# too kink to be square?
# mapping satellite polygon footprints onto regular grids by tessellation

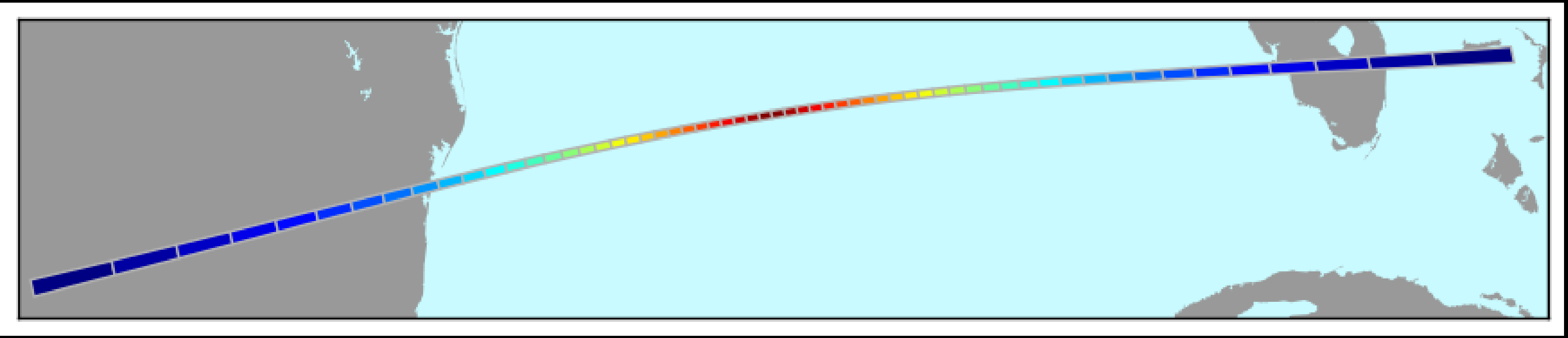
9th GEMS Science Team Meeting
2 October 2018, Seoul

thomas p kurosu
jet propulsion laboratory, california institute of technology

# 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.

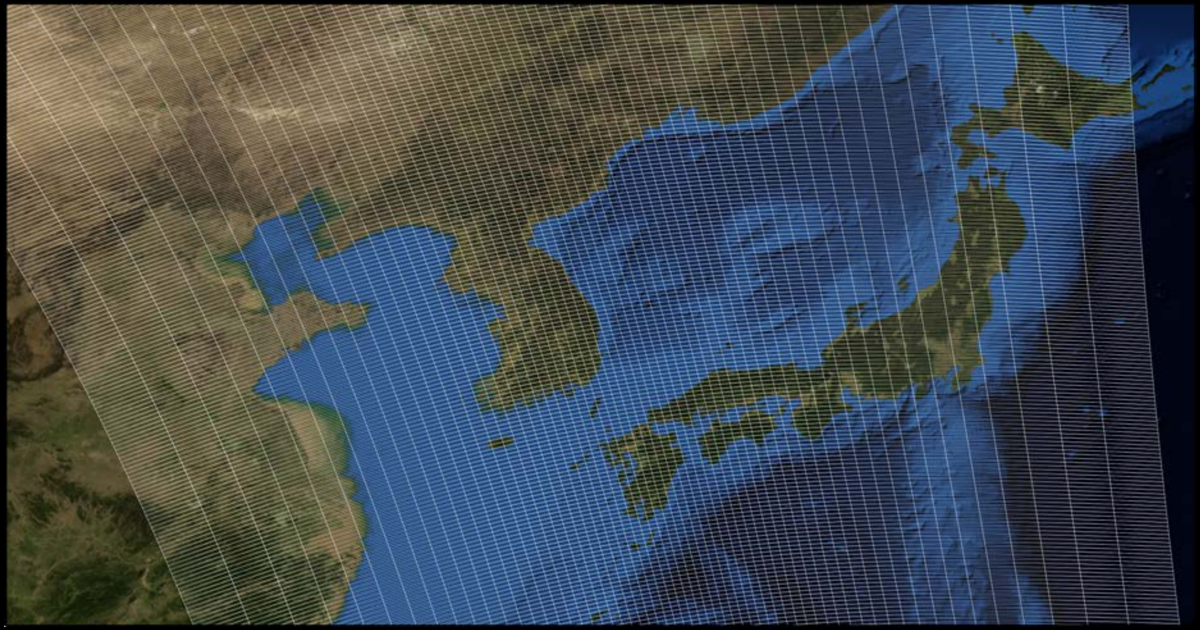


example of an OMI swath line

2,600 km swath divided into 60 cross-track pixels

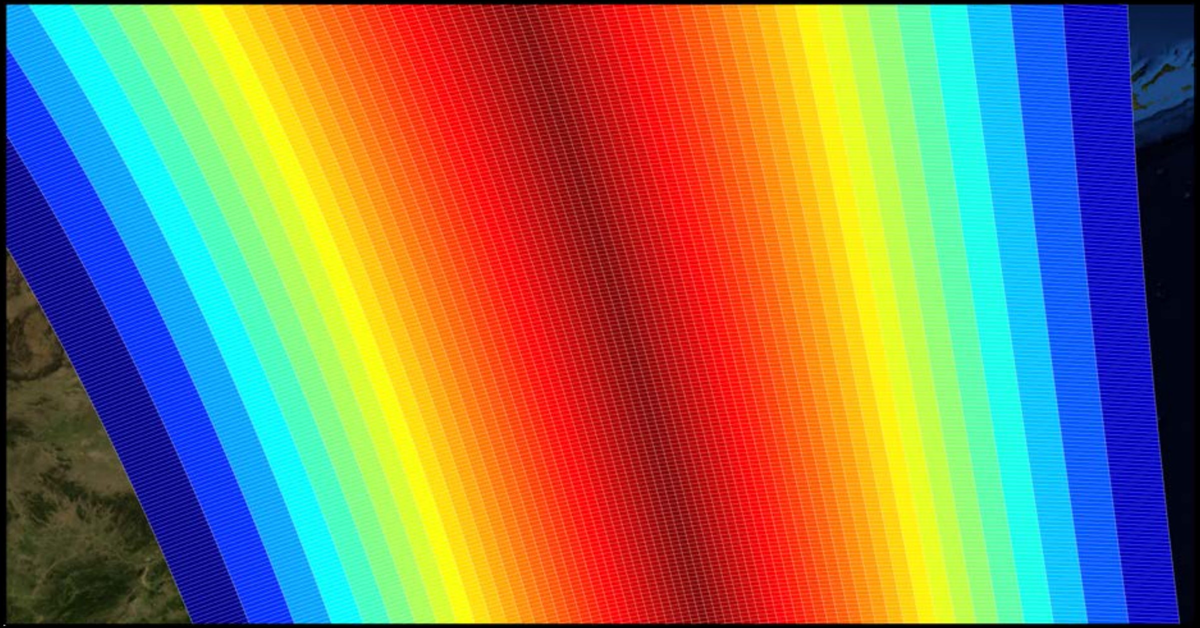
range of pixel size: 340 km$^2$ (center) to 4,600 km$^2$ (edges)

