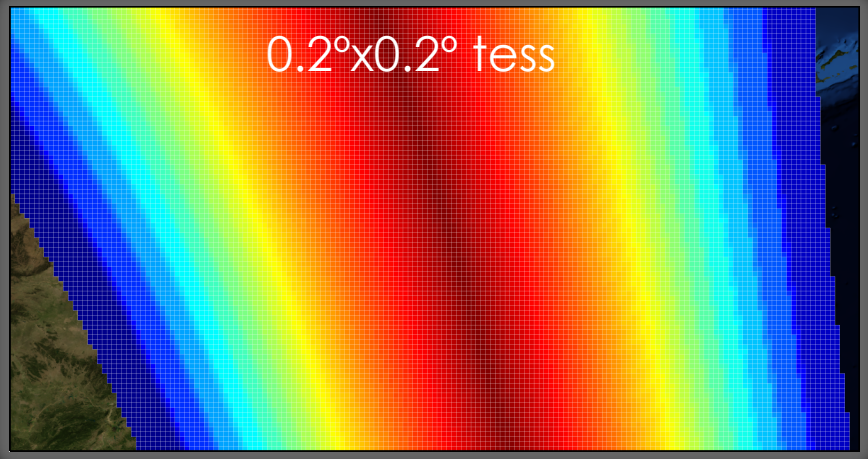
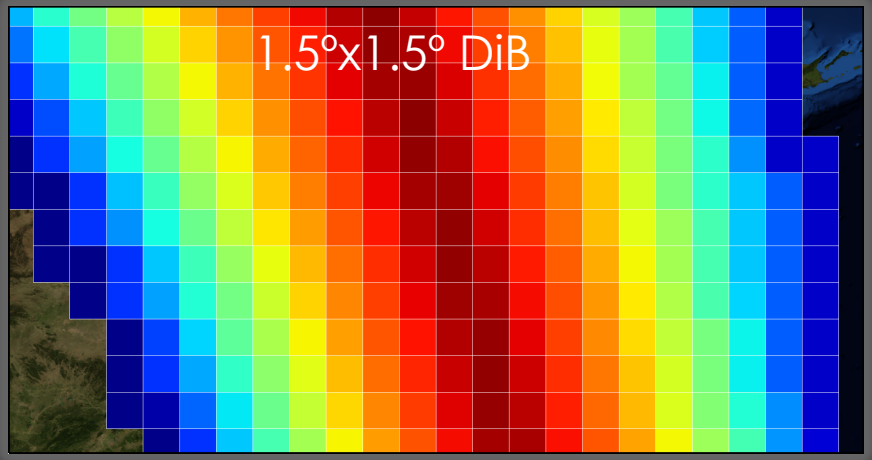
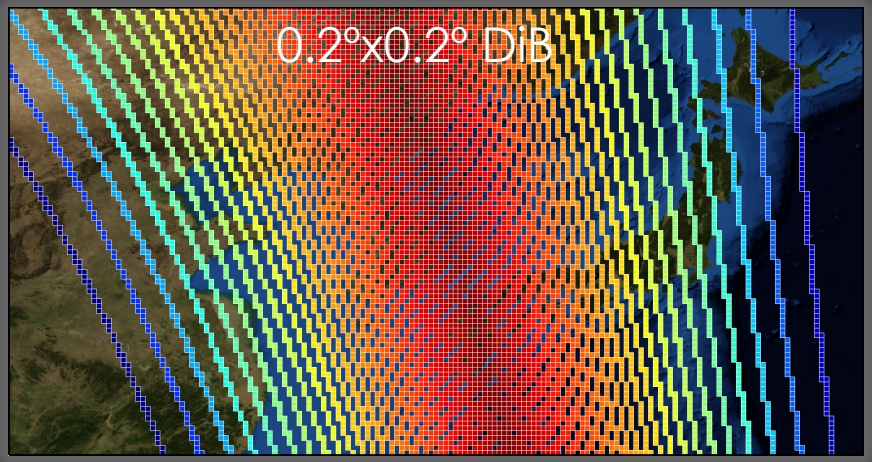
recall *motivation #1*

example : OMI orbit 75170 on 2018-09-02







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application to GEMS, OMI, TROPOMI

use NASA Earth images from

https://visibleearth.nasa.gov/view_cat.php?categoryID=1484&p=1
https://earthobservatory.nasa.gov/Features/NightLights/page3.php

sample digital images with the instruments' spatial resolution

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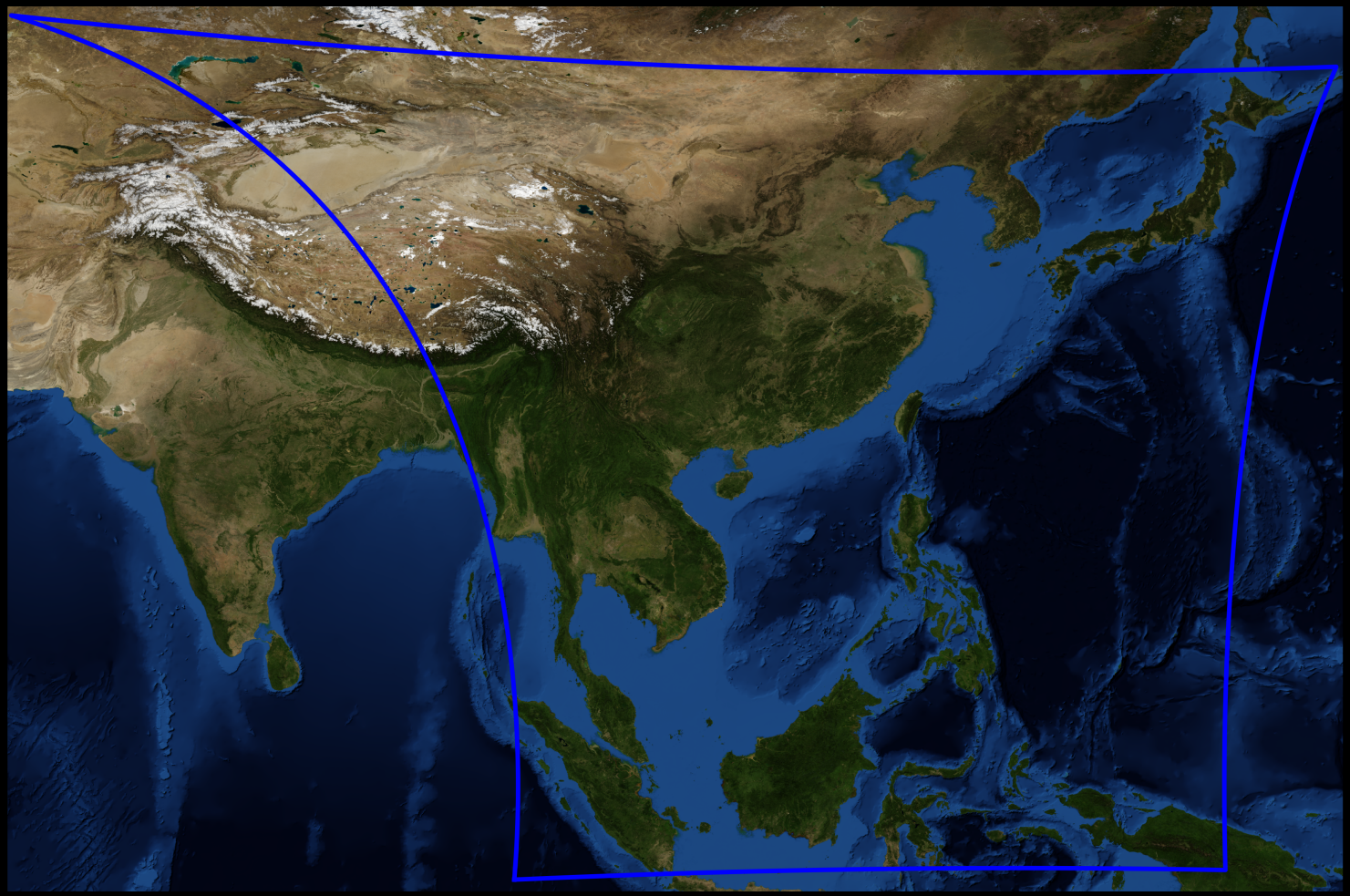
application to GEMS, OMI, TROPOMI



