Applications of uniform space-time gridding method for comparisons of satellite radiances and cloud properties

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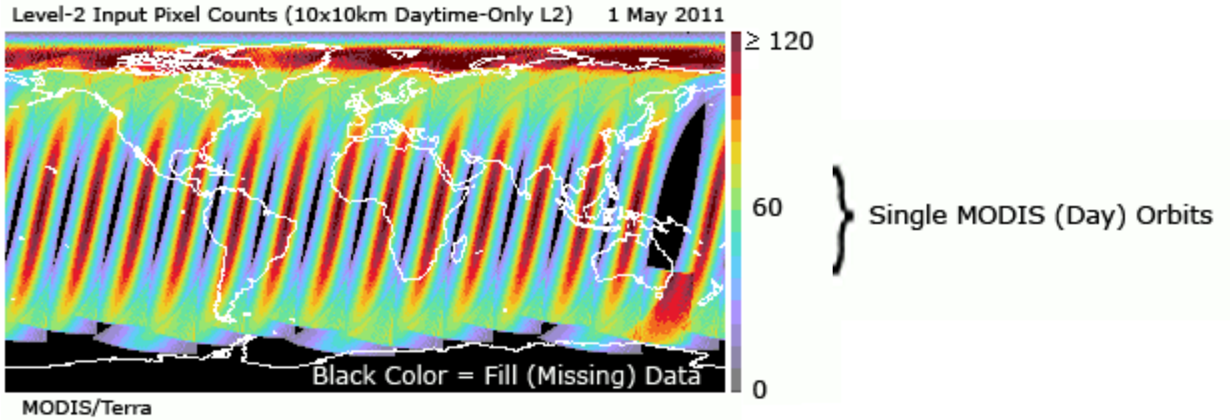
Abstract

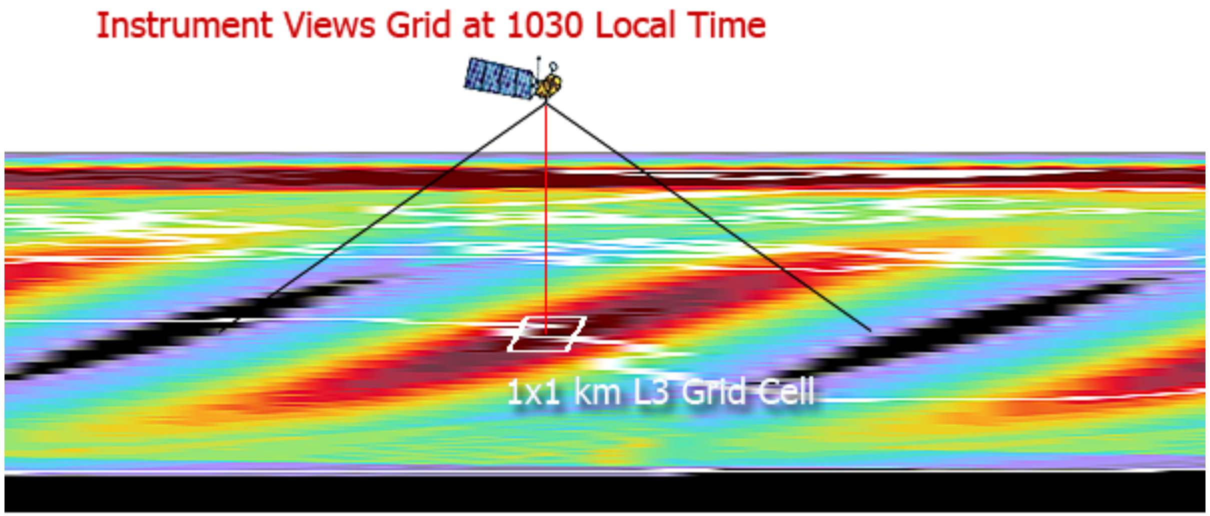
To overcome the complexities associated with combining or comparing multi-sensor data, a statistical gridding algorithm has been developed for projecting data from their unique instrument domain to a uniform space–time domain. The algorithm has two components: 1) a spatial gridding phase in which geophysical properties are filtered on the basis of a set of criteria (e.g., time of day or viewing angle) and then aggregated into nearest neighbor clusters as defined by equal-angle grid cells and 2) a temporal gridding phase in which daily statistics are calculated per grid cell from which longer time-aggregate statistics are derived. The sensitivity of the gridding algorithm is demonstrated using a month of level 1 Visible Infrared Imaging Radiometer Suite (VIIRS) and Cross track Infrared Sounder (CrIS) radiances as an example. Algorithm sensitivity is tested for grid size, number of days in the definition of a time average, viewing angle, and minimum number of observations per grid cell per day. This gridding algorithm greatly facilitates the intercomparison of satellite derived products as well. Its simplicity lends transparency to understanding the behavior of a given parameter and makes it useful for both research and operational use.

Illustration of L2 to L3 Issues

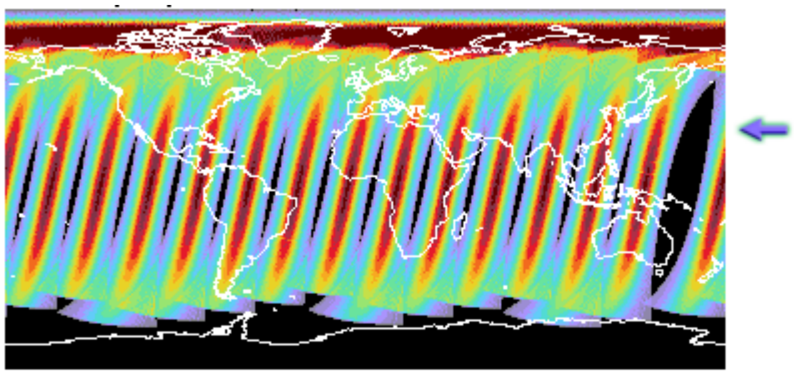
Pixel Count for Daytime



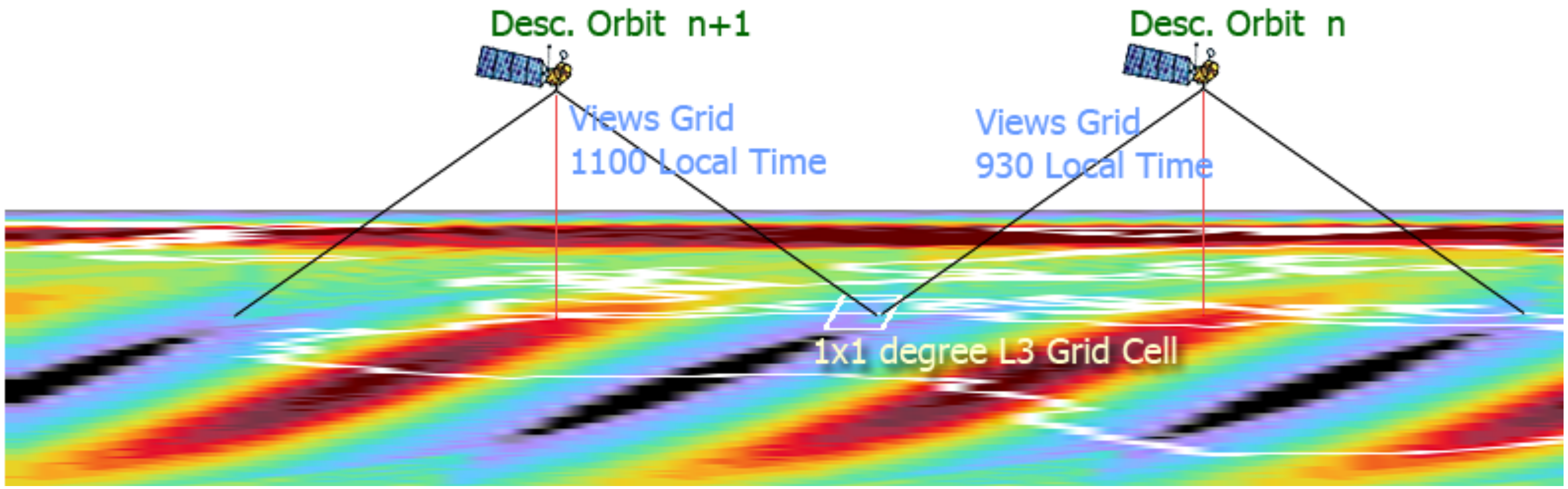
For a L3 Daily 1x1° grid cell between 30N – 30S there is only 1 view of grid per node (asc/dsc)



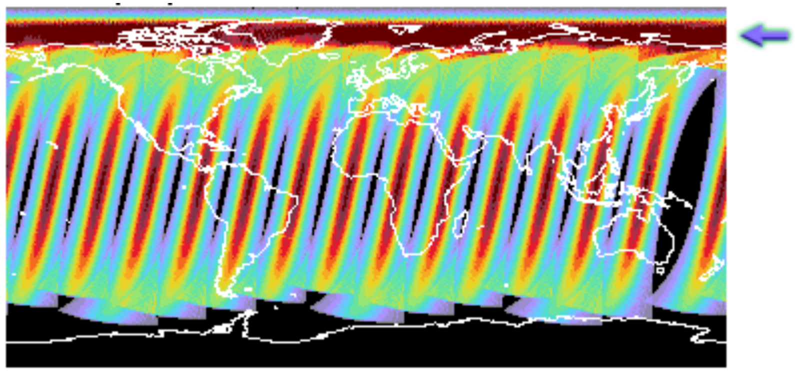
For a 1x1° L3 grid cell around 45N



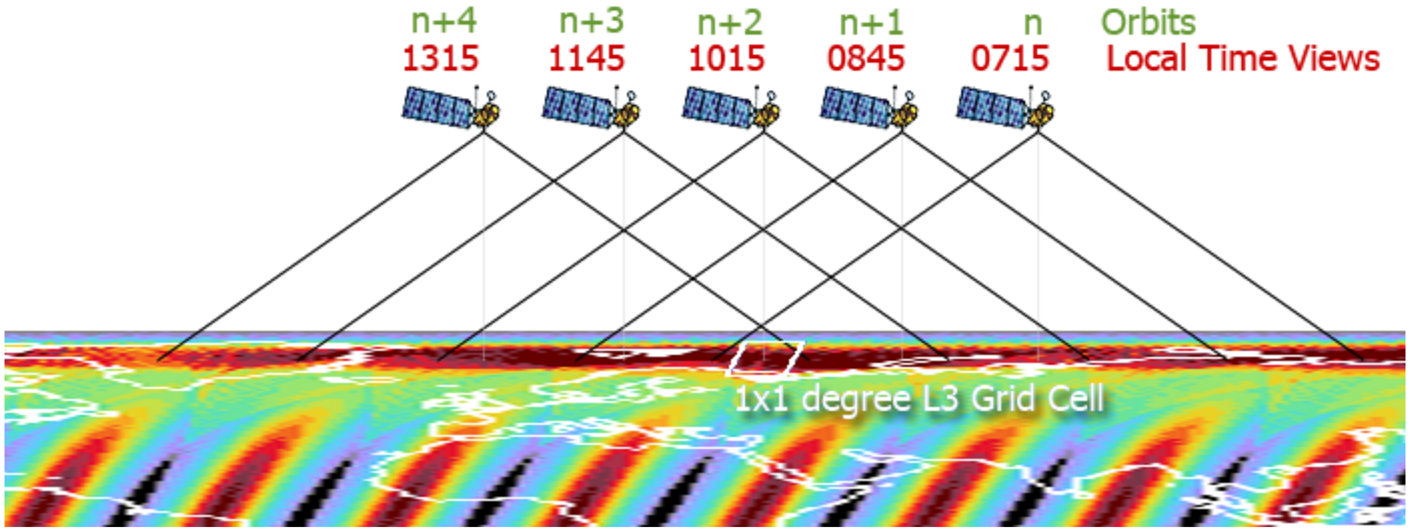
there are 2 views of grid per node (asc/dsc)



For a 1x1° L3 grid cell around 80N



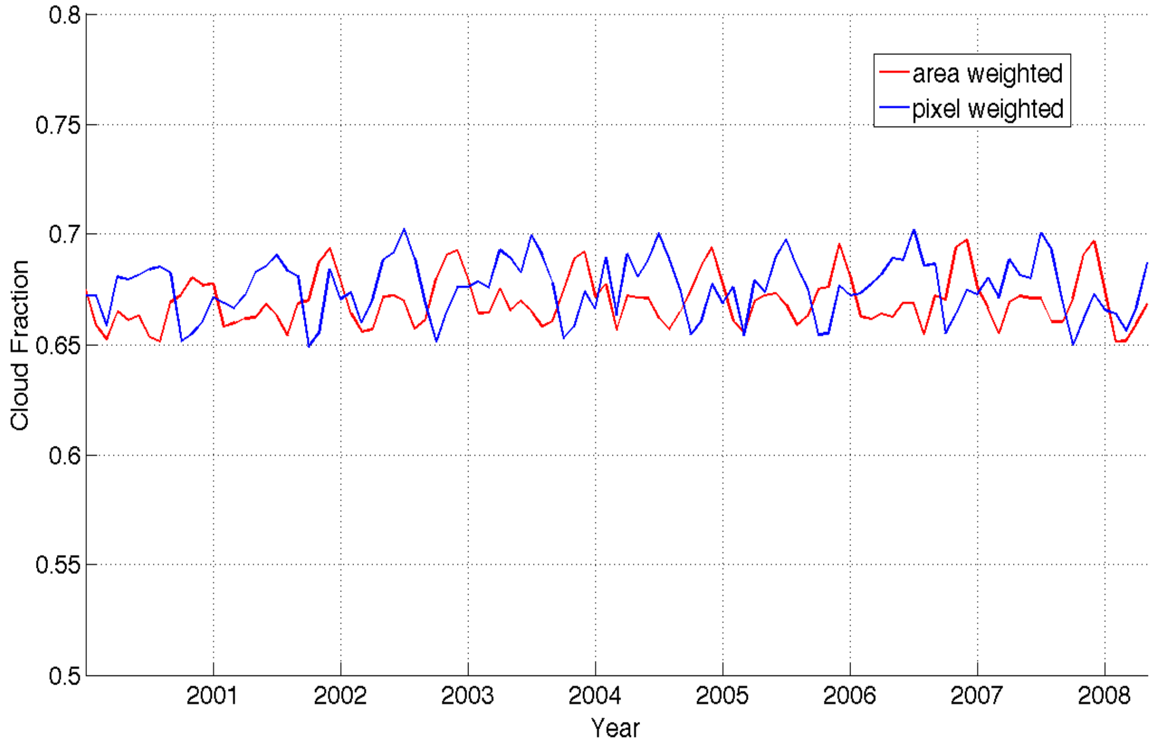
there are many views of grid per node (asc/desc)