# motivation #1



example : OMI orbit 75170 on 2018-09-02

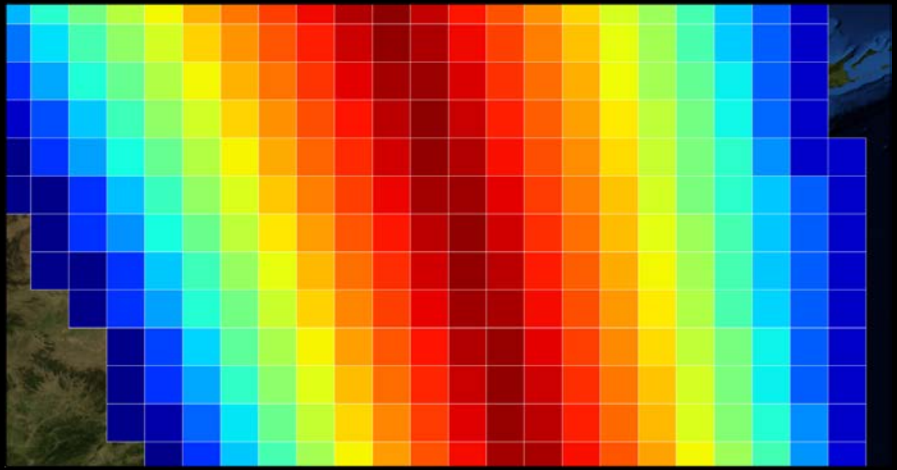
# motivation #1



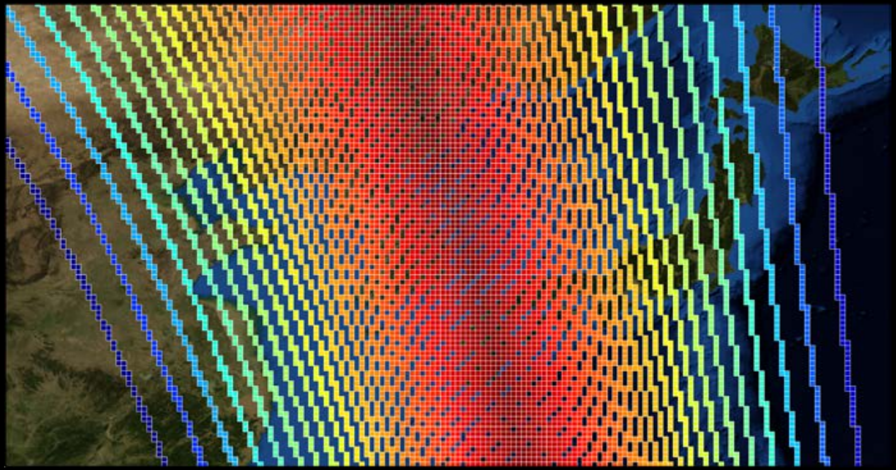
example : OMI orbit 75170 on 2018-09-02
color-coded by footprint area

# motivation #1

## drop-in-the-box gridding



1.5ºx1.5º grid
preserves spatial coverage



0.2ºx0.2º grid
preserves highest spatial resolution

example : OMI orbit 75170 on 2018-09-02

# 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

# motivation #2

GEMS, synthetic
(courtesy Heesung Chong)

OMI 2018-09-02
(OMPIXCOR, tiled)

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

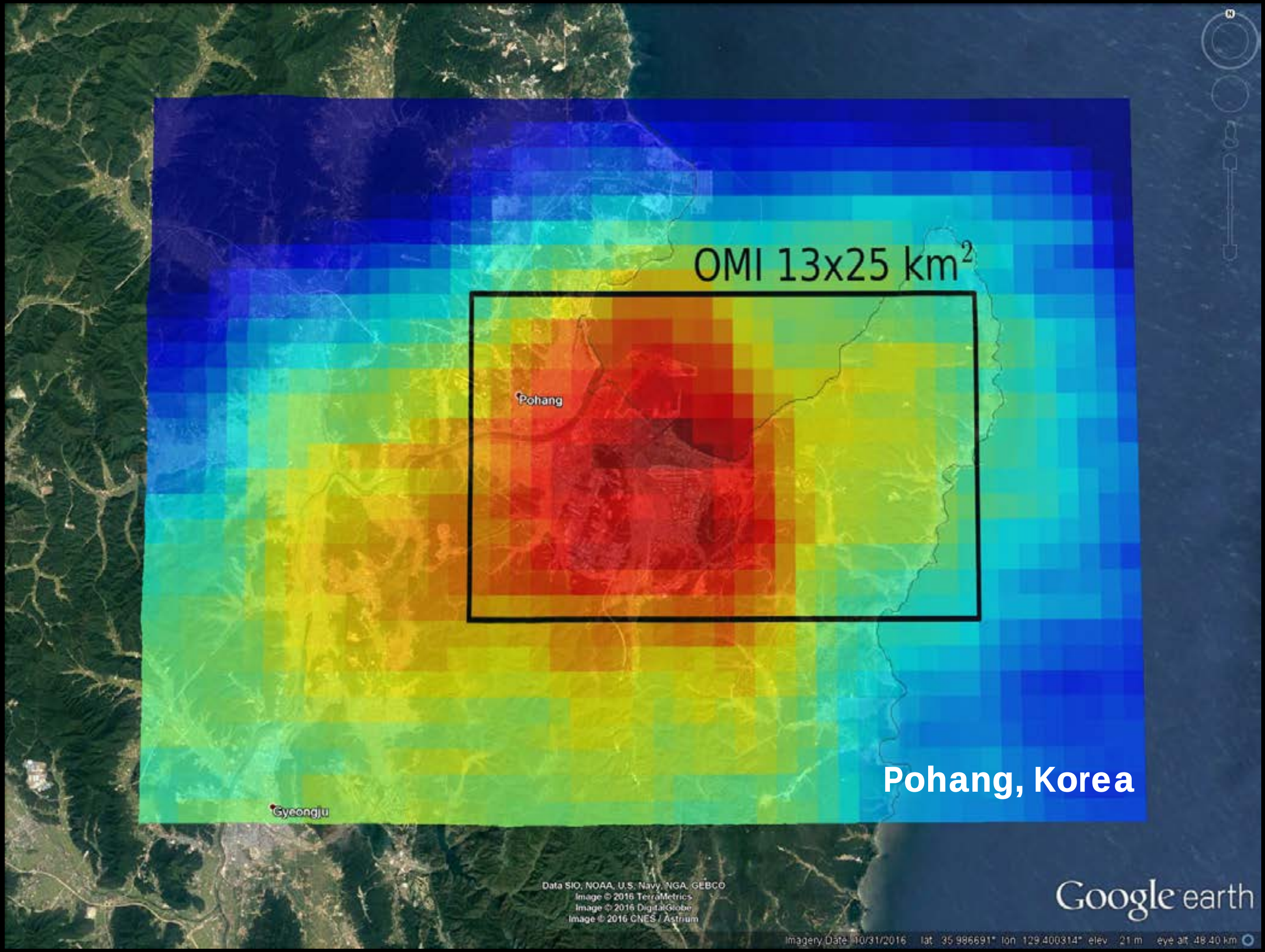
three satellite data sets with significantly different spatial characteristics