the GEMS field of regard

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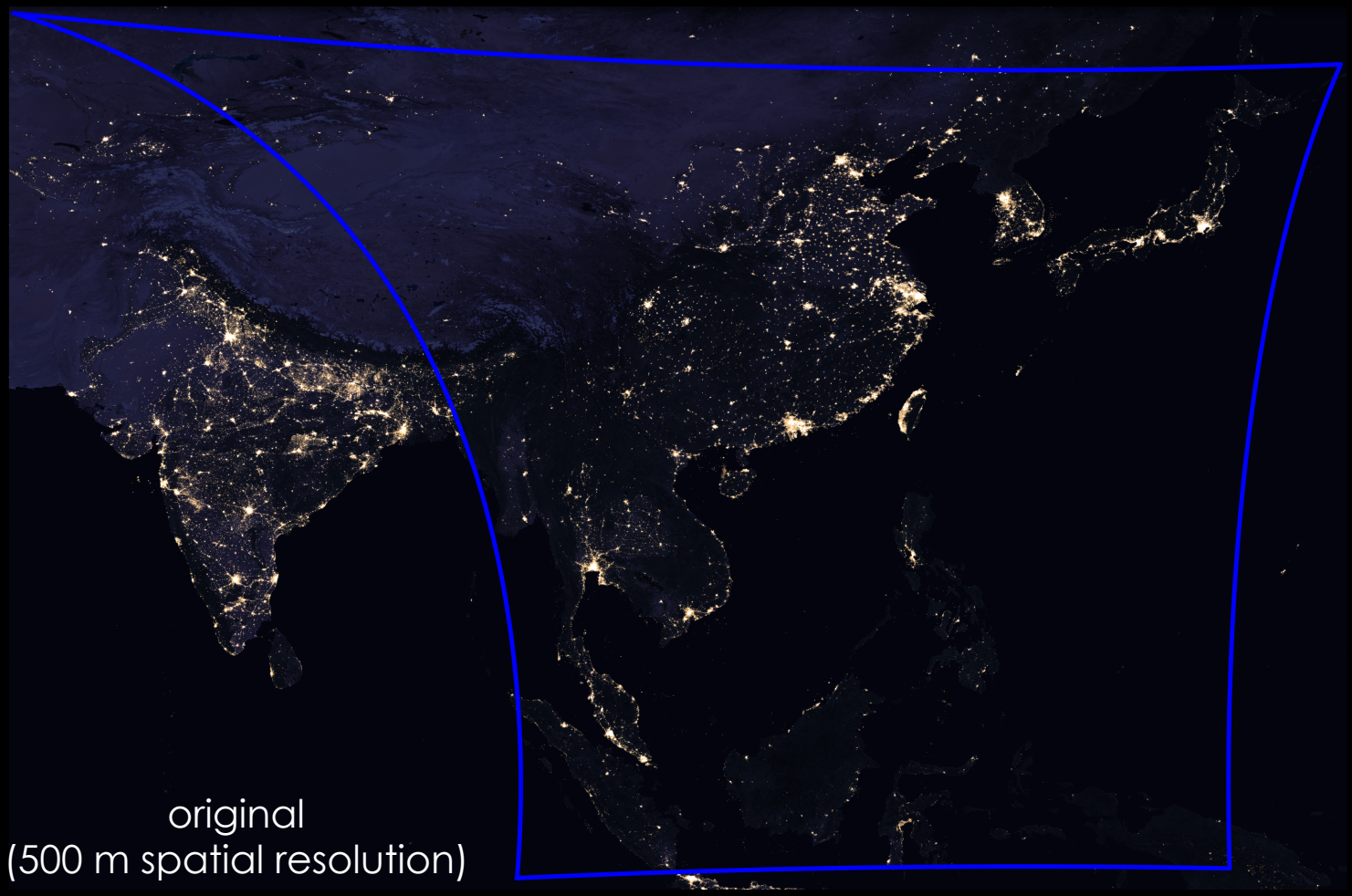
application to GEMS, OMI, TROPOMI