Aggregating to L3 by Pixel vs Area Weighting

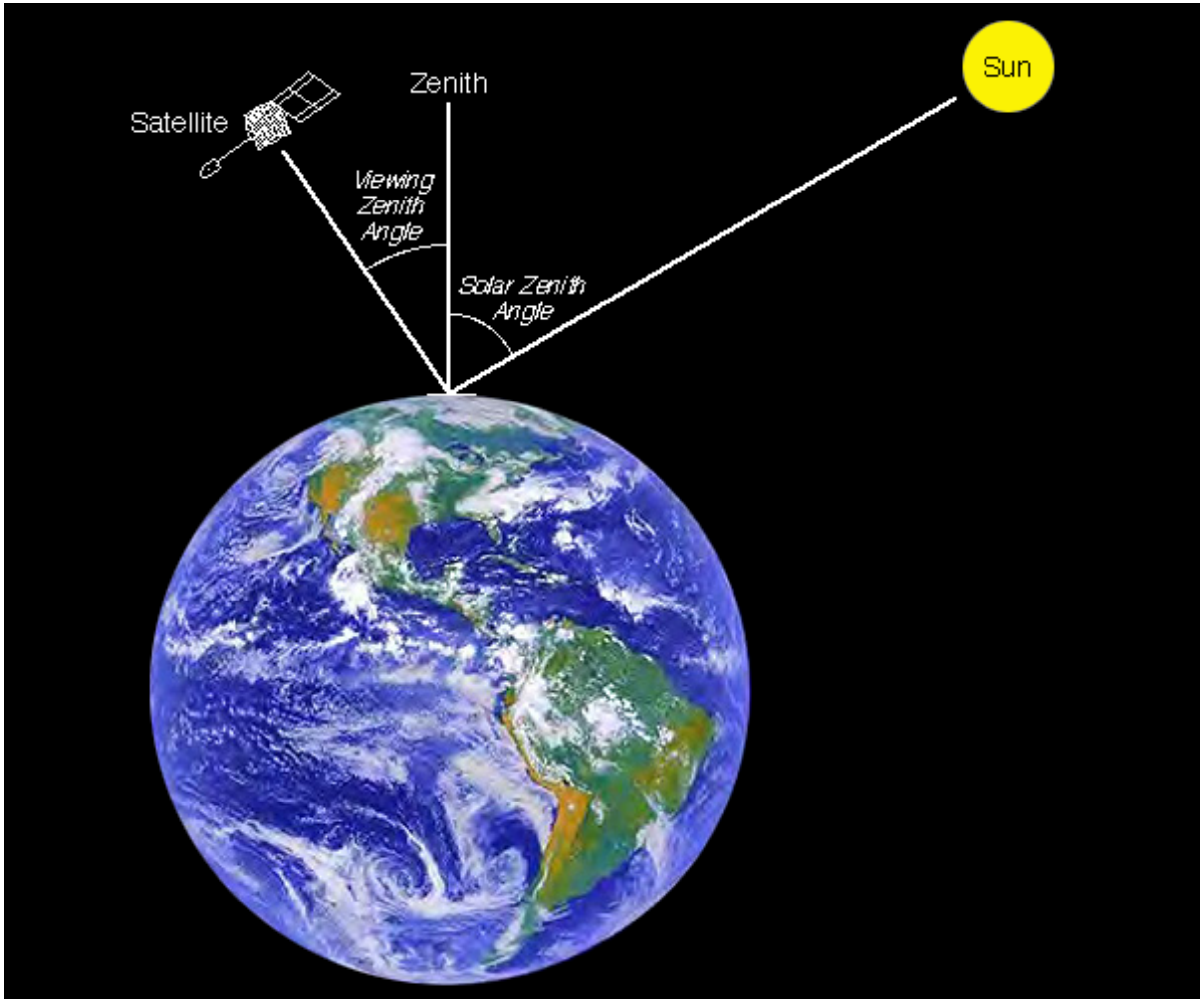
- Offset is not uniform
- Long term mean (.2%) is not changed
- Polar regions are out of phase with mid-latitudes

MODIS Terra Global Cloud Fraction
by Area (Red) vs Pixel (Blue)



Make L3 a Snapshot in Time

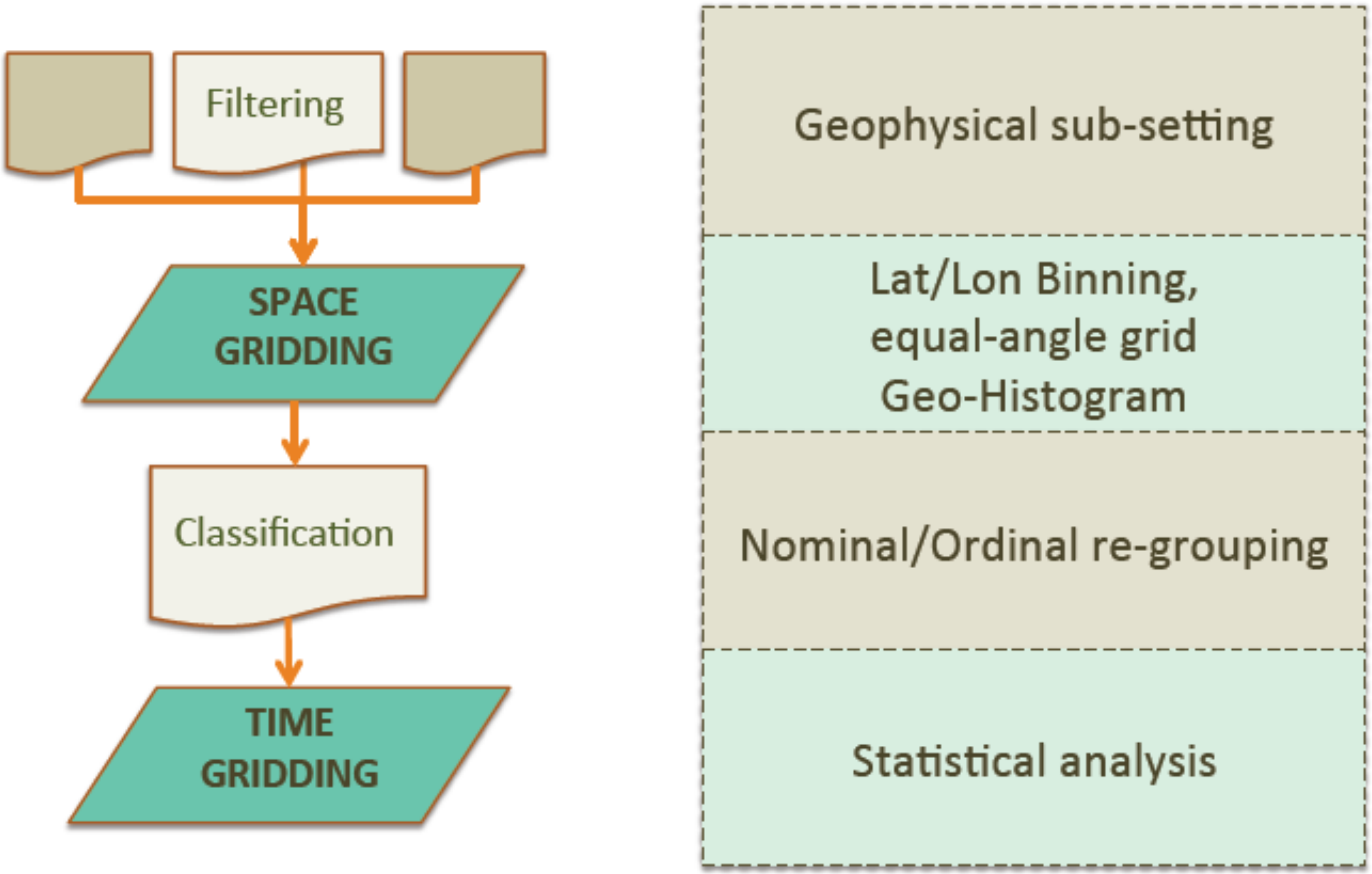
For each 1x1 deg. L3 Grid Cell, use only the L2 Granule that contains data with the most nadir view



STG

Converting from the observation domain into the spatial and temporal domains

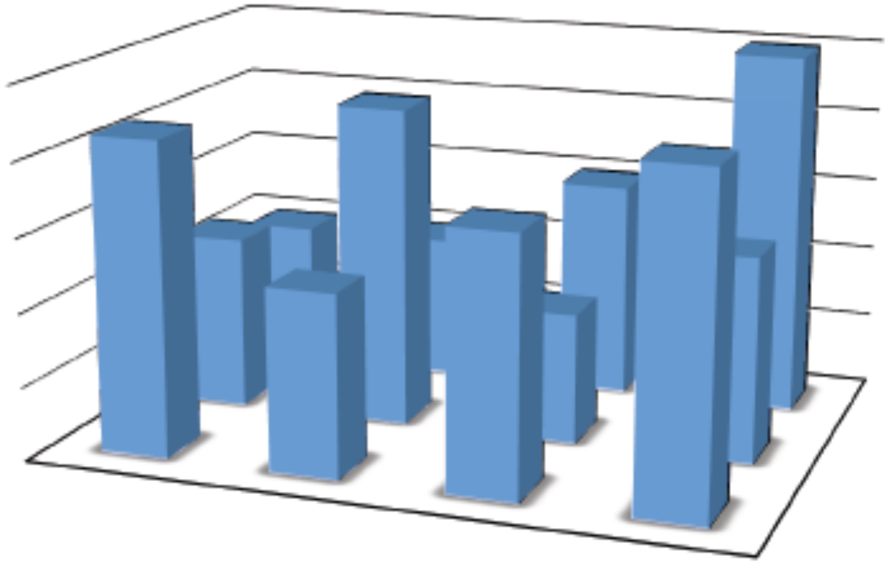
Space-Time-Gridding: Data-to-Information flow



Two phases in the Space-Time-Gridding Framework

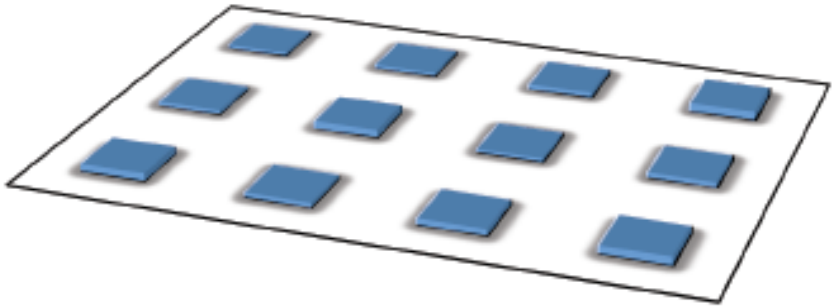
(1) **Space aggregation**

- Parameter filtering (based on ancillary data
- Physical data reduction
- Choice of grid size



(2) **Time aggregation**

– Min sample size testing
– Data classification (e.g., nominal/ordinal scales)
– Statistical data reduction (mean, mode, std-dev, etc.)
– Daily gridded values/statistics aggregated into time. Choice of number of days.