# 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

# motivation #3



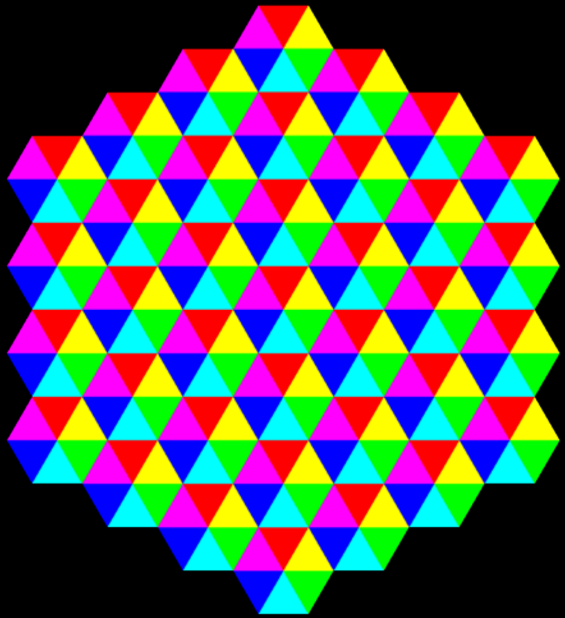

OMI tropospheric $NO_2$ – 2006, weighted tessellation to 0.01ºx0.01º

# 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

# 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)

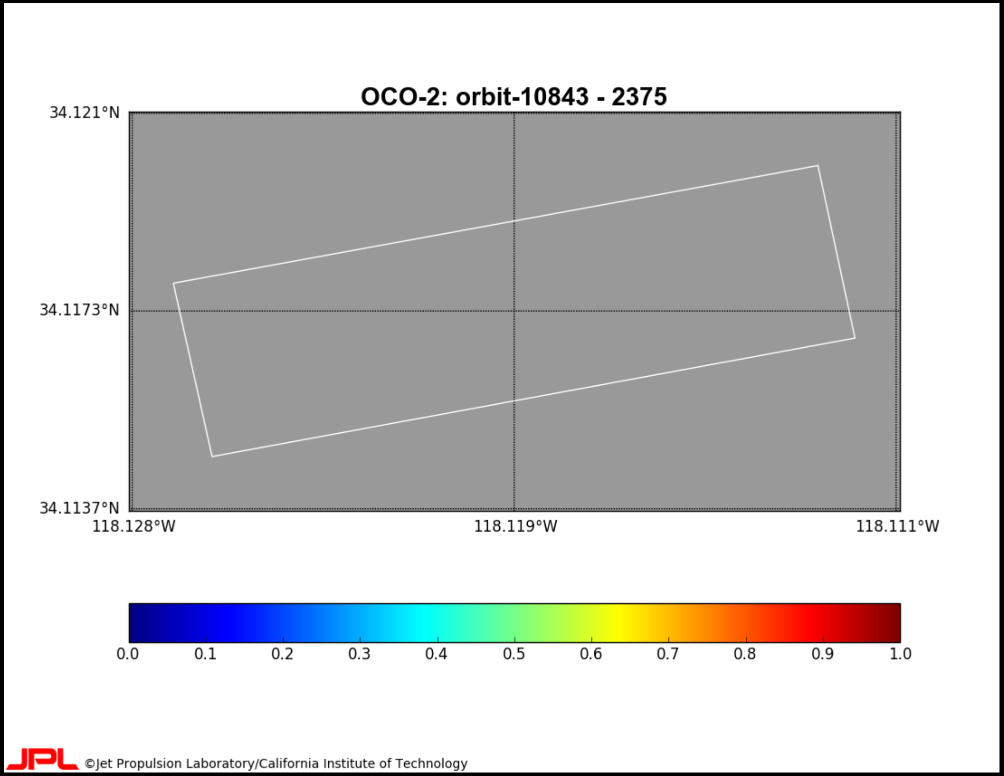
(image from https://www.iconspng.com/image/1978/hexagonal-triangle-tessellation)

# 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

# the tessellation process

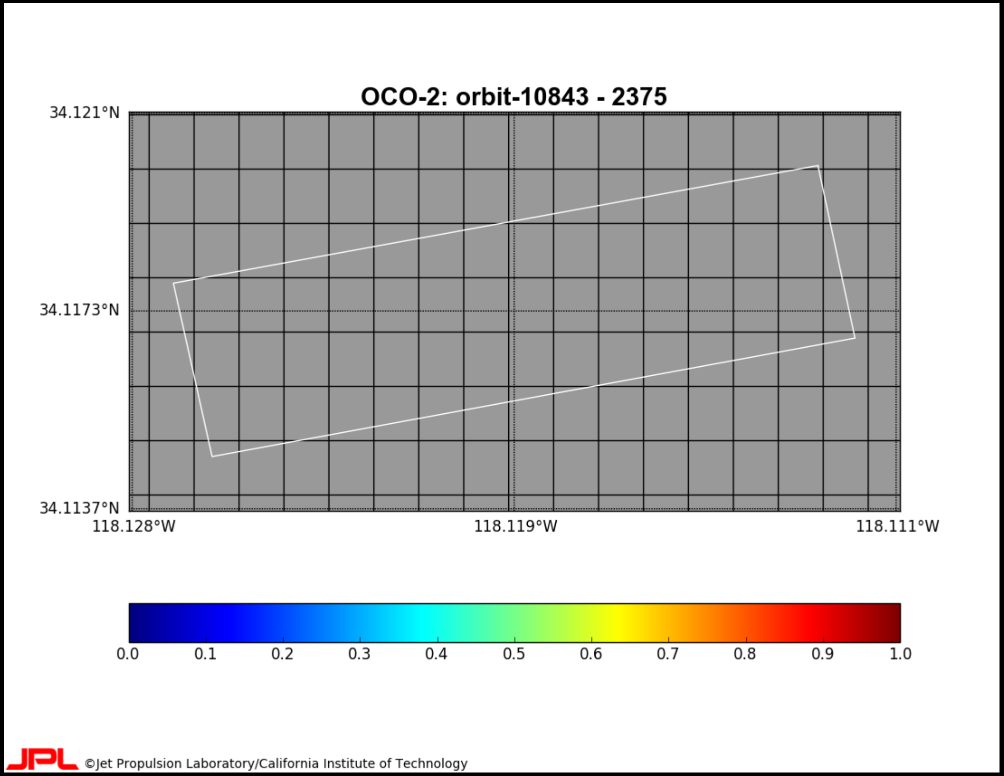
start with a satellite ground pixel (*e.g.*, OCO-2 target data, ~1x1 km$^2$)