the GEMS field of regard

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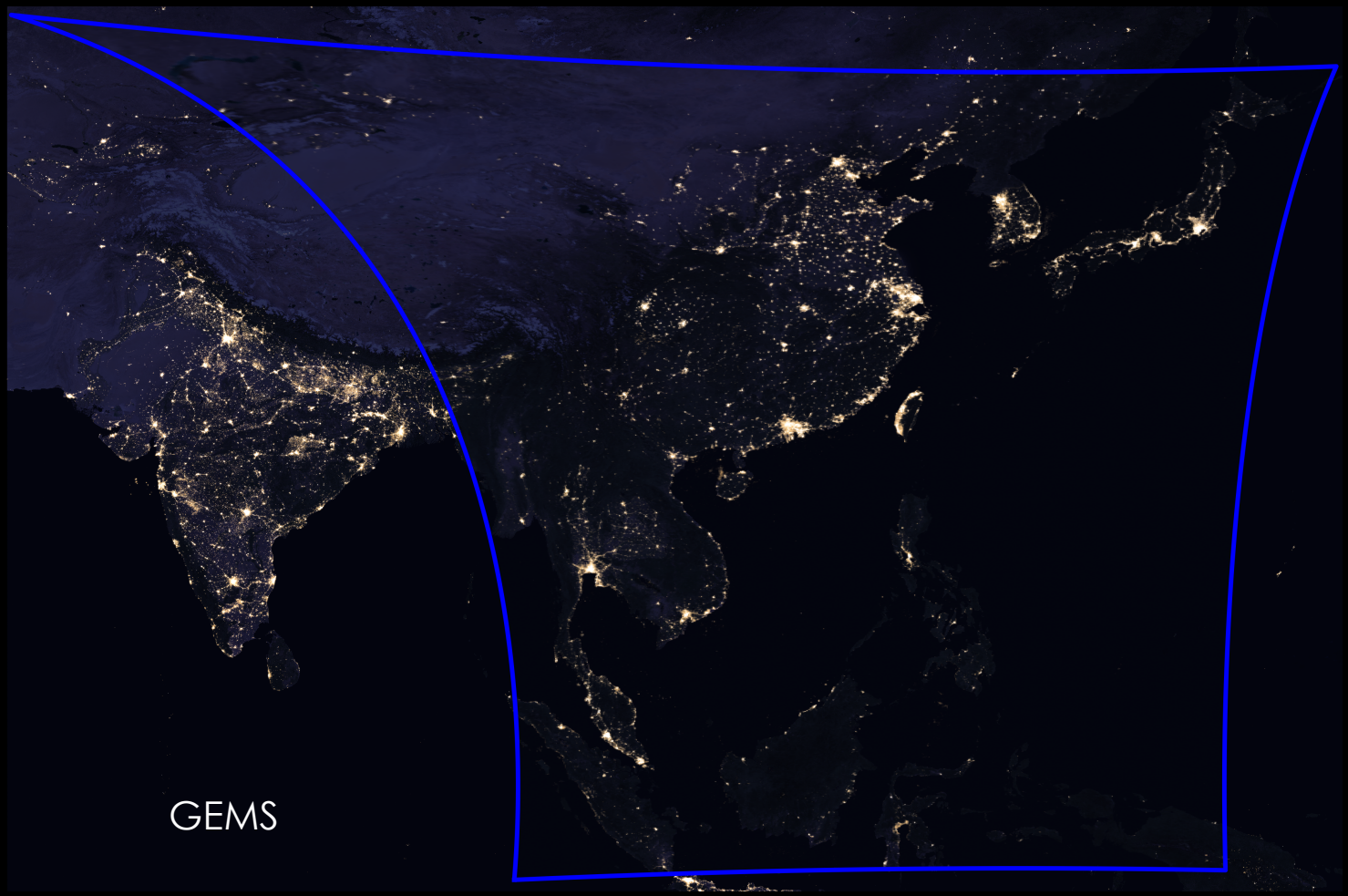
sampled with GEMS footprints



GEMS footprints provided by Heesung Chong

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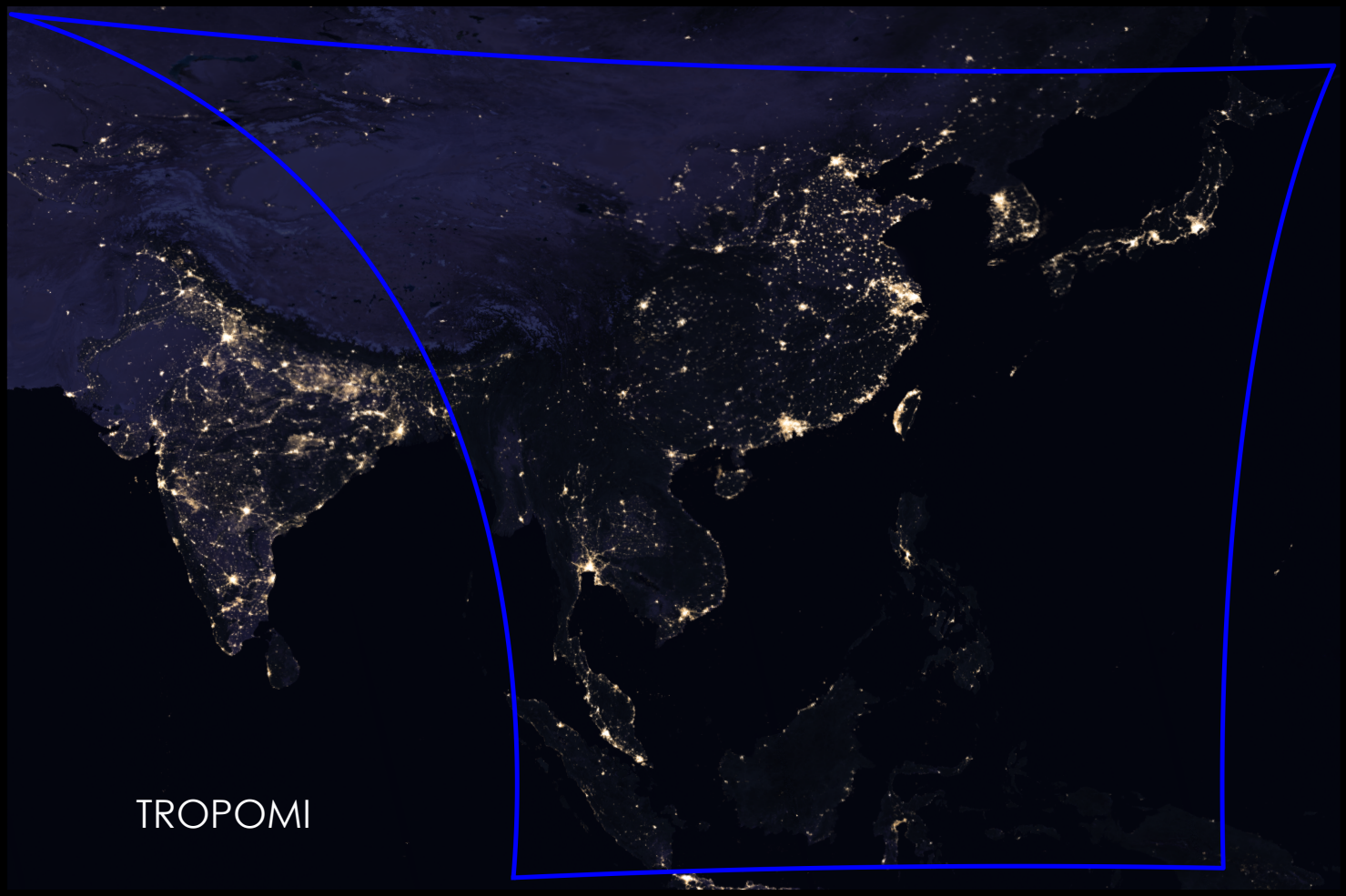
sampled with TROPOMI footprints