Efficiency through STG Array Indices

Lat Lon revealed by STG indices

STG (i, j) where i =1 to 180 / (lat bin size)

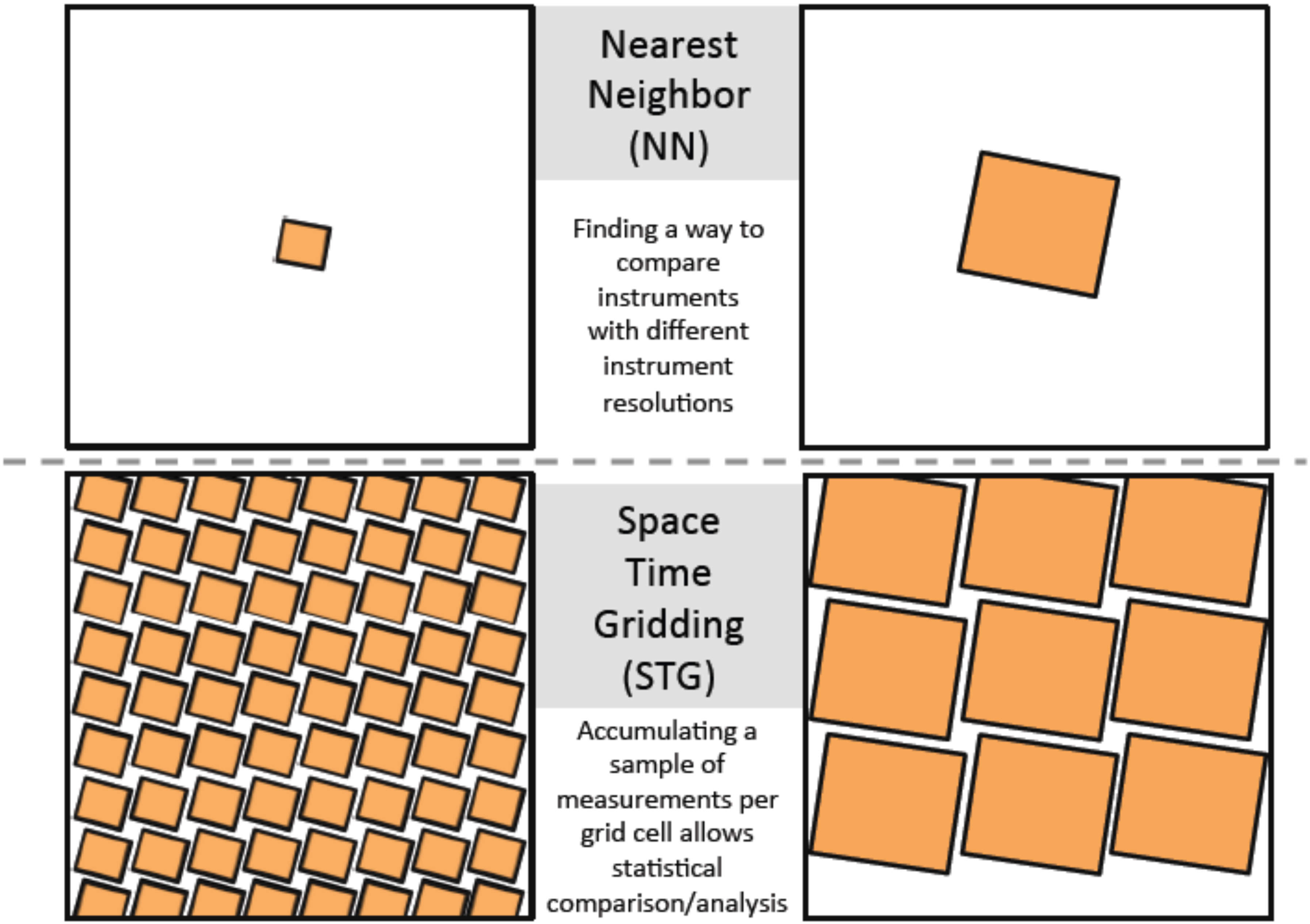
and j = 1 to 360 / (lon bin size)

Example for lat bin = 1 deg and lon bin = 1 deg

STG (31, 175) refers to data in bin located

at 59 N lat and 175 lon (or 5 W)

Space Gridding


Nearest Neighbor (NN)
Finding a way to compare instruments with different instrument resolutions
Space Time Gridding (STG)
Accumulating a sample of measurements per grid cell allows statistical comparison/analysis

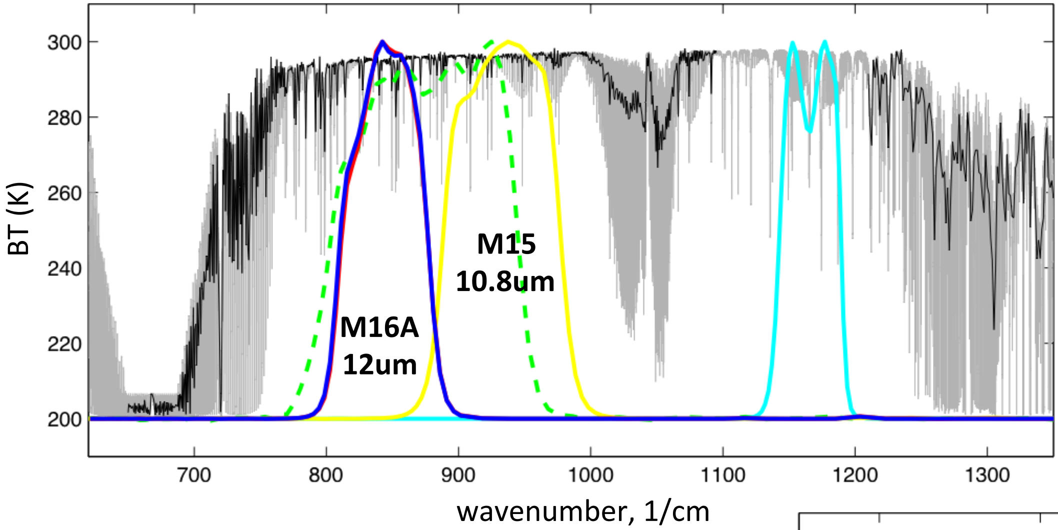
Advantages
Global satellite data are processed on the fly as research needs arise
Output grid size is dynamically determined by the research application
Time averages can be any length of time (number of days ≥ 1)
Instrument independent any GEO or LEO instrument can be processed and/or combined
Fast, Transparent, Easy, Simple Requires basic computer resources only, processes a day of data in minutes

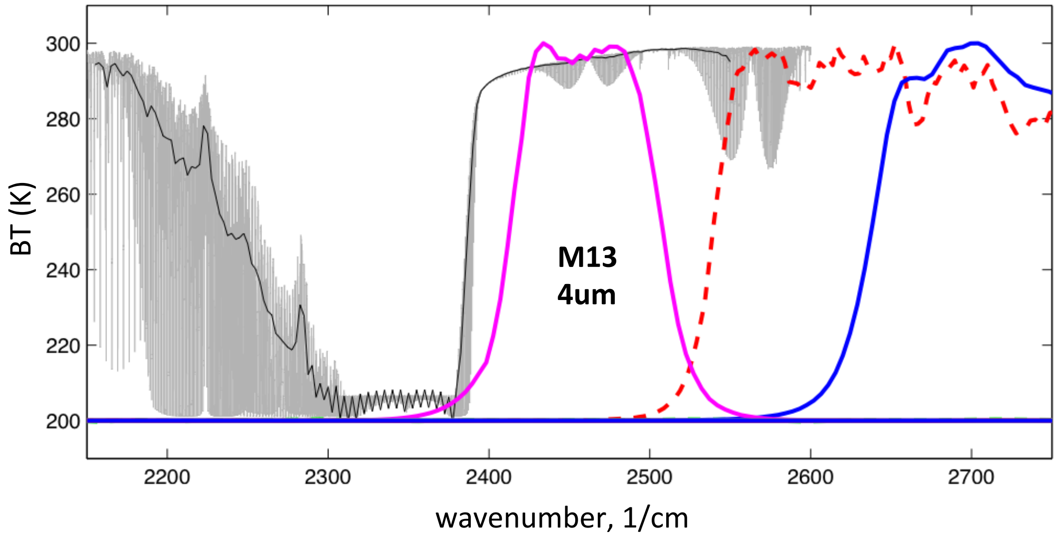
Example 1:
Comparing Radiances from VIIRS and CrIS

- The STG approach is demonstrated in the comparison of the brightness temperature (BT) difference of two instruments, where sensitivity to co-location and heterogeneity issues are overcome.

- Results are calculated for the daytime orbits of two instruments on 1 May 2012 (viewing angles ≤ 32°) gridded to 0.5°/1.0°/2.0° grids
  - Suomi-NPP Visible Infrared Imaging Radiometer Suite (VIIRS)
    at spatial resolution ~1km
  - Suomi-NPP Cross-track Infrared Sounder (CrIS)
    with radiance spectra convolved to VIIRS band M15 (~11μm)
    at spatial resolution of 13.5 km.

Monochromatic spectrum, CrIS spectrum, and VIIRS SRFs

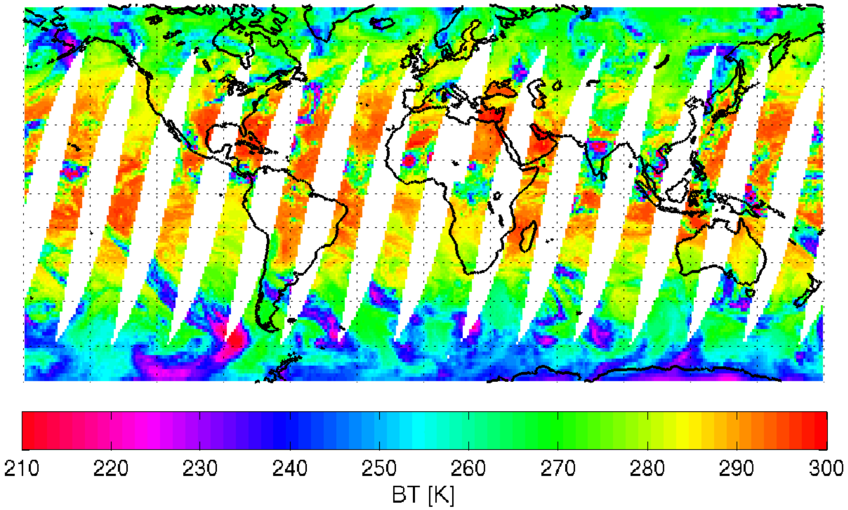




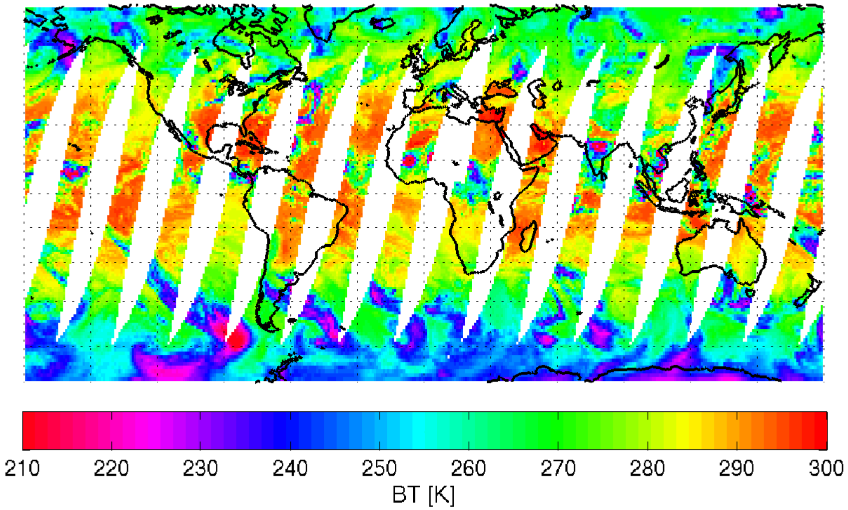
- Comparisons are performed routinely for bands M13, M15, M16A, and I5 (not shown)
- M15 and M16A SRFs include small OOB contributions in the 8.5μm gap region

Example Daily comparisons, M15 band @ 10.8um, Descending

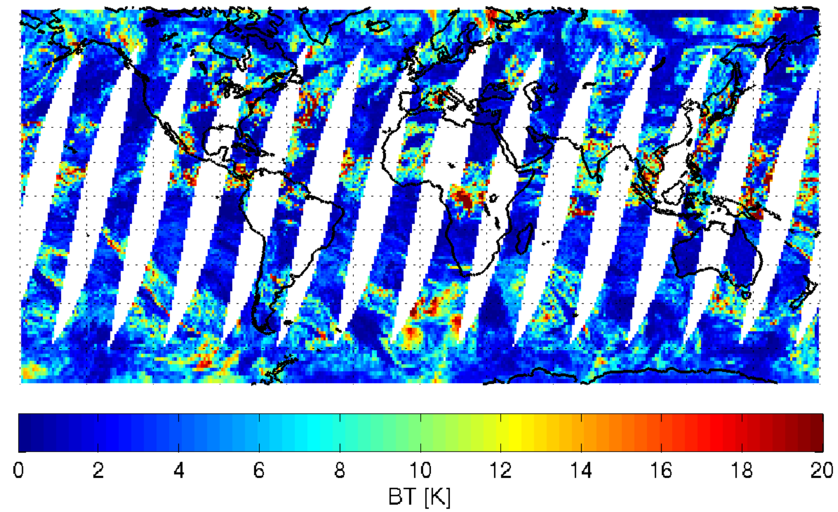
CrIS (convolved with VIIRS SRF) mean within 1deg grid cells