Jet Propulsion Laboratory
California Institute of Technology

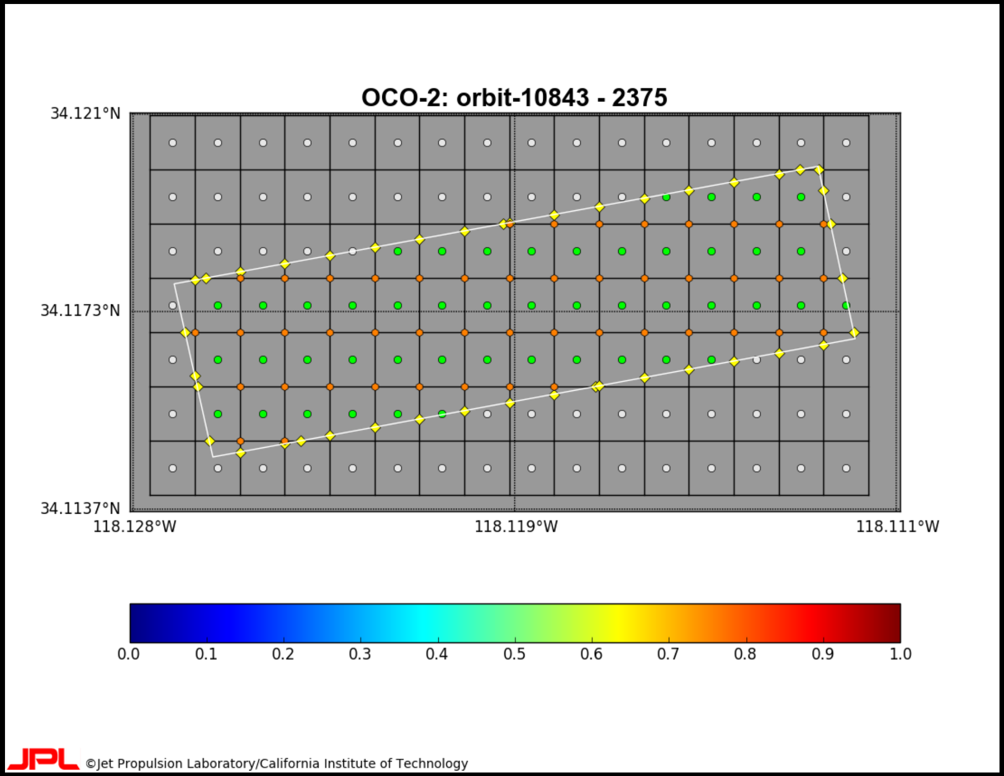
# the tessellation process

1. define a rectangular grid, *e.g.*, 0.001ºx0.001º resolution (~100 m)



# the tessellation process

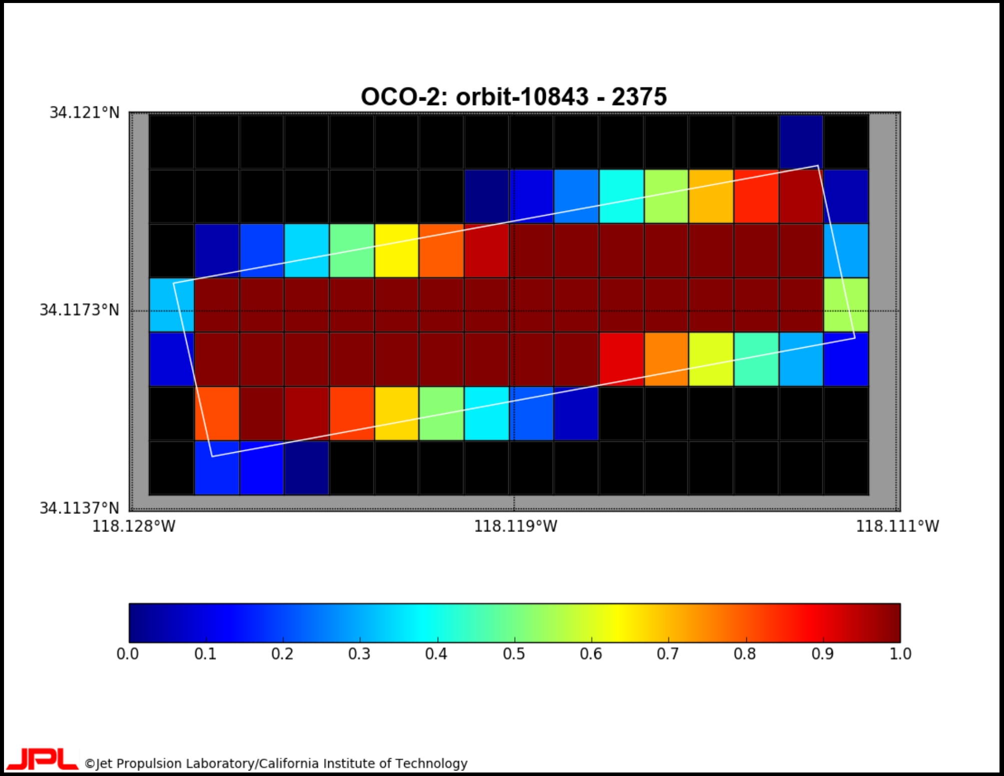
## 2.1 calculate intersects of footprint and grid cell boundaries