TROPOMI footprints provided by Michel van Roozendael

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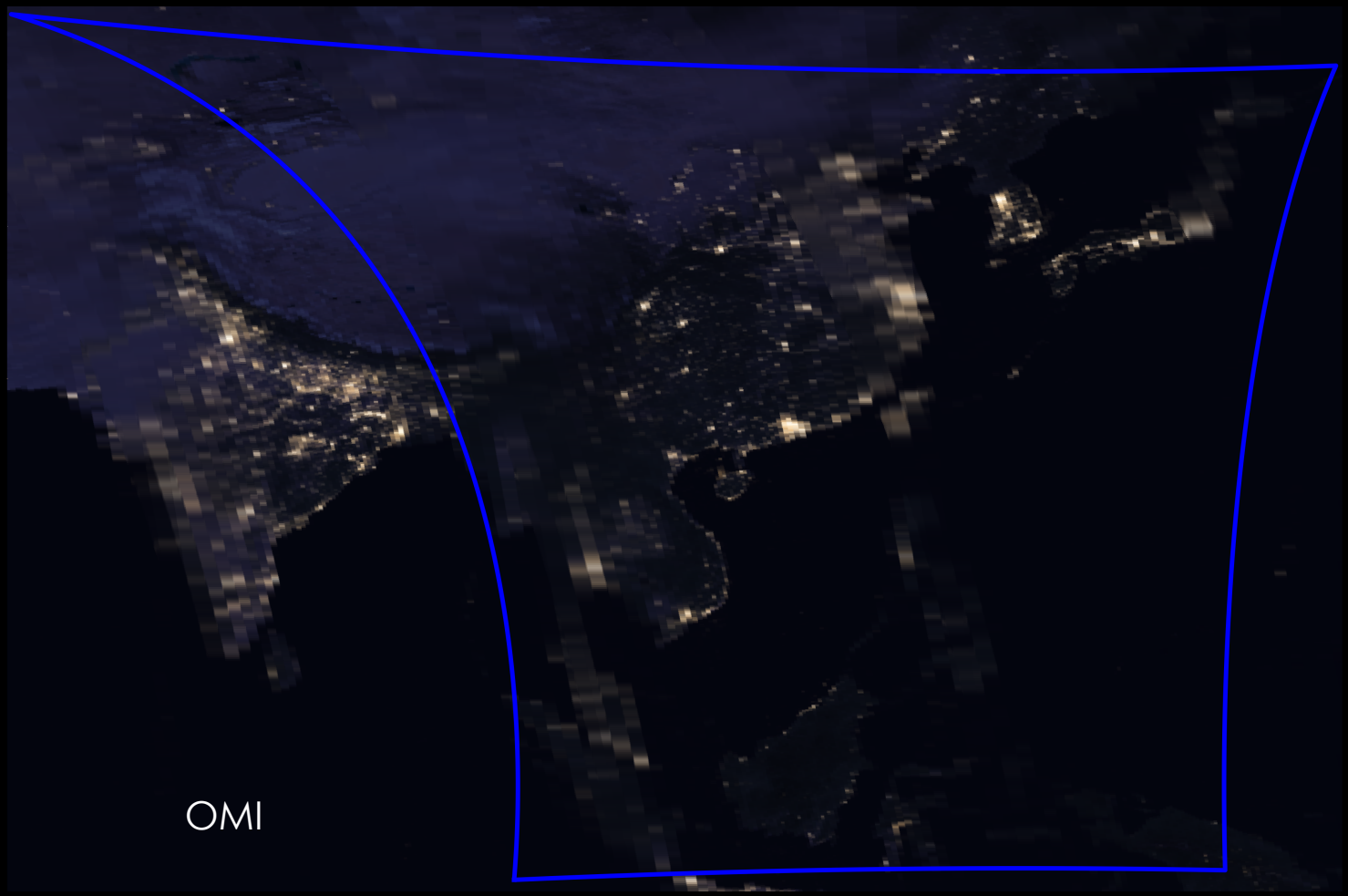
sampled with OMI footprints