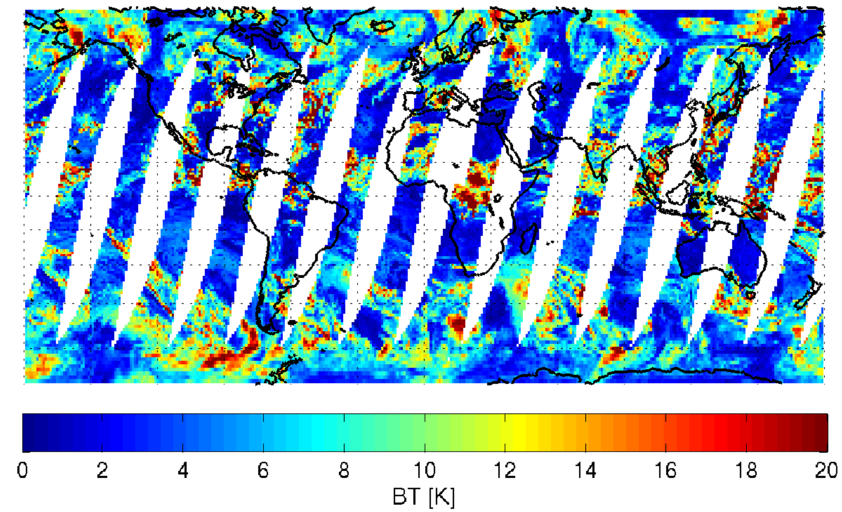
VIIRS mean within 1-deg grid cells



CrIS (convolved with VIIRS SRF) standard deviation within 1deg grid cells



VIIRS standard deviation within 1deg grid cells

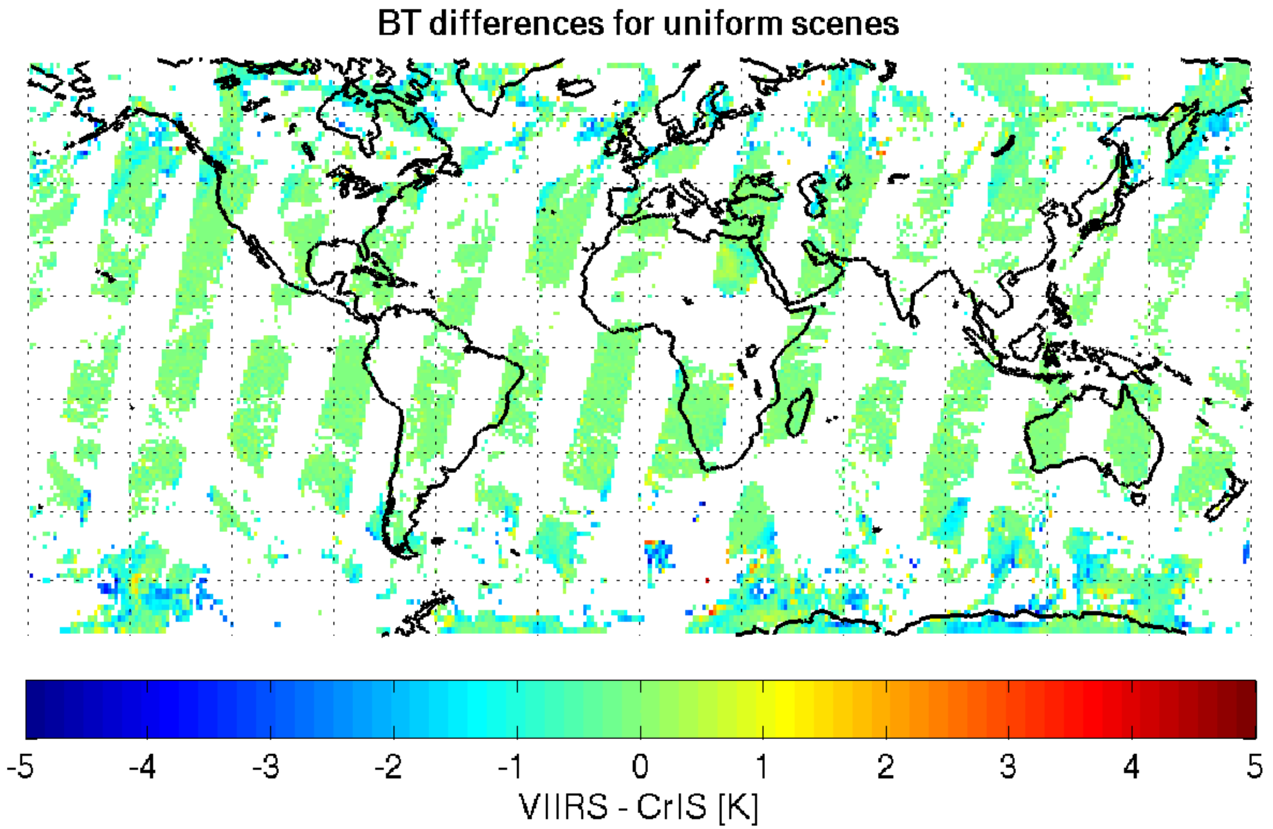


- CrIS processing is ADL/CSPP with v33 Eng. Packet; VIIRS is IDPS product
- Each day includes thousands of grid cells which pass a spatial uniformity test

Spatial Uniformity Test based on Standard Deviation (SD) in each grid cell

(1) Find all cells where VIIRS SD < Threshold 1

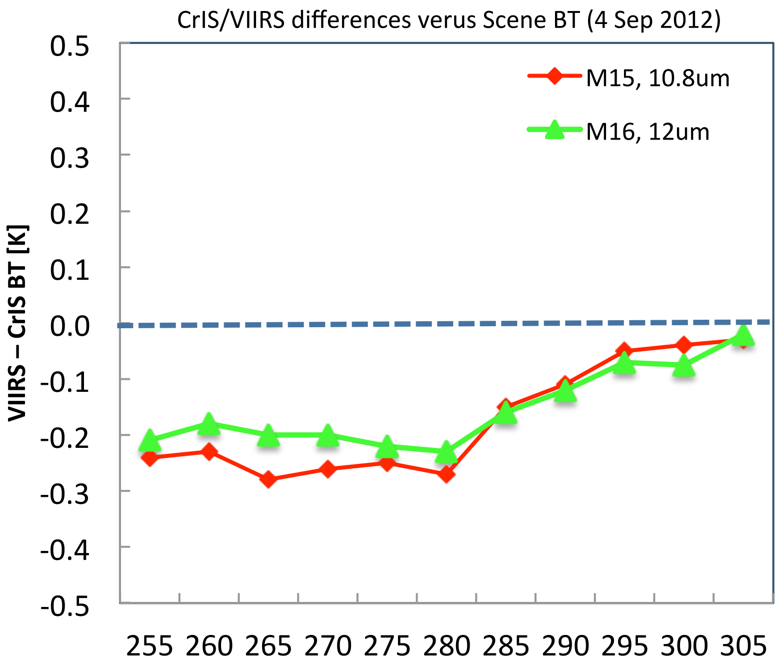
(2) Find all cells in (1) where VCrIS SD < Threshold 2



Limiting results to the tropical zone (30N to 30S), and near-nadir observations (< 32 view angle) then, whatever the uniformity thresholds (barring they're large enough to allow a statistically significant sample size) the BT bias <= 0.1 K

1-degree grid; TROPICAL (30N to 30 S), NEAR-NADIR (view angle < 32)				
Thres1/Thres2	sample size	BT bias	mean SD VIIRS	mean SD VCrIS
0.5/0.25	125	-0.04	0.26	0.176
1.0/0.5	549	-0.04	0.54	0.322
2.0/1.0	1807	-0.05	1.024	0.59
4.0/2.0	3861	-0.06	1.67	1.0337
8.0/4.0	6720	-0.09	2.6575	1.8
10.0/5.0	7405	-0.10	2.956	2.054

Scene Temperature Dependence



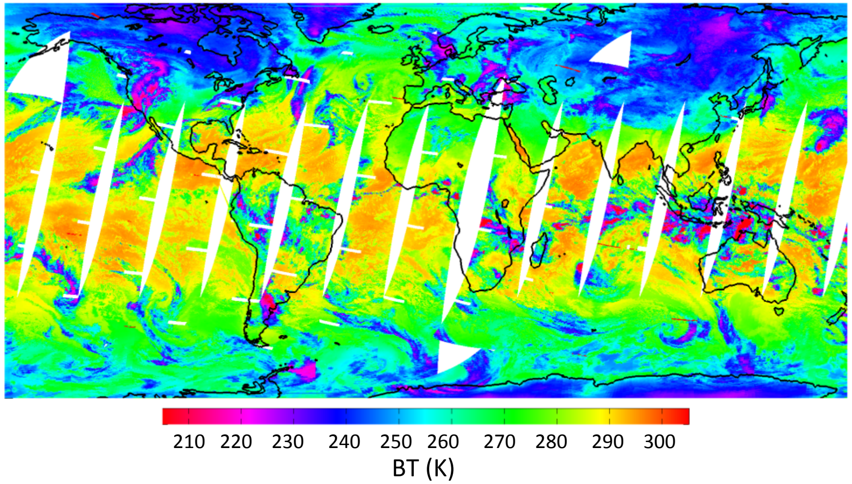
These results are for ONE DAY, NEAR-NADIR (scan angle < 32), and NIGHT-TIME only.

Global, 90 lat limit, thres1/thres2 = 2/2; where VIIRS SD < Thres1; CrIS SD < Thres 2				
	BAND 16		BAND 15	
Scene T	BT Bias	Sample Size	BT Bias	Sample Size
255	-0.21	178	-0.24	165
260	-0.18	259	-0.23	253
265	-0.2	566	-0.28	573
270	-0.2	730	-0.26	722
275	-0.22	683	-0.25	647
280	-0.23	584	-0.27	574
285	-0.16	1229	-0.15	1116
290	-0.12	852	-0.11	749
295	-0.07	1756	-0.05	1449
300	-0.075	252	-0.04	517
305	-0.02	10	-0.03	15

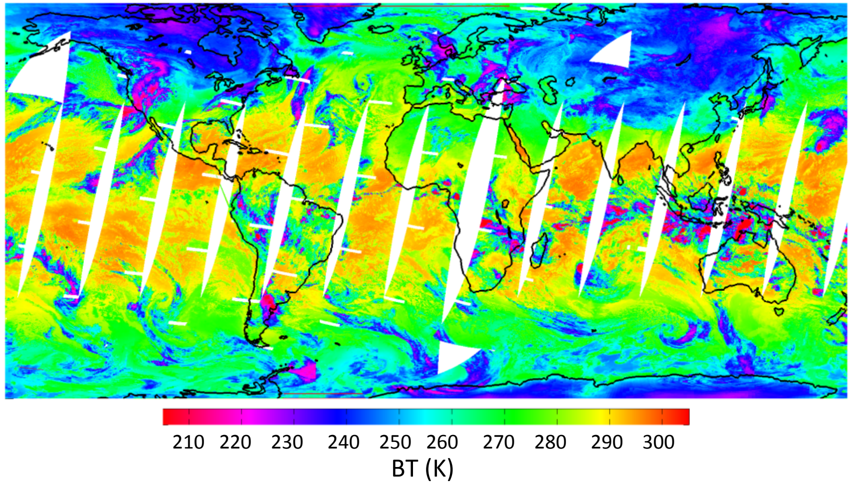
Comparing with Results from Careful Colocations