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

# the tessellation process

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



# 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*

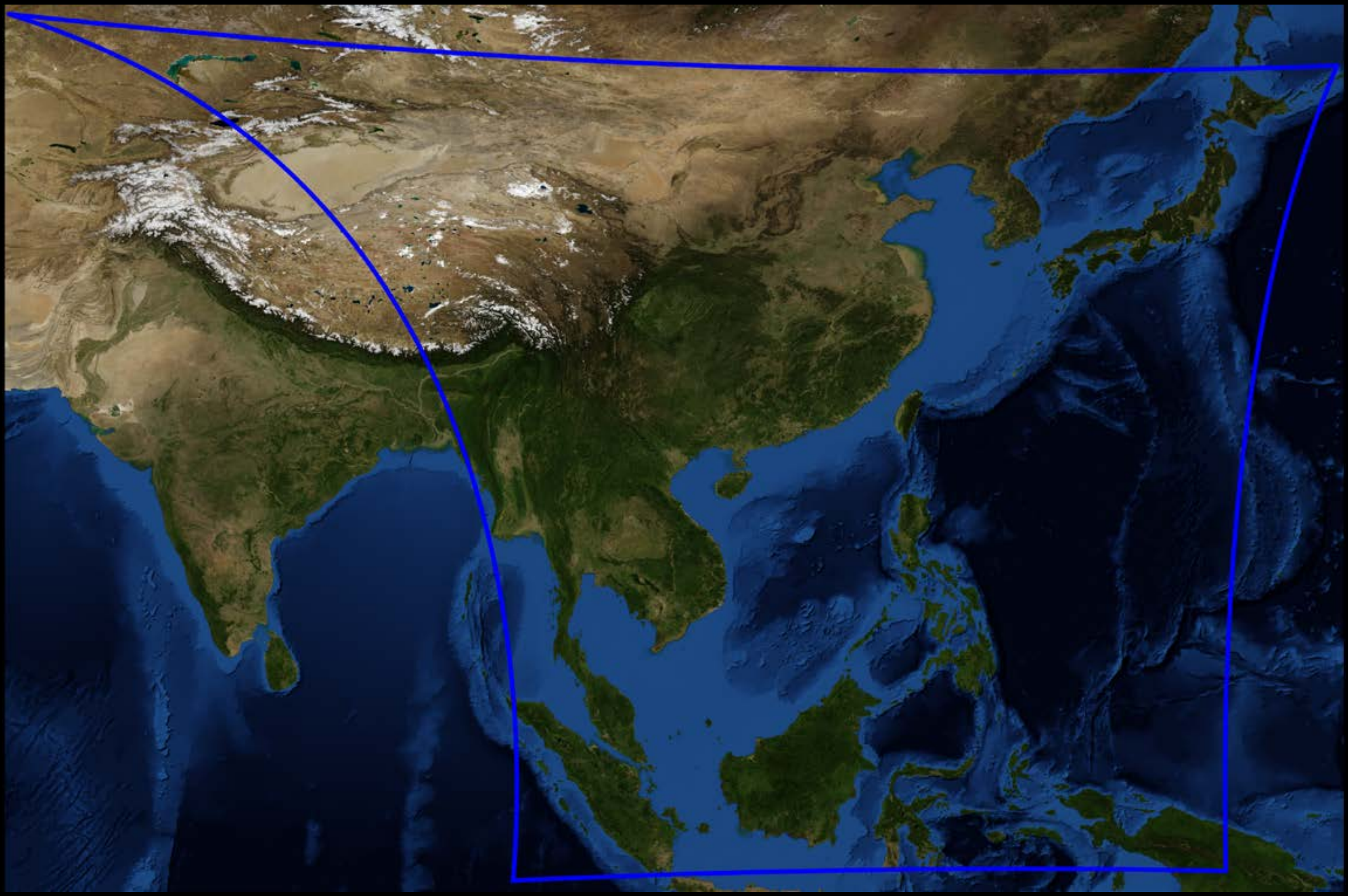
# application to GEMS, OMI, TROPOMI

use NASA Earth images from

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

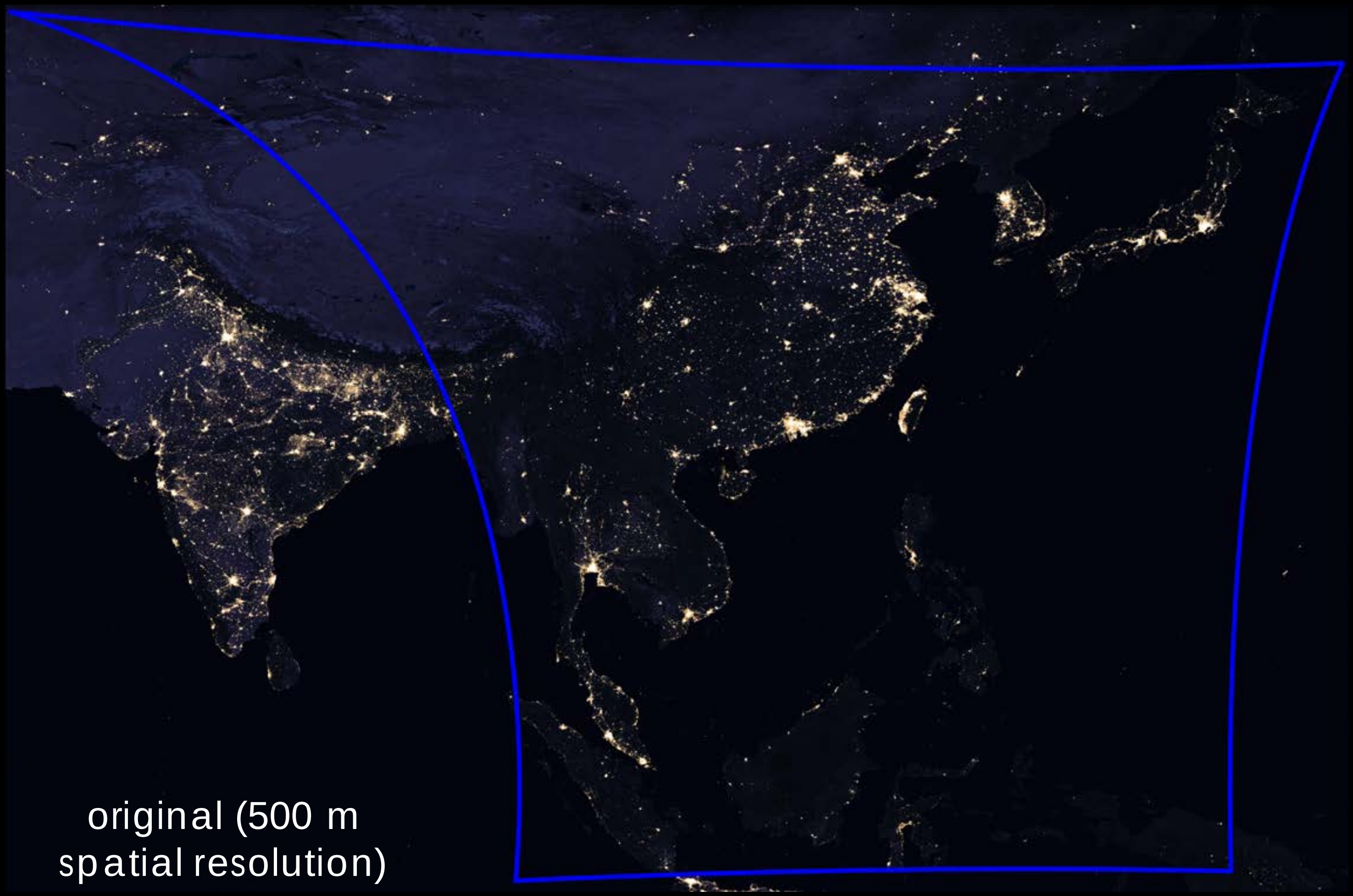
sample digital images with the instruments' ground footprints