OMI footprints from OMPIXCOR product, tiled

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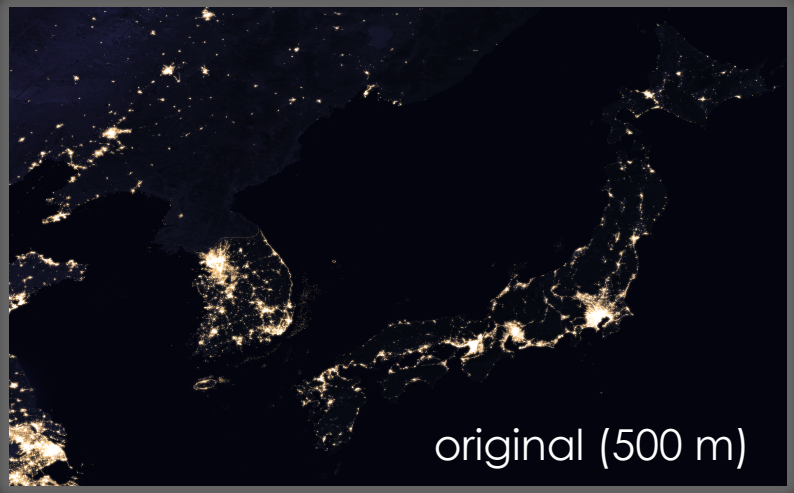
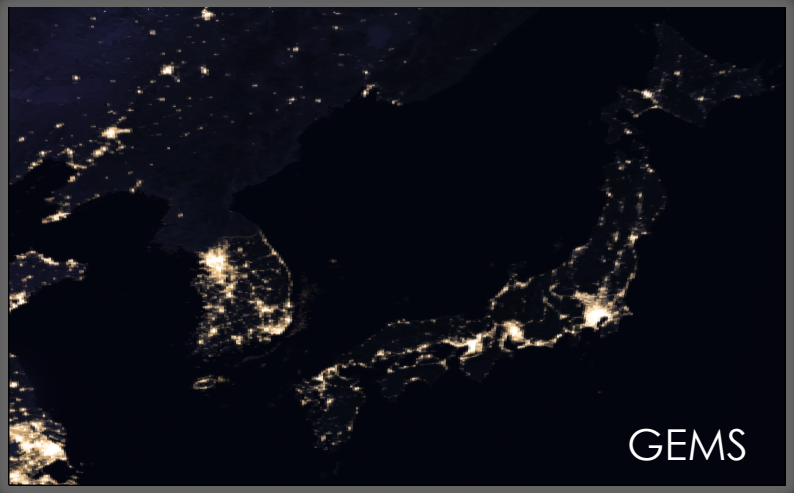
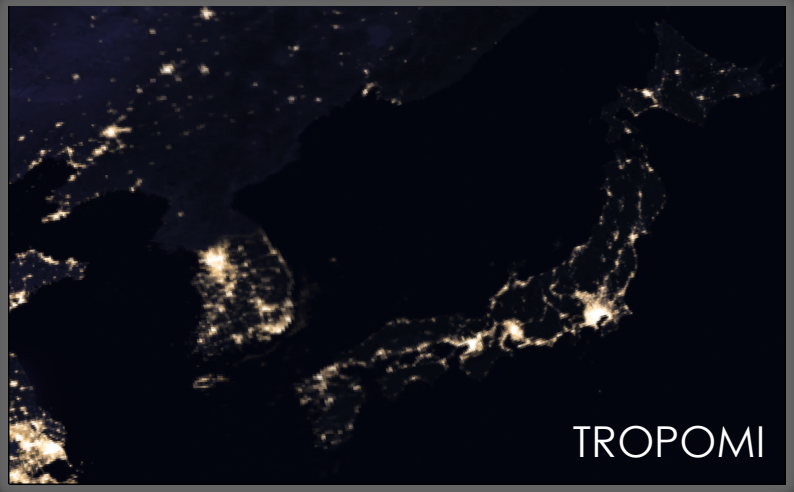
sampled with GEMS, OMI, TROPOMI footprints







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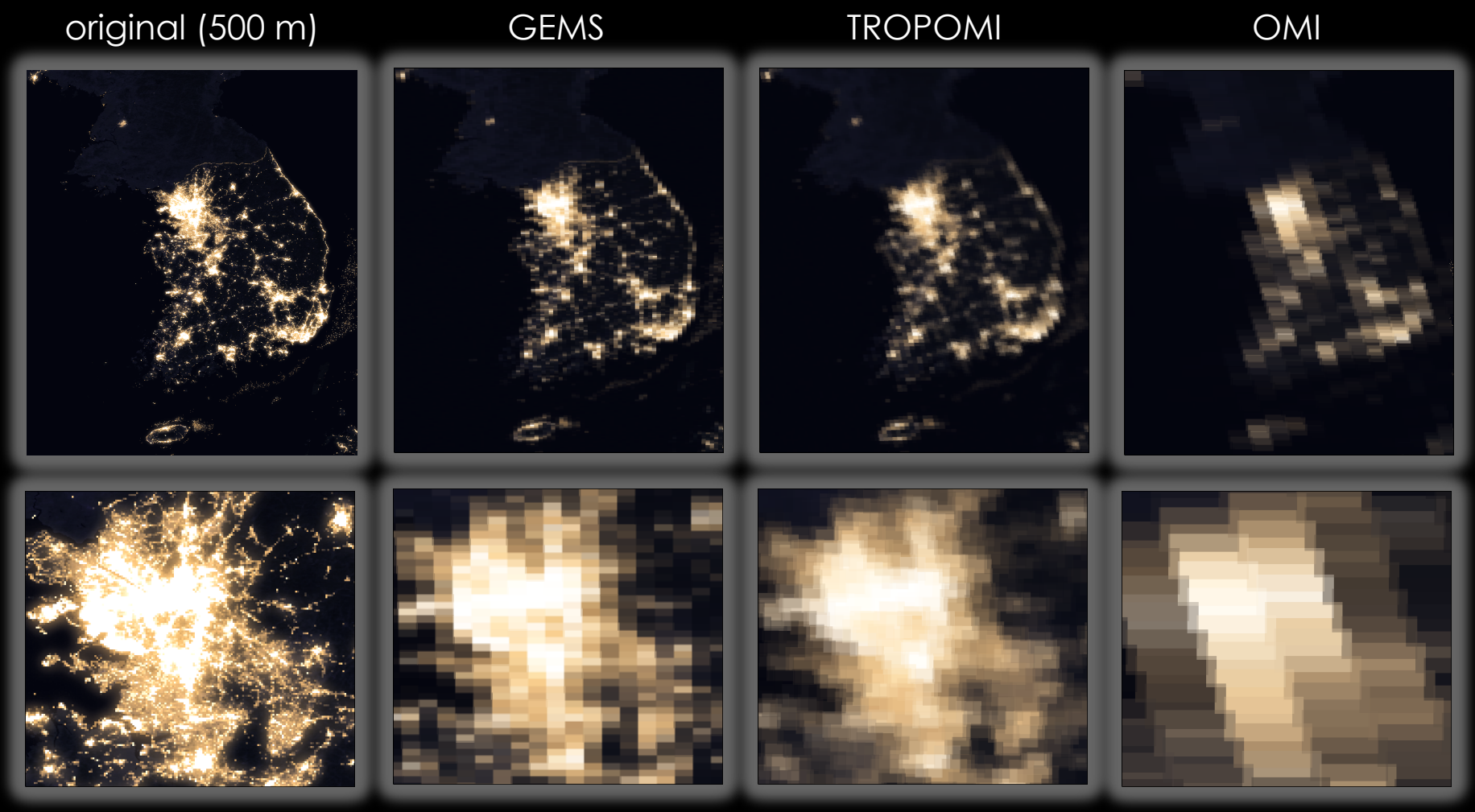
sampled with GEMS, OMI, TROPOMI footprints