Example Daily comparisons, M15 band @ 10.8μm, Descending

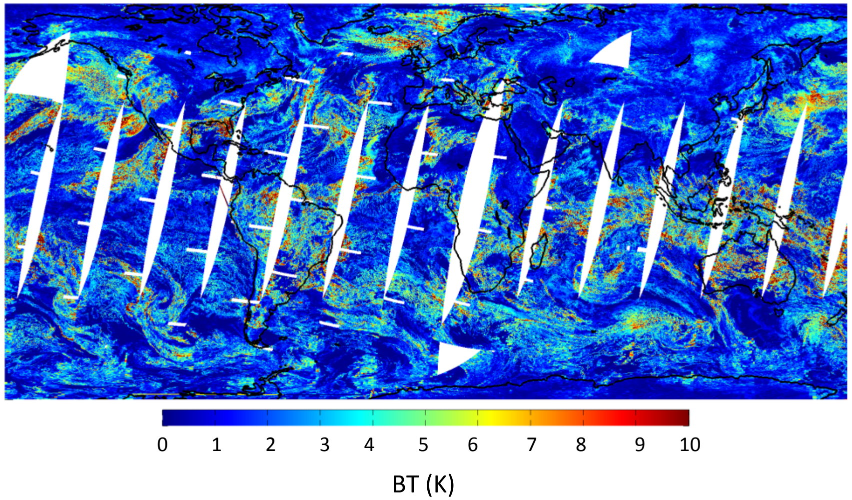
CrIS convolved with VIIRS SRF



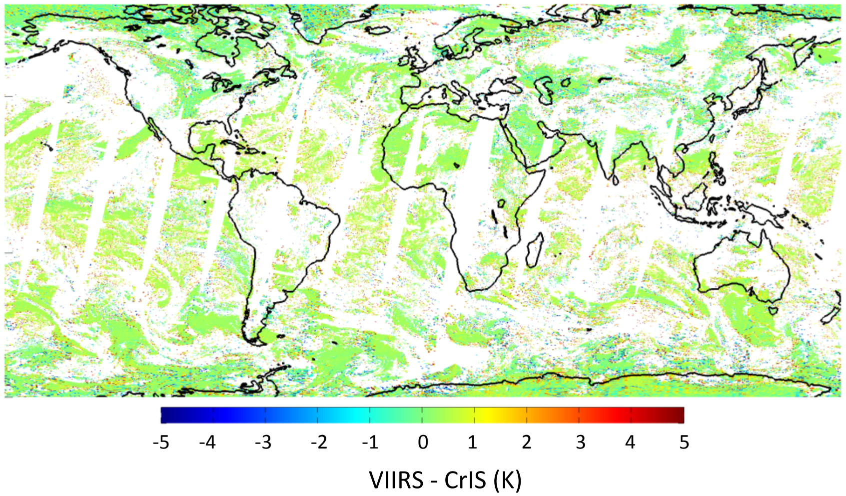
VIIRS mean within CrIS FOVs



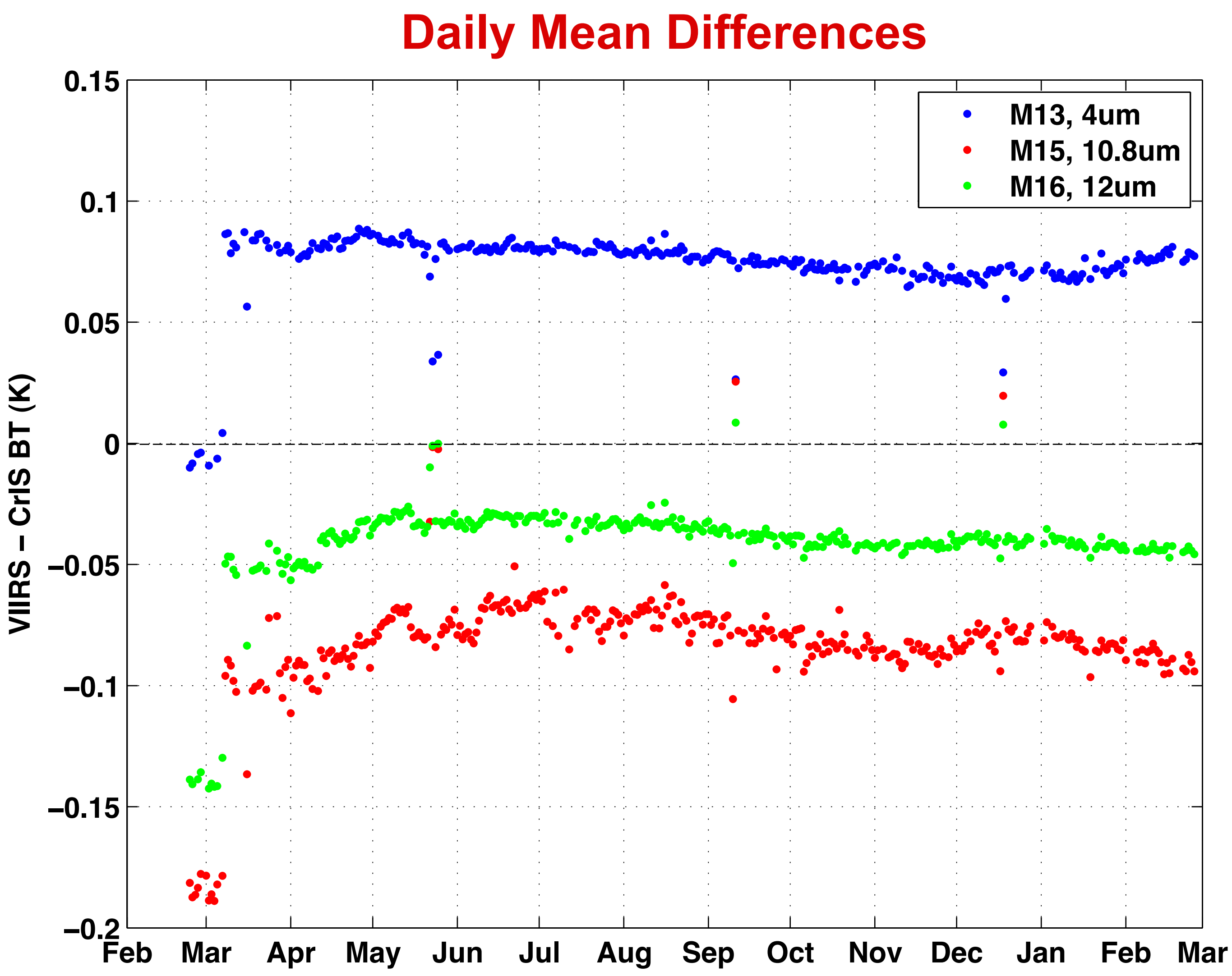
VIIRS standard deviation within CrIS FOVs



Differences for uniform scenes

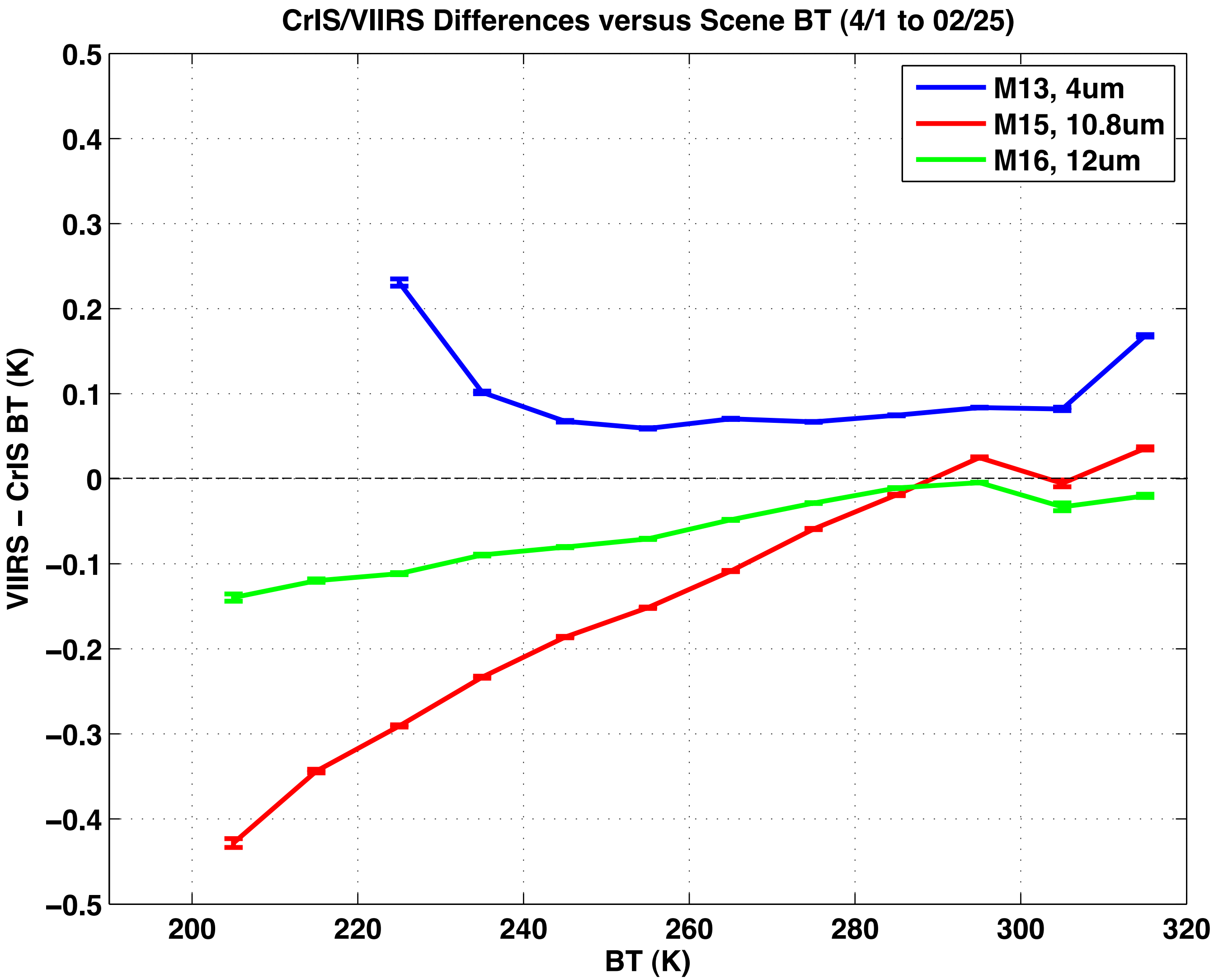


- CrIS processing is ADL/CSPP with v33 Eng. Packet; VIIRS is IDPS product
- Each day includes ~500,000 colocations which pass a spatial uniformity test

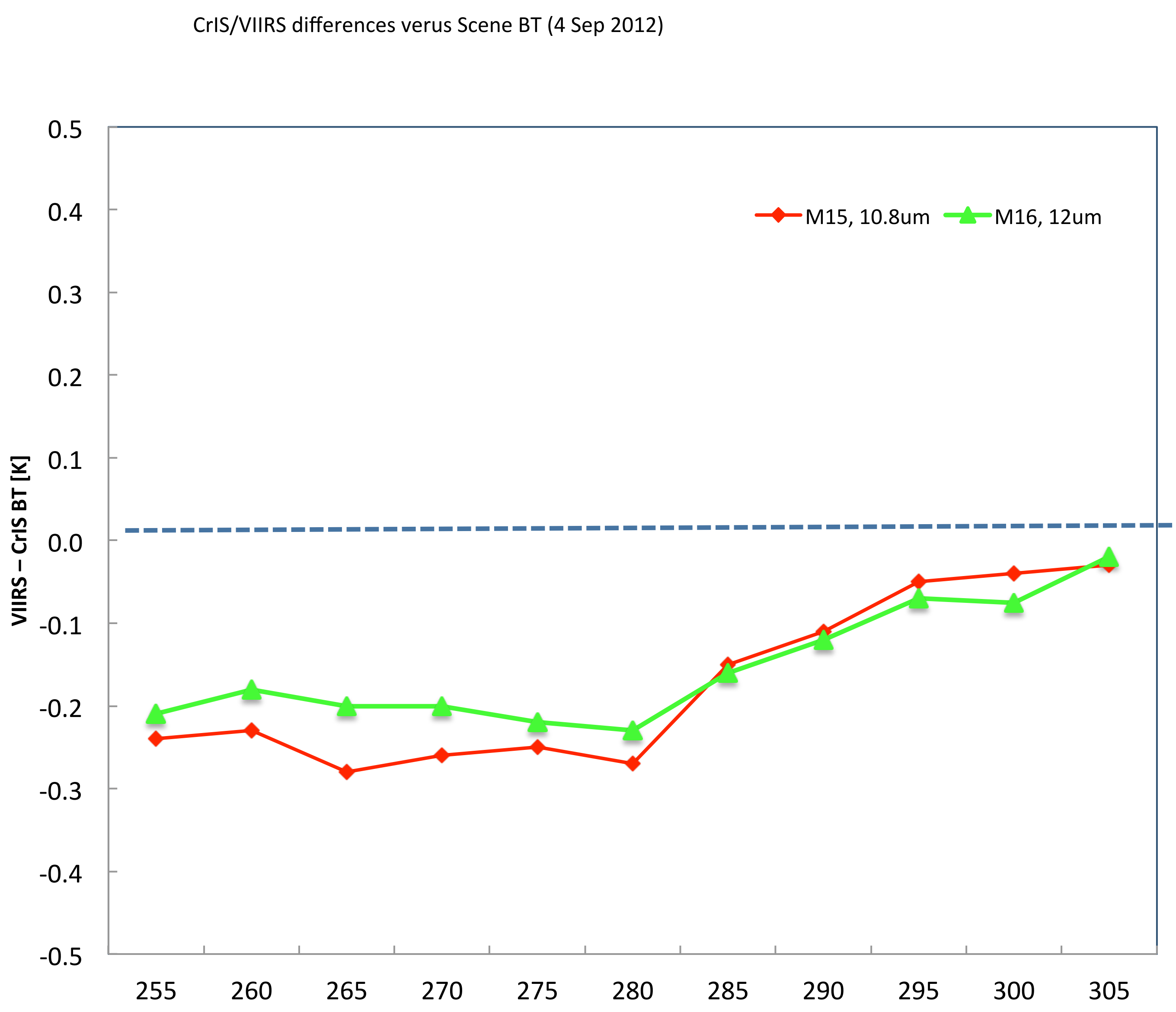


- Daily mean differences are < 0.1K since VIIRS OBC LUT change in early March
- Slow trends are observed in all three bands, ~15 mK, over the past year
- Discontinuities are due to known events (e.g. VIIRS OBC LUT change in early March, shutdown/ restart on March 24/25, VIIRS nonlinearity tests in May, Sep, Dec)

Scene Temperature Dependence



- M13 differences show little dependence on scene BT, except for coldest scenes
- M15 and M16 show clear scene BT dependence of differing magnitude; Further investigations are underway, including signal dependence of the CrIS calibration uncertainty, VIIRS SRF OOB effects, and VIIRS comparisons with IASI and AIRS.


CrIS/VIIRS differences verus Scene BT (4 Sep 2012)
VIIRS – CrIS BT [K]
M15, 10.8um
M16, 12um
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
255
260
265
270
275
280
285
290
295
300
305

Time Gridding

Example of CTP: Weighted Monthly Mean

$$\mathrm{CTP}_m = \frac{\sum_{days} \left(\% \times \mathrm{CTP}_d\right)}{\sum_{days} (\%)} = \frac{\sum_{days} \left(\frac{\mathrm{obs}_C}{\mathrm{obs}_\mathrm{T}} \times \mathrm{CTP}_d \right)}{\sum_{days} \left(\frac{\mathrm{obs}_C}{\mathrm{obs}_\mathrm{T}} \right)}$$

CTP_m = weighted monthly mean of cloud top pressure (CTP)

CTP_d = daily mean of **high** CTP (≥ 440 hPa)

obs_T = total instrument observations per grid point per day

obs_C = total **high** cloud observations per grid point per day

Key Questions

- When is a day of observations not worth averaging?
- What is the minimum threshold of observations necessary to make up an average for that day?
- Is there an objective method with which to calculate a statistically significant CTP_m?