# application to GEMS, OMI, TROPOMI



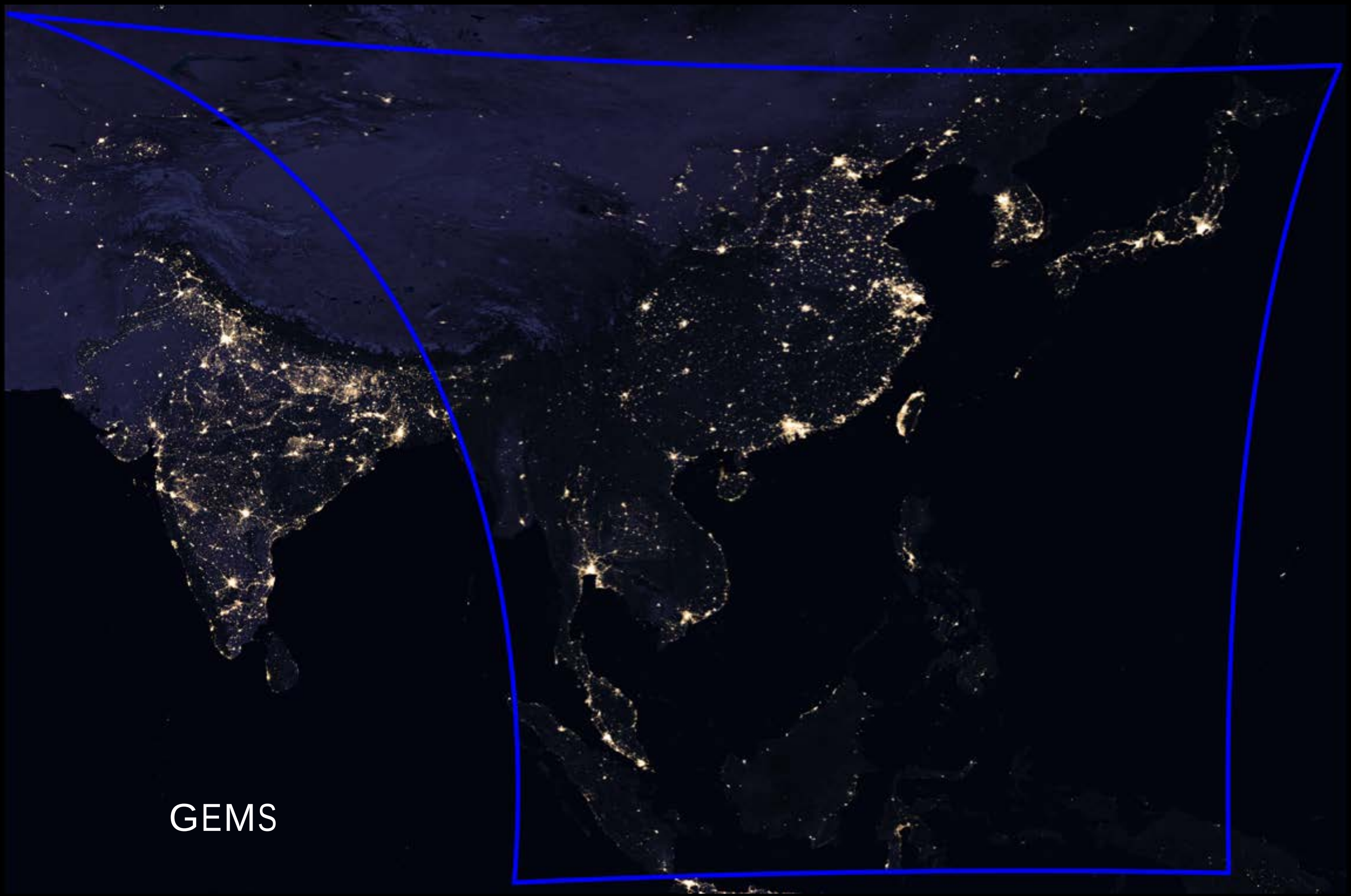
the GEMS field of regard

# application to GEMS, OMI, TROPOMI



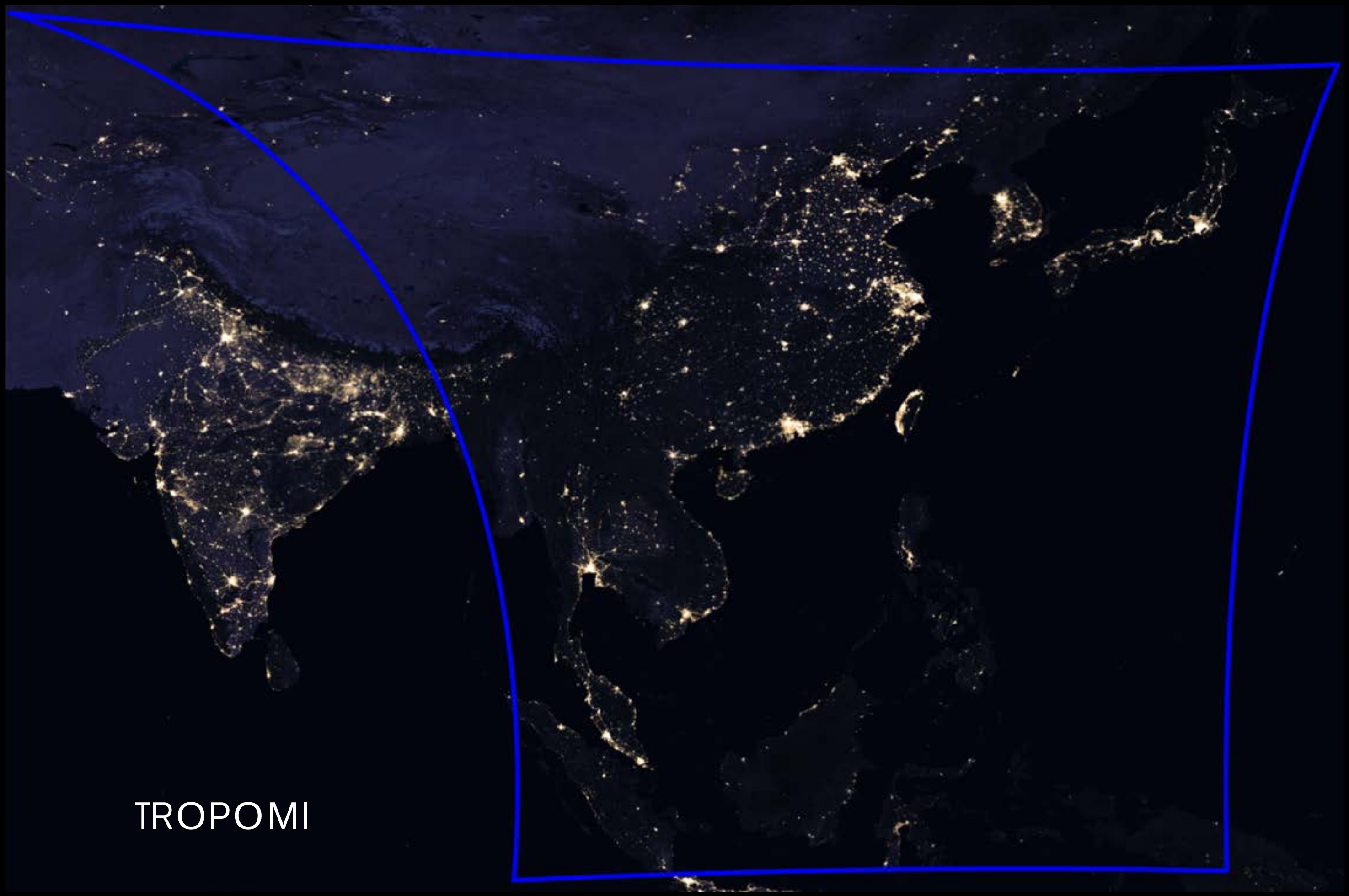

**the GEMS field of regard**

# sampled with GEMS footprints



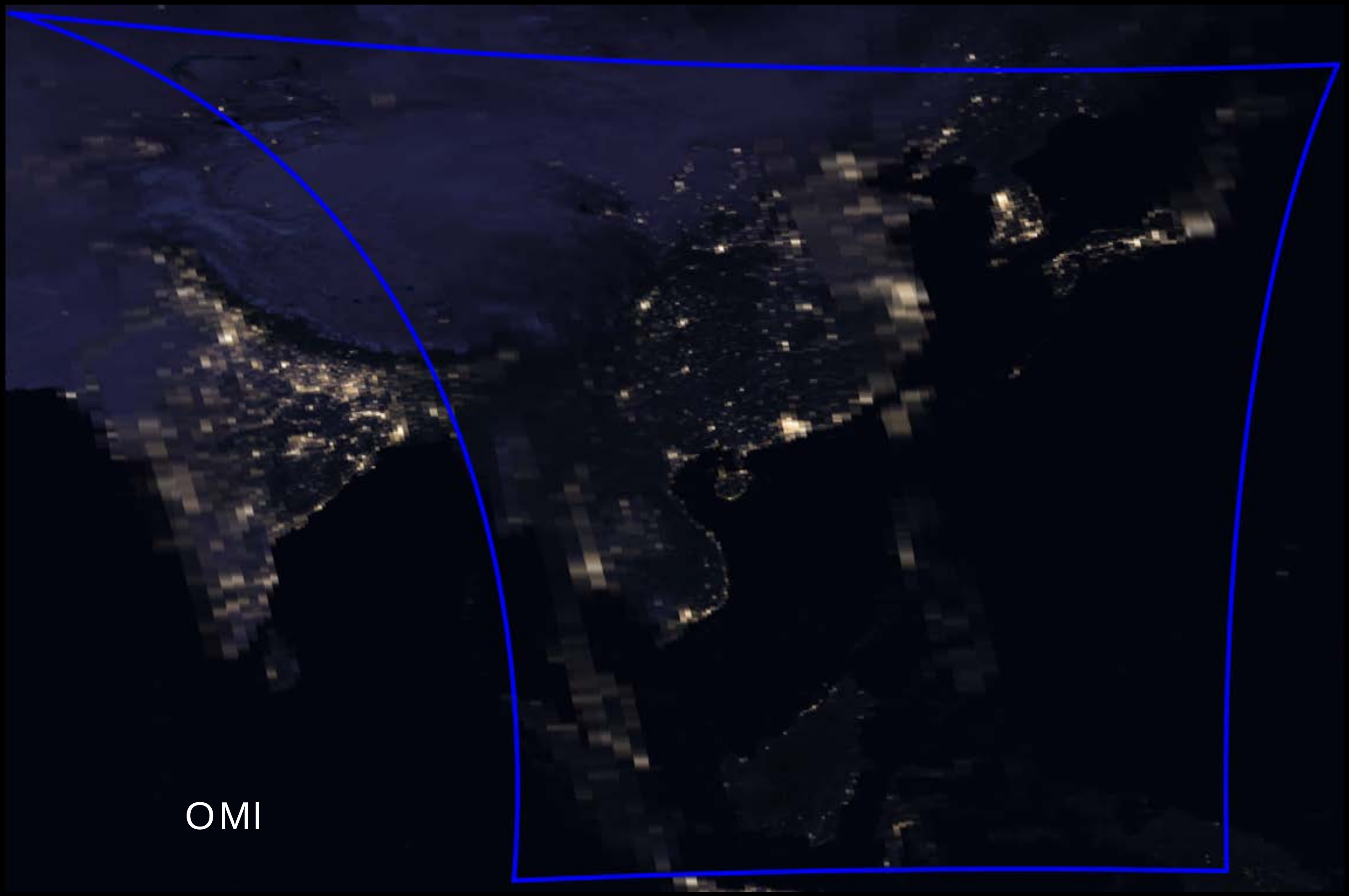

GEMS footprints provided by Heesung Chong