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sampled with GEMS, OMI, TROPOMI footprints

Pearson's *R*

	GEMS Field of Regard	Korea/ Japan	Korea	Seoul
GEMS	0.948	0.913	0.893	0.799
TROPOMI	0.889	0.900	0.870	0.762
OMI	0.735	0.733	0.784	0.567

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sampled with GEMS, OMI, TROPOMI footprints

Pearson's *R*

	GEMS Field of Regard	Korea/ Japan	Korea	Seoul
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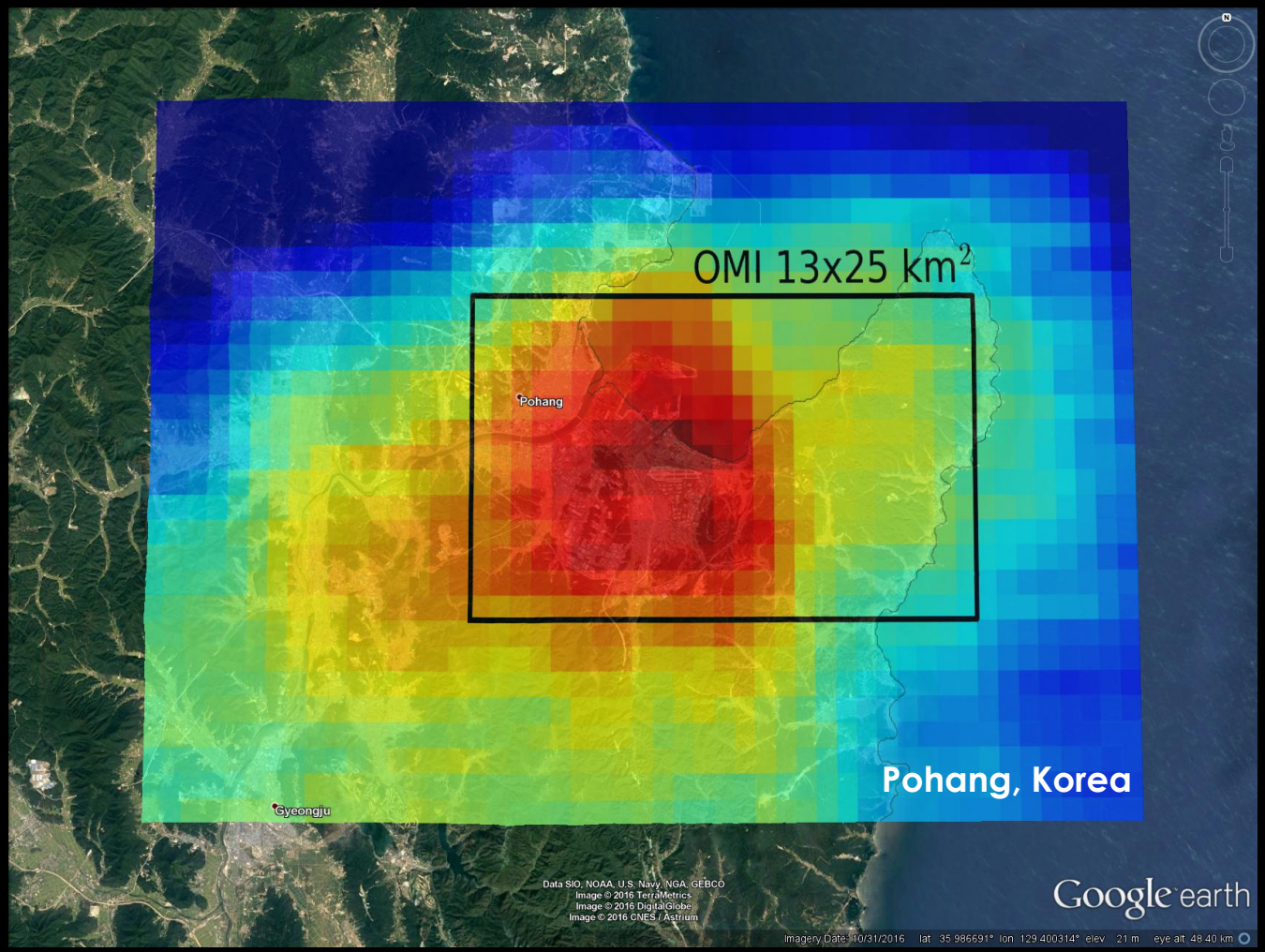
spatial oversampling – some examples