Example of CTP: Weighted Monthly Mean

$$\mathrm{CTP}_m = \frac{\sum_{days}(\% \times \mathrm{CTP}_d)}{\sum_{days}(\%)} = \frac{\sum_{days}\left(\frac{\mathrm{obs}_C}{\mathrm{obs}_\mathrm{T}} \times \mathrm{CTP}_d\right)}{\sum_{days}\left(\frac{\mathrm{obs}_C}{\mathrm{obs}_\mathrm{T}}\right)}$$

Suggested Answer

The necessary total number of observations in a grid box in one day will be determined objectively by the criteria

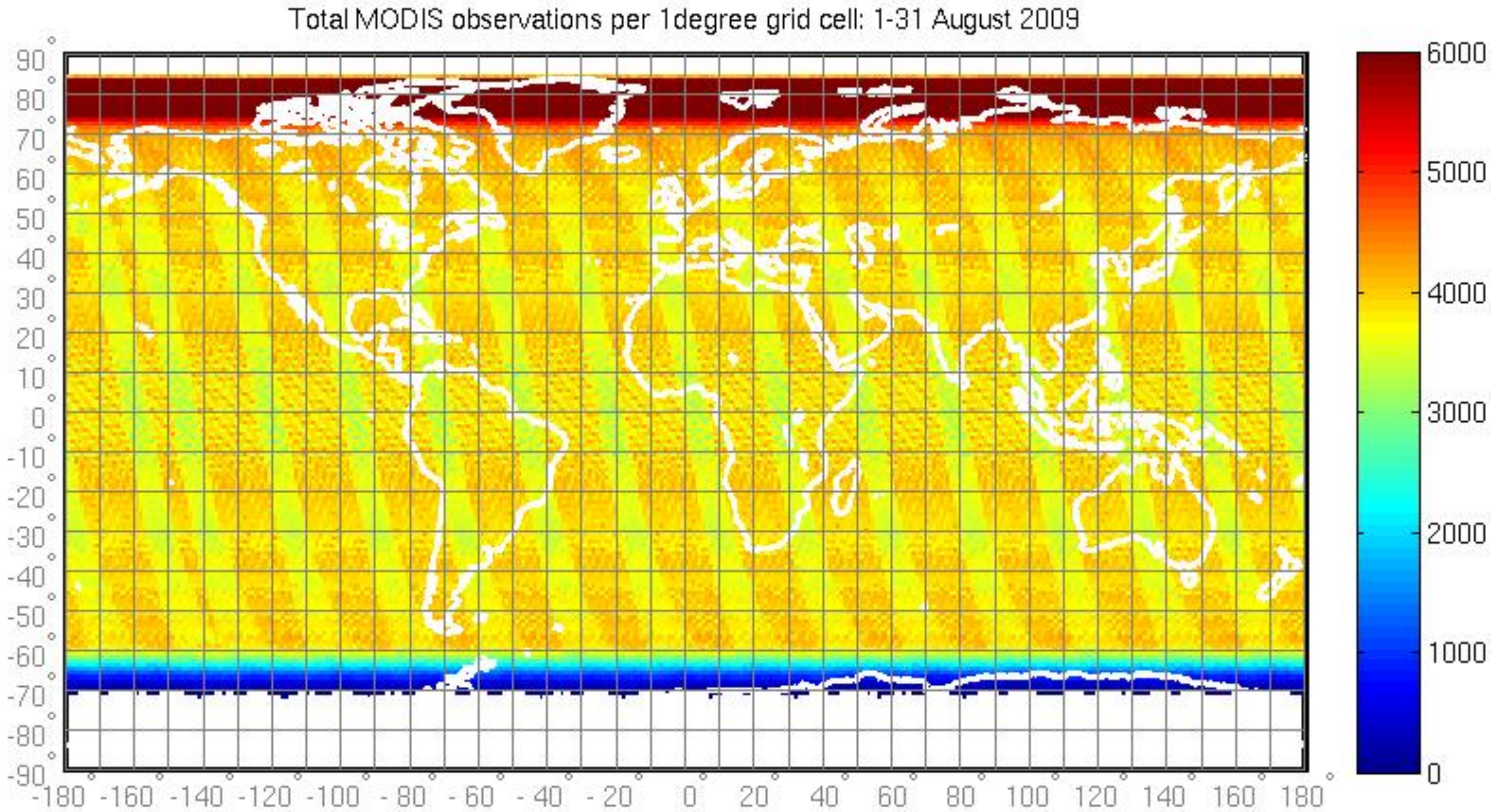
$$\mathrm{Nobs} \geq \mathrm{M(Nobs)} - 1.5\ \sigma(\mathrm{Nobs})$$

where M(Nobs) = mean of daily obs for month = $\dfrac{\sum_{days} \mathrm{obs}_T}{\sum days}$

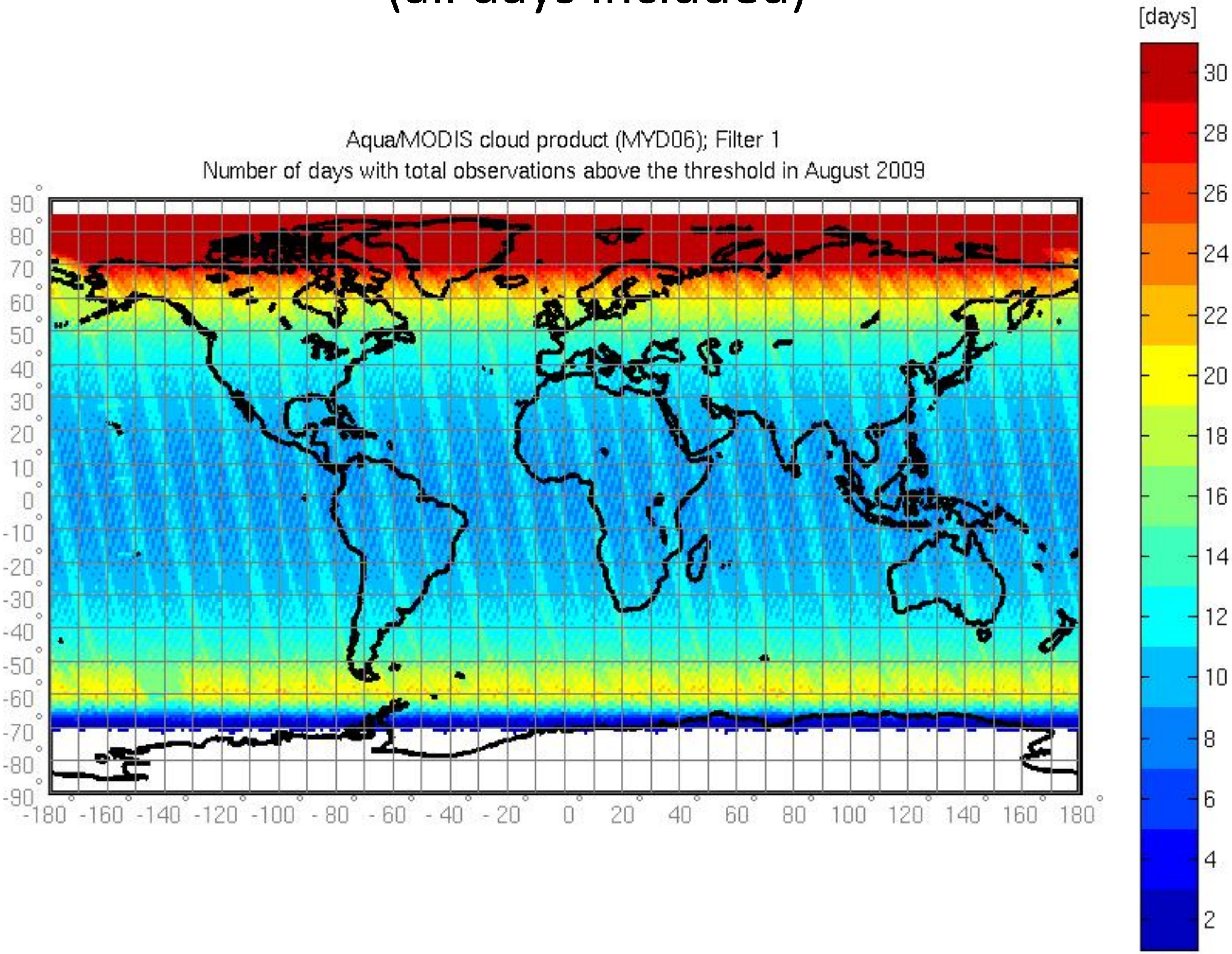
σ(Nobs) = standard deviation of daily obs for month about mean

This includes 93% of a Gaussian distribution

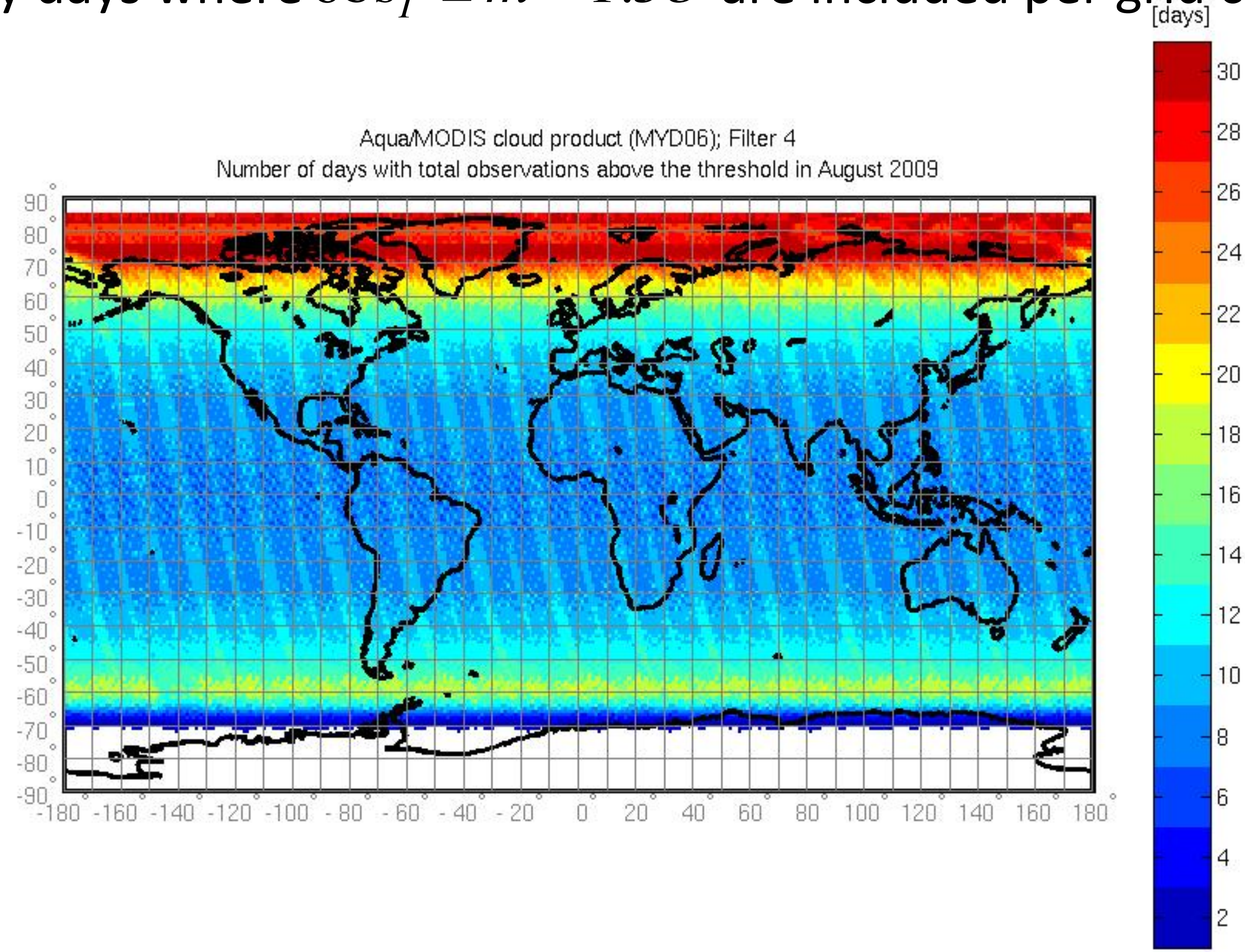
Total MODIS observations per 1 deg cell for 1-31 Aug



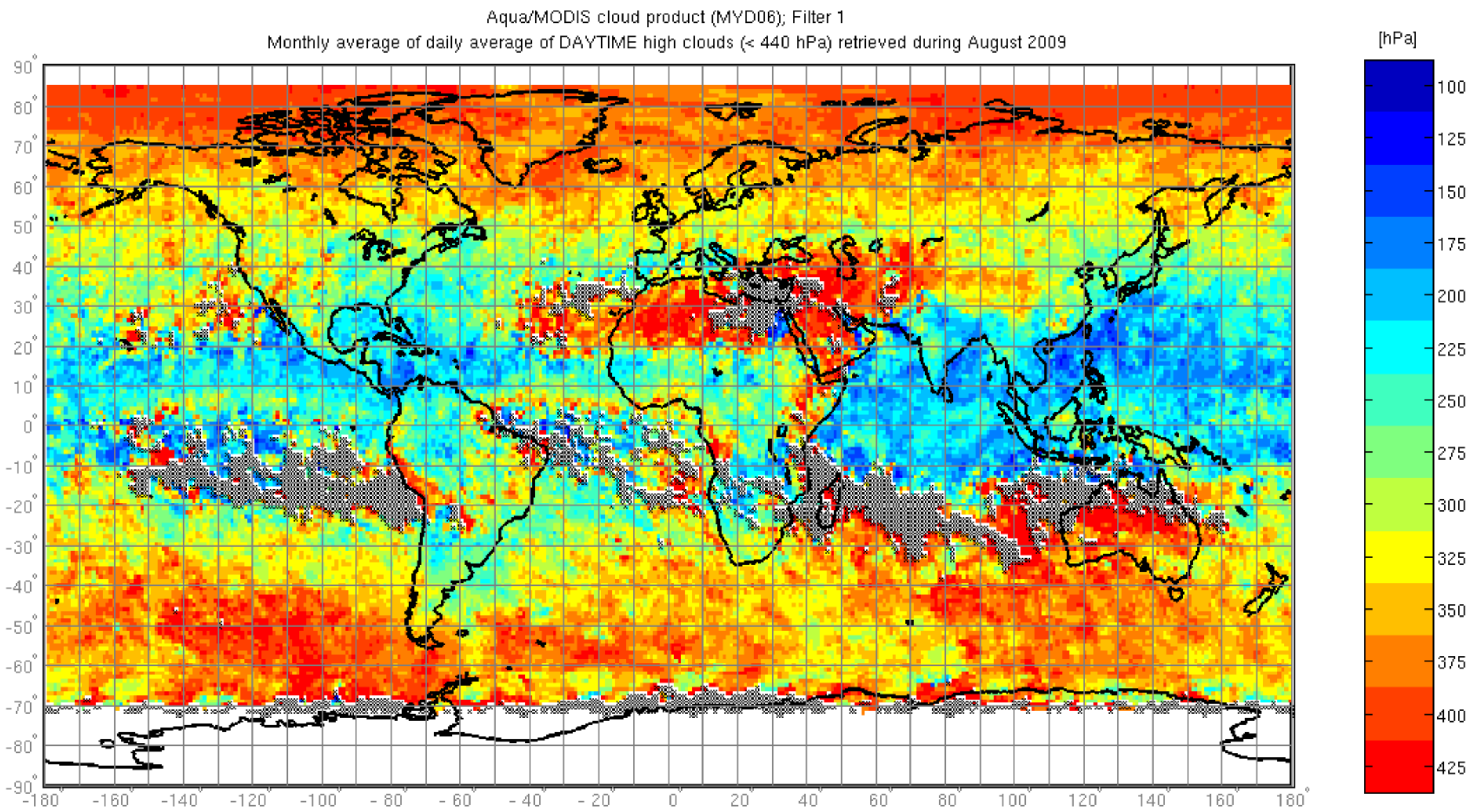
Number days with observations per grid cell in August (all days included)