## sampled with TROPOMI footprints



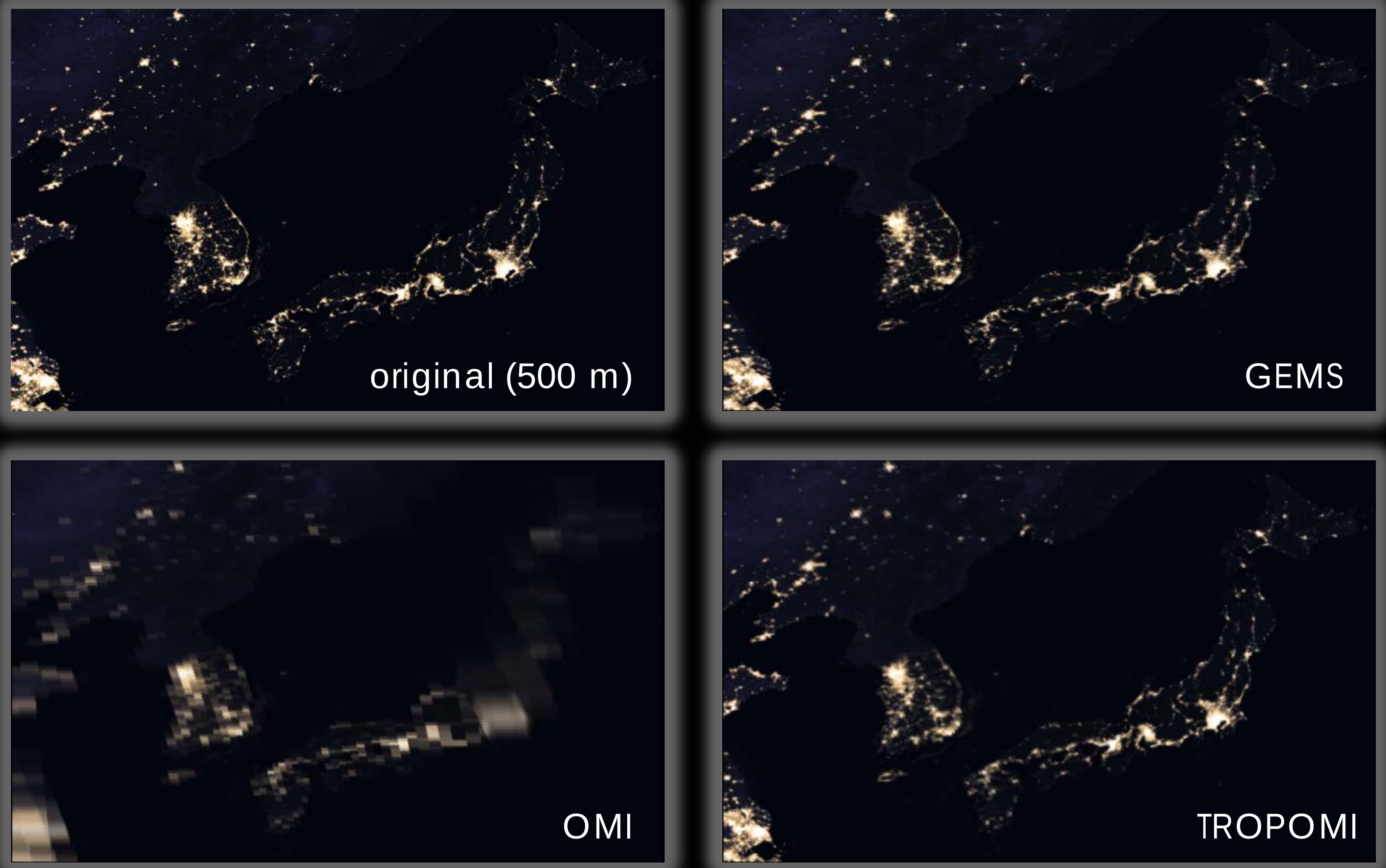

TROPOMI footprints provided by Michel van Roozendael

# sampled with OMI footprints



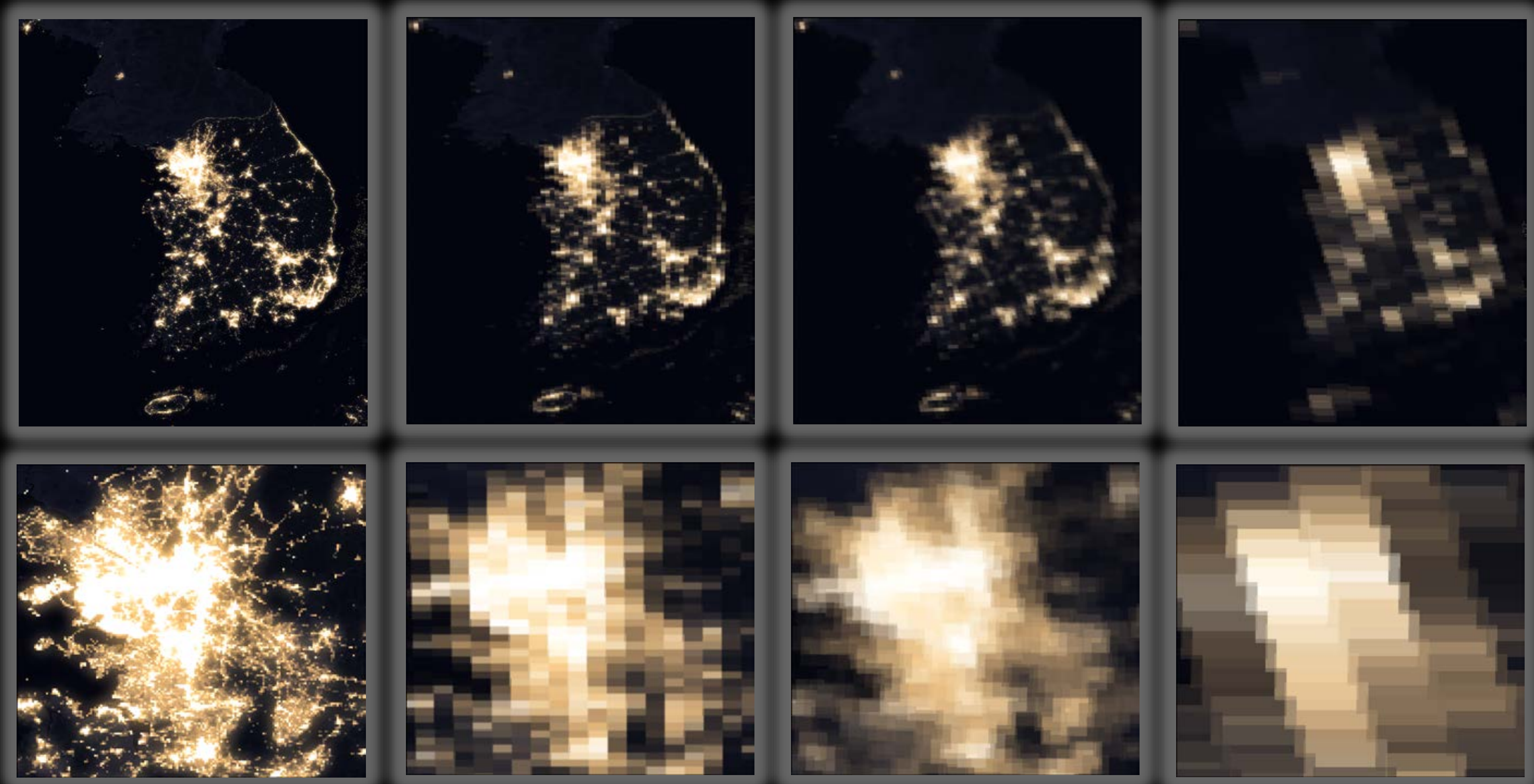

OMI footprints from OMPIXCOR product, tiled

# sampled with GEMS, OMI, TROPOMI footprints



# sampled with GEMS, OMI, TROPOMI footprints

original (500 m) | GEMS | TROPOMI | OMI



Jet Propulsion Laboratory
California Institute of Technology

## 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 |

# 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

# 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)

thank you