OMI tropospheric NO_2 – 2006, weighted tessellation to 0.01°x0.01°

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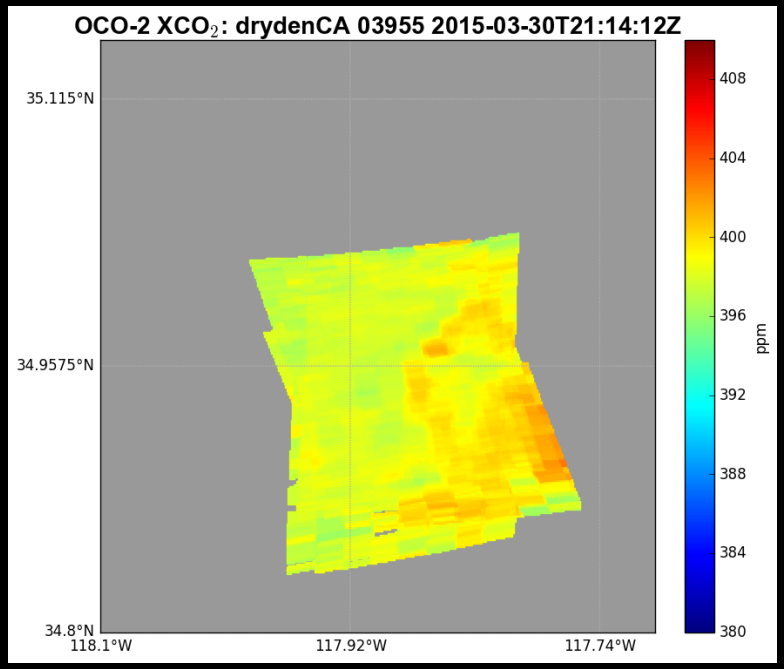
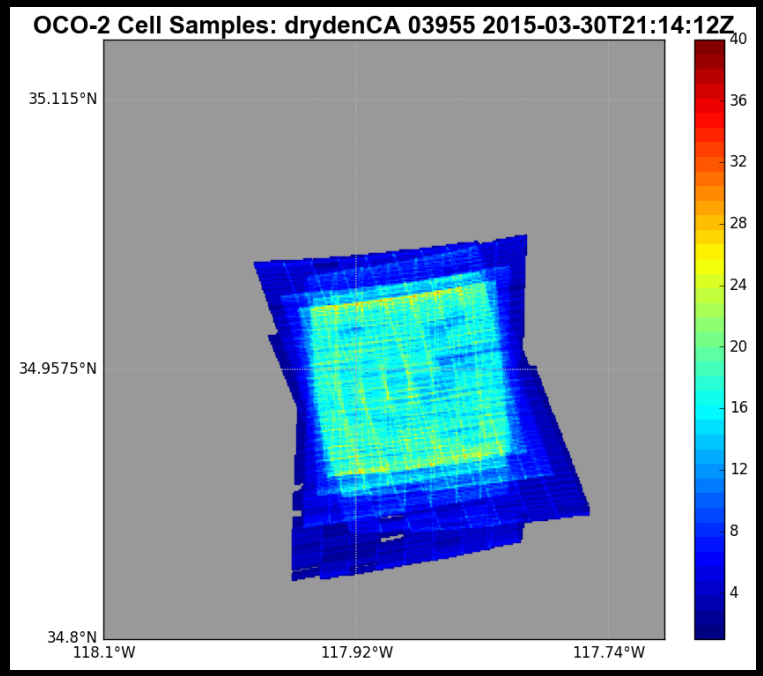
OCO-2 XCO_2 Target Mode over Edwards AFB, CA 0.001°

single target overpass



number of cell samples



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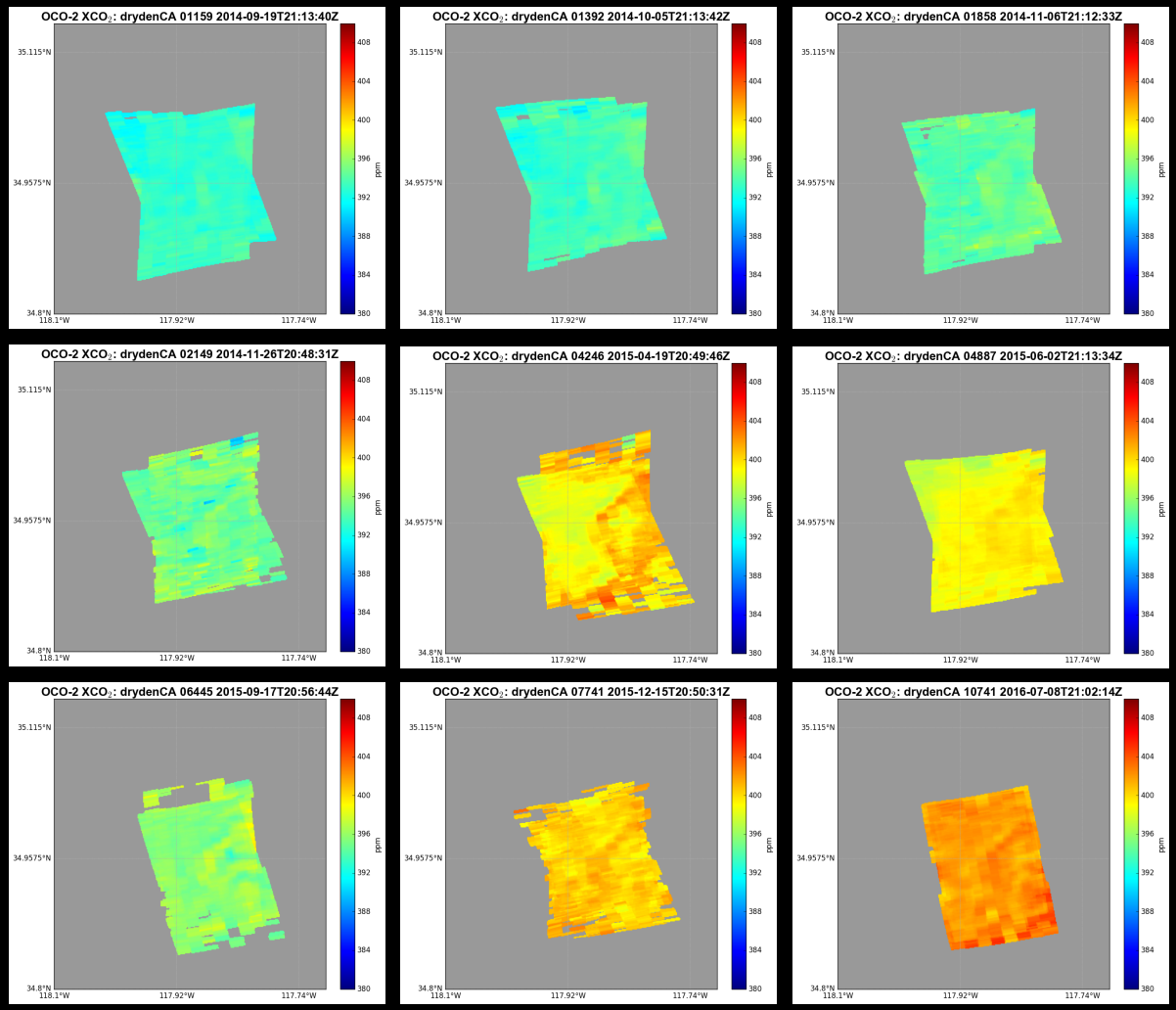
OCO-2 XCO_2 target data over Edwards AFB, CA 0.001°