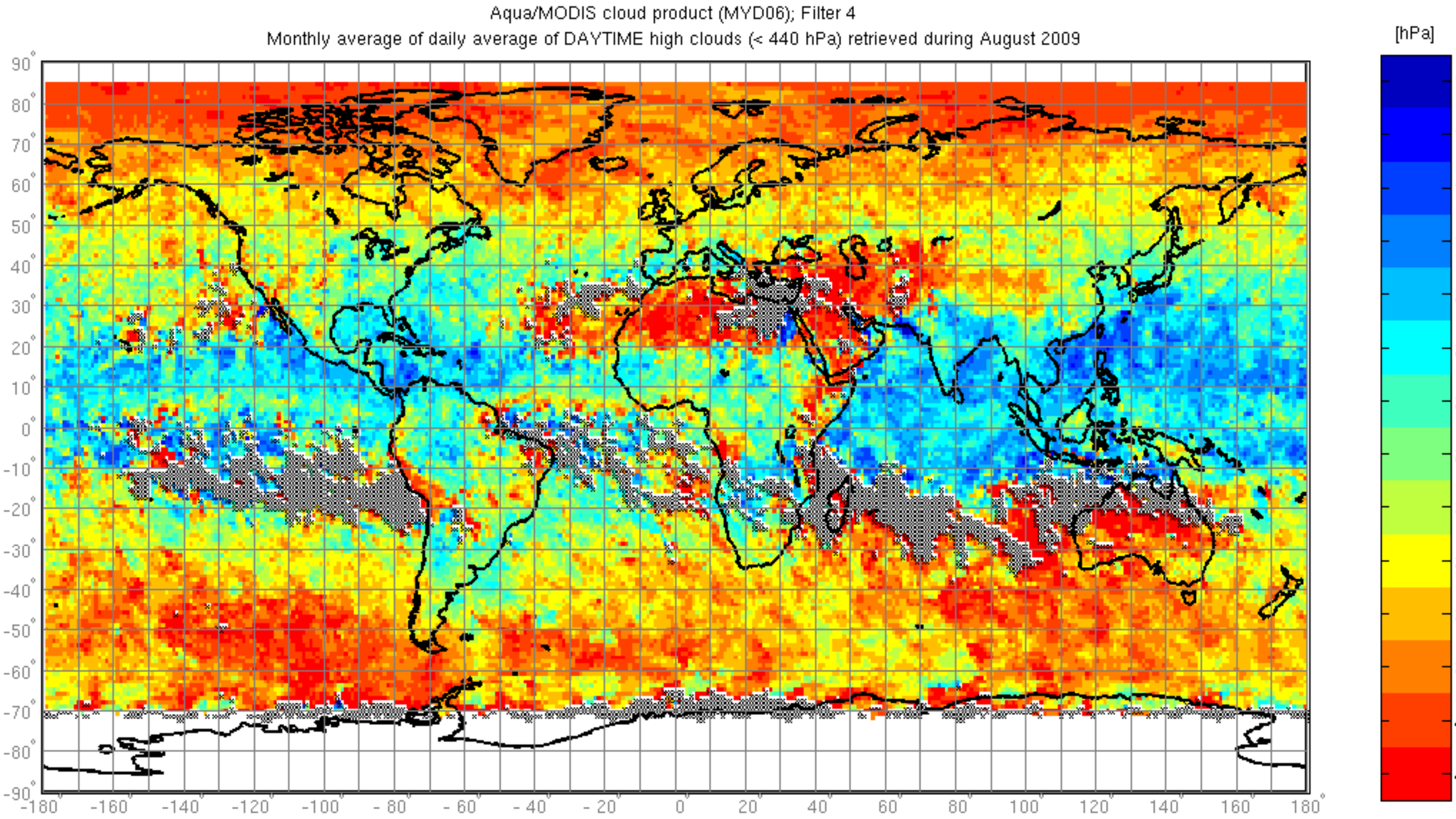
Number days with observations per grid cell in August (only days where $\mathrm{obs}_T \geq \overline{m} - 1.5\sigma$ are included per grid cell)



Mean high CTP for August 2009 (all days included)



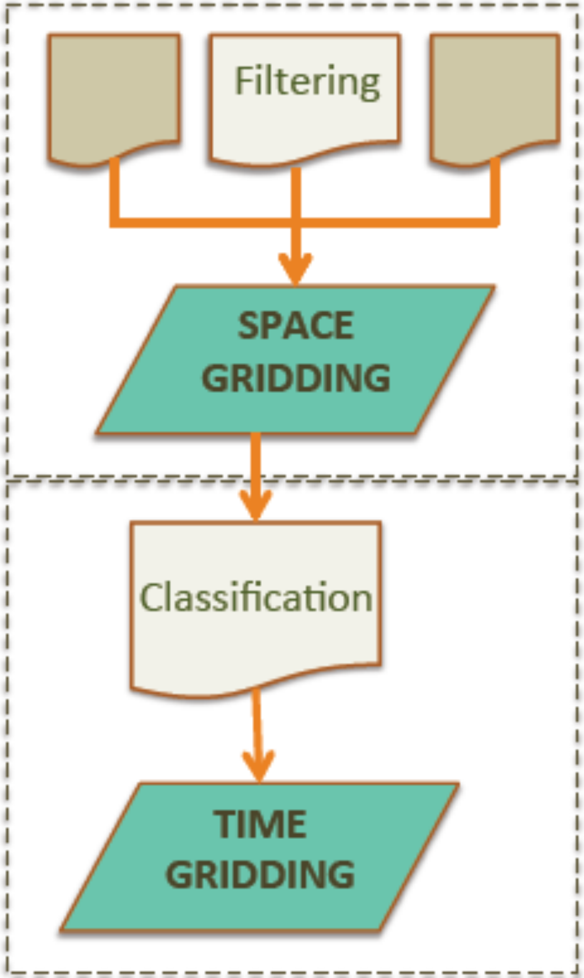
Mean high CTP for August 2009
(low obs days excluded)



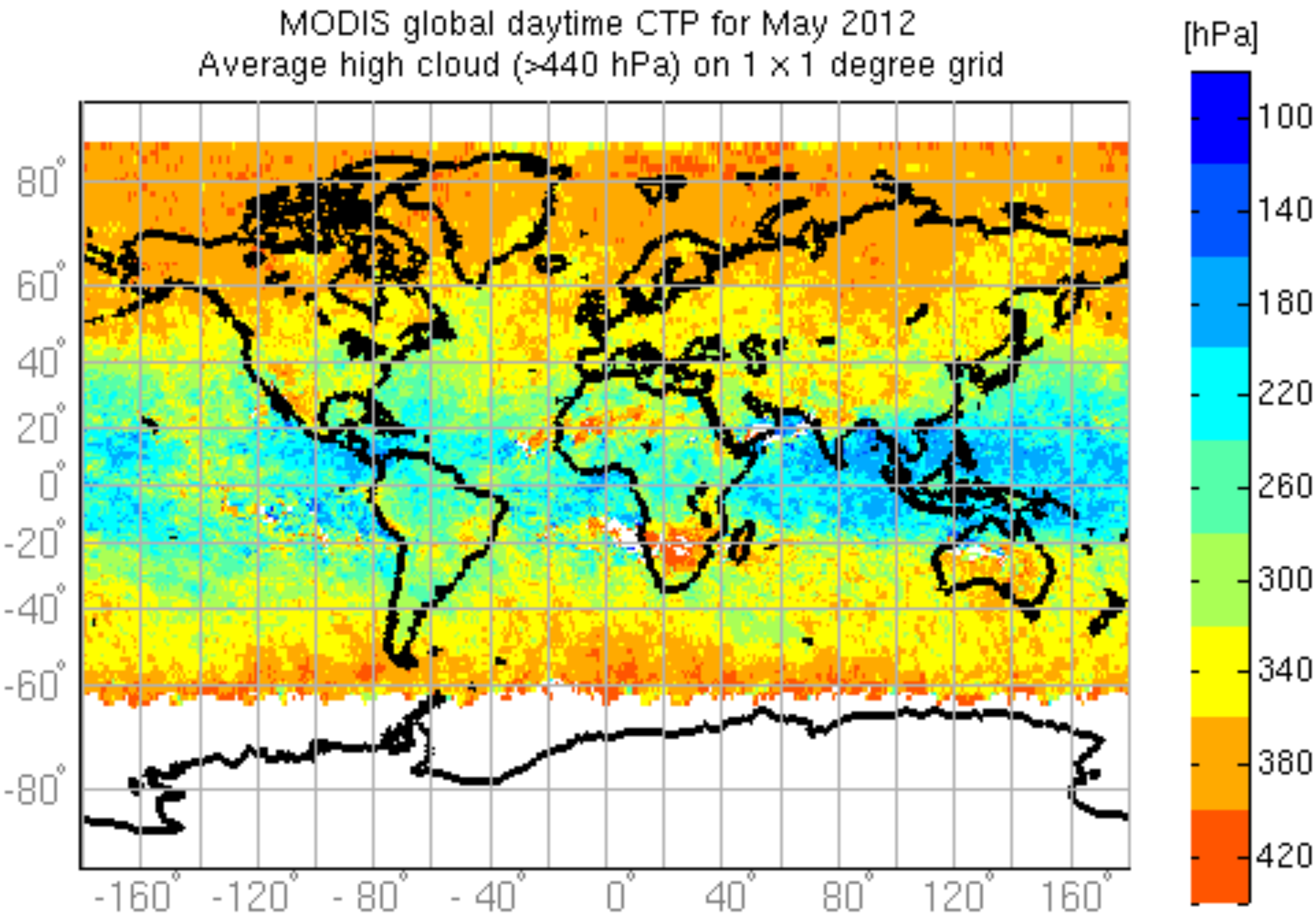
Example 2:
Comparing CTPs from VIIRS and MODIS

STG requirements for two Cloud Properties

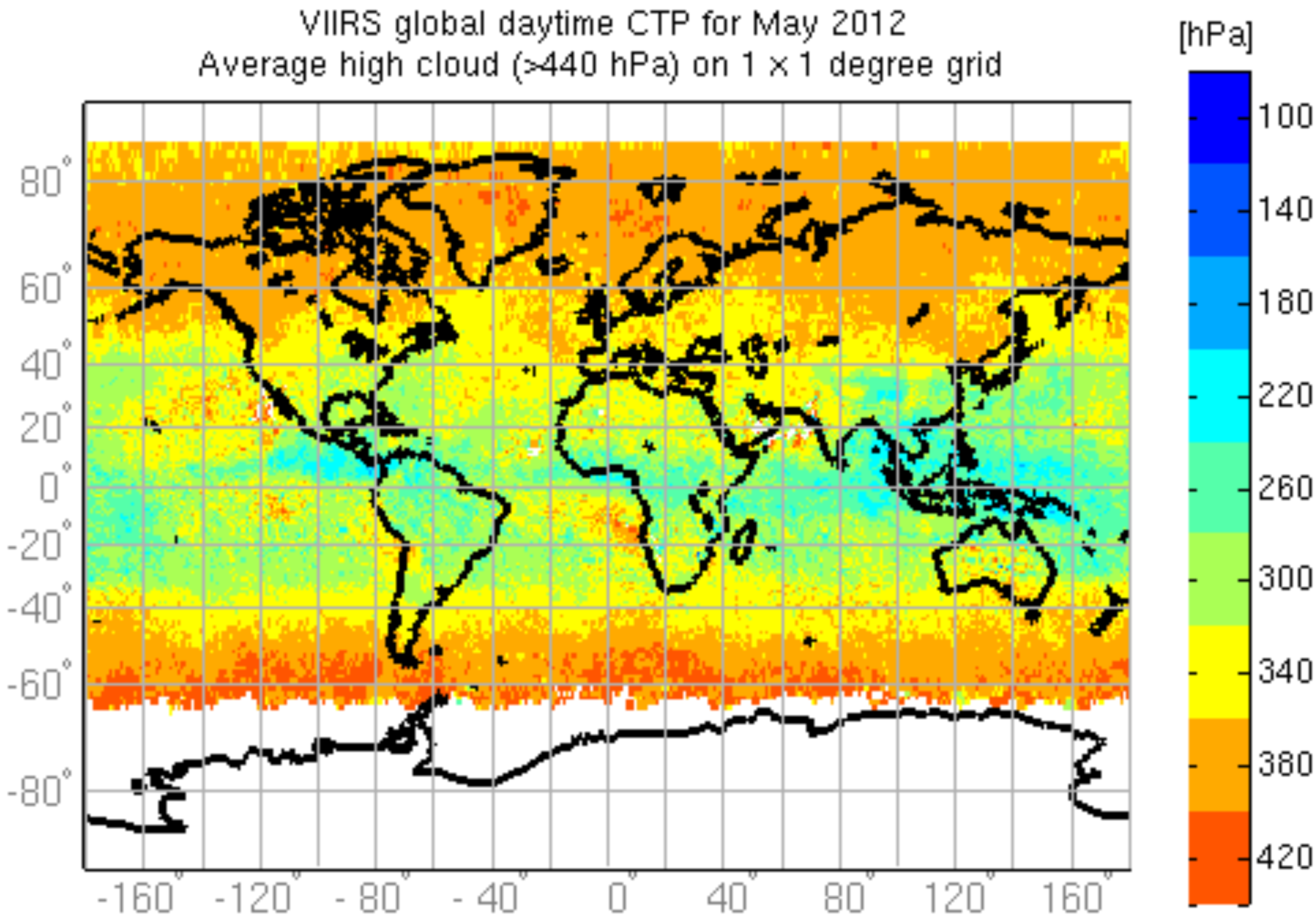
Cloud Top Pressure	Effective Particle Size
Solar zenith: day/night *Viewing angle*: near-nadir	*Cloud phase*: water/ice *Quality flag*: successful retrieval
1-degree grid cell size	*1-degree grid cell size*
According to height: *High* *Mid* *Low*	*According to surface type:* *Ocean, coastal* *desert, land*
Monthly average is average of daily averages weighed by % cloudiness	*Monthly average is average of all values weighed by total number of observations*