single-day target overpasses, at different times of year



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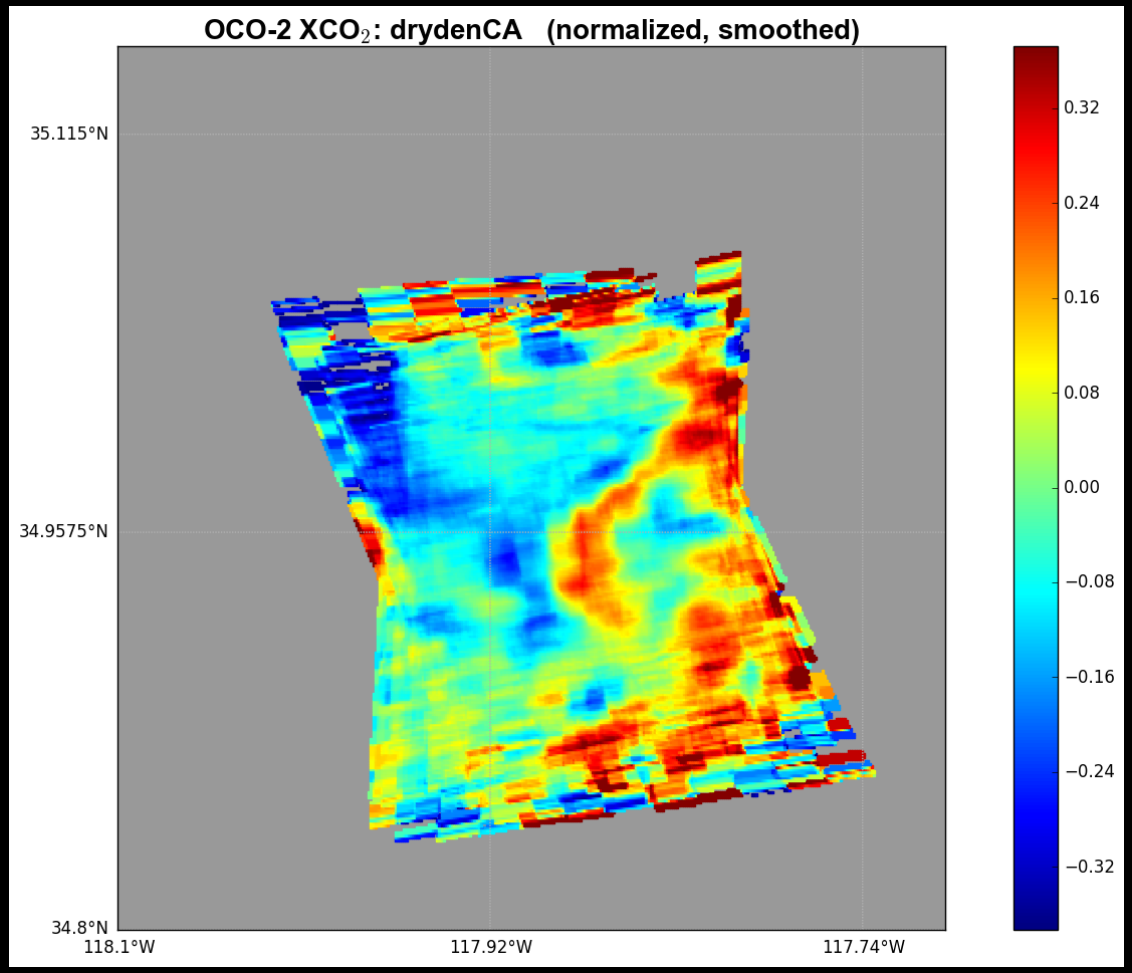
OCO-2 XCO_2 target data over Edwards AFB, CA 0.001°

normalized difference to the combined de-seasonalized median



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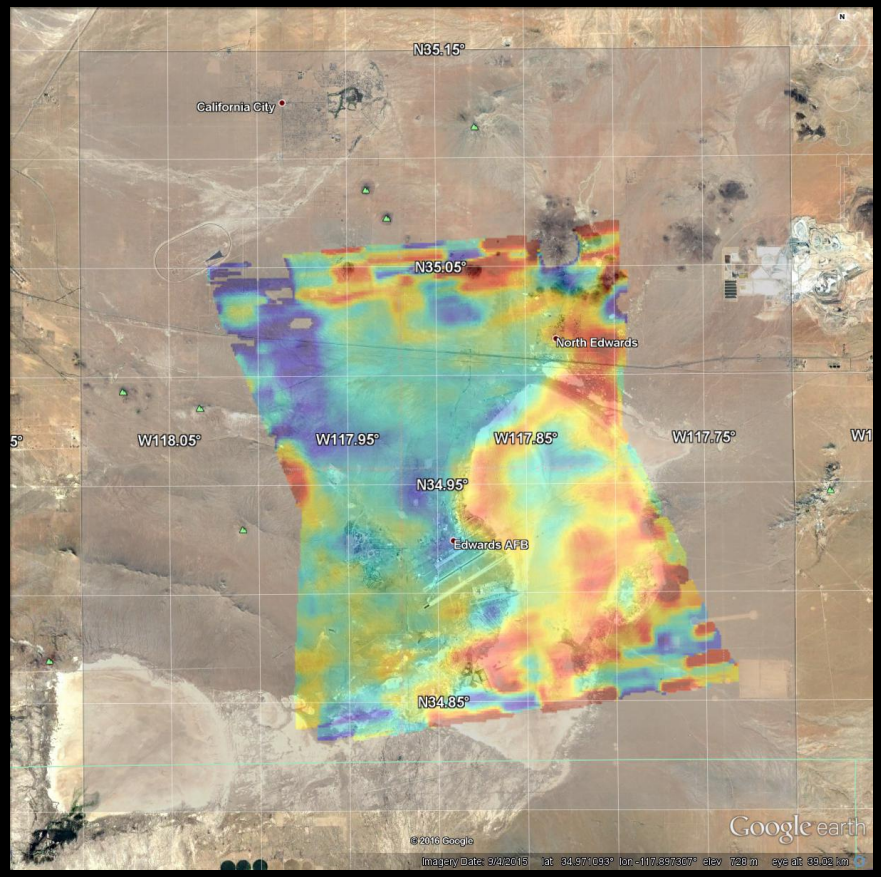
OCO-2 XCO_2 target data over Edwards AFB, CA 0.001°

google earth overlay

oversampling exposes surface albedo effects



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the status quo

Python 3 implementation of a prototype algorithm, consisting of

core routines
which perform the mapping of the satellite footprint and calculate the fractional coverage of each rectangular grid cell underlying the footprint

wrapper routines
which interface the core routines with the satellite data and perform temporal and spatial averaging

successful applications
OCO-2, OMI, OMPS, ASTER, GOME-2, TROPOMI, GEMS

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next steps

prototype implementation, requires improvement
(robustness, turn-key/black-box, operational)

speed-up
(execution times scale with grid dimension and number of footprints)

implementation for GEMS processing
(contingent upon algorithm being fit-for-use)

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thank you

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