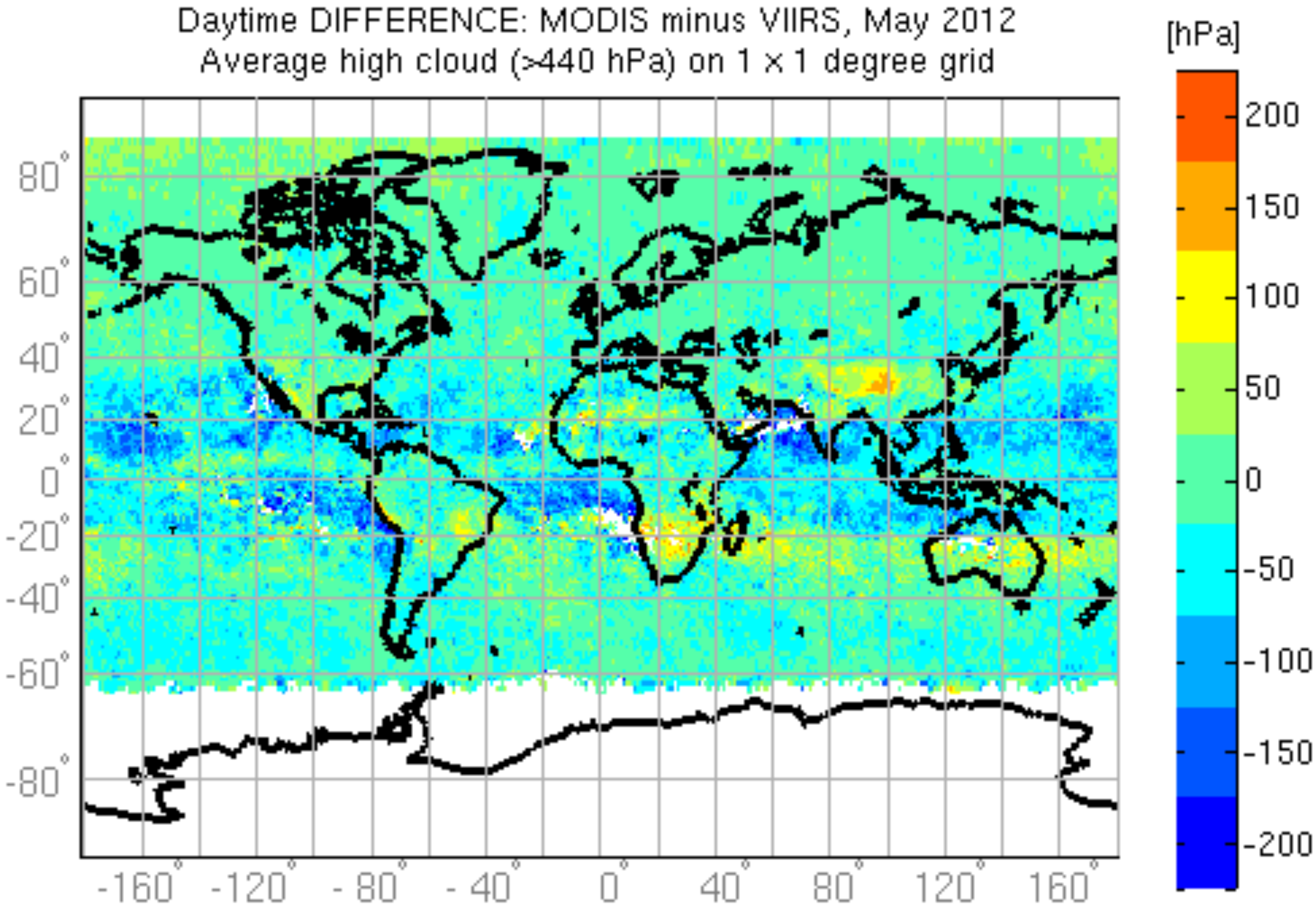
Daytime MODIS-c6 average high CTP



Daytime VIIRS average high CTP



Daytime difference: MODIS minus VIIRS



Conclusions

- STG offers a fast, transparent, and simple procedure for accumulating level 3 data
- STG is instrument (sounder or imager) and orbit (geo or leo or other) independent
- STG space and time intervals can be easily adjusted
- STG enables radiance or derived product intercomparisons
- Global satellite data are processed on the fly as research needs arise

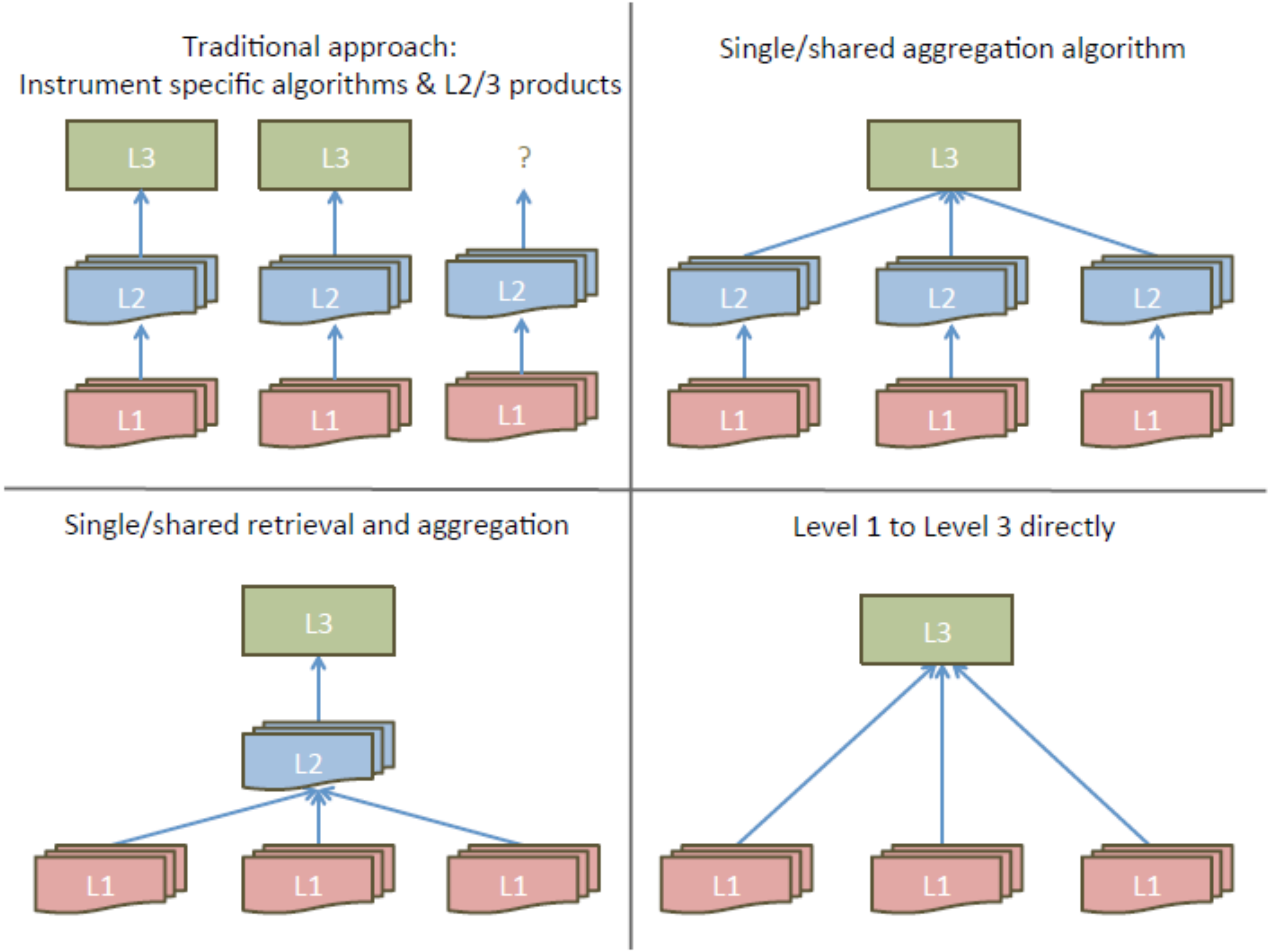
Extra Slides

Aggregating Data into Information

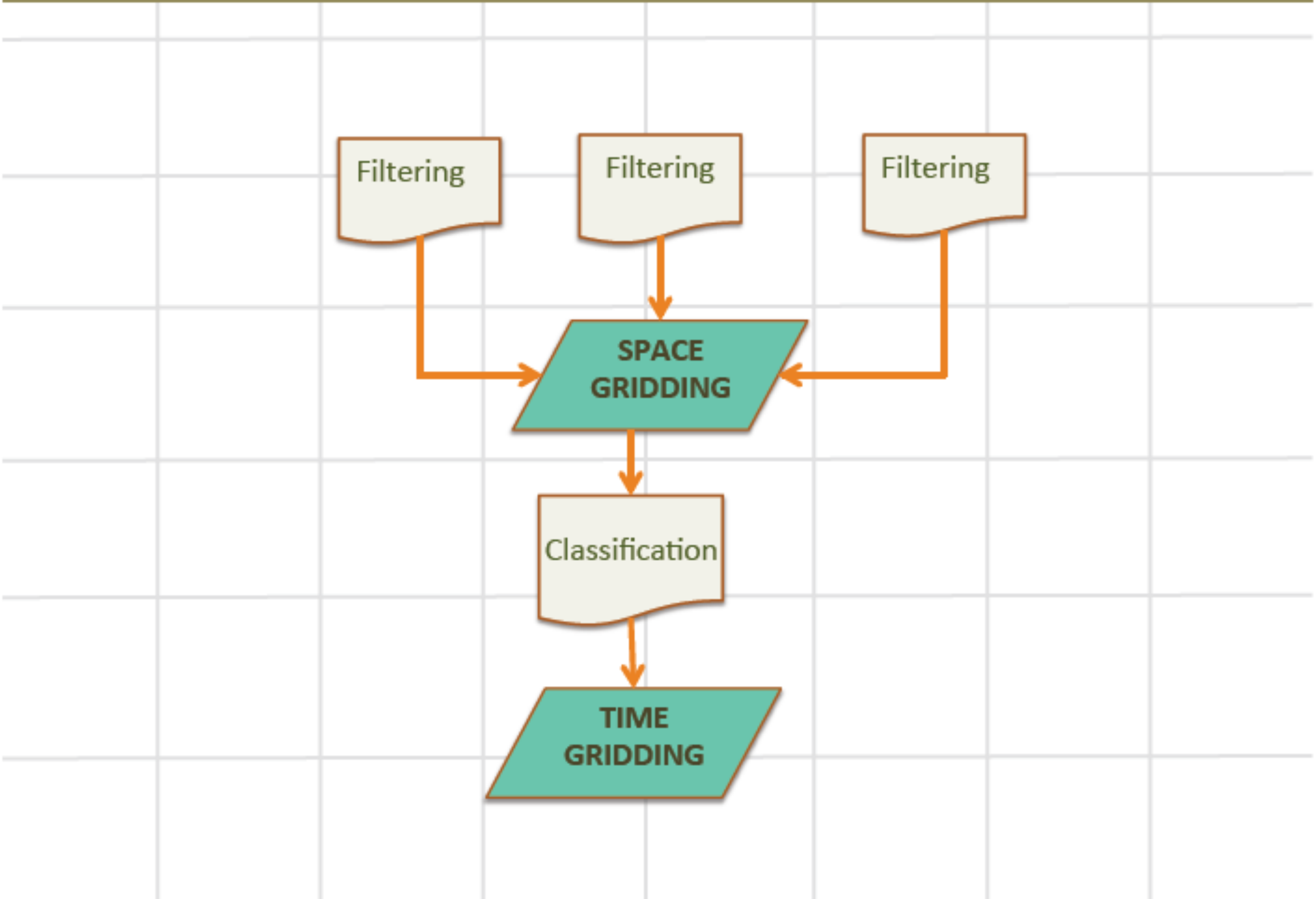
- It's not (only) about visualization and data reduction
- Its about performing analysis in a uniform space.
- It's about doing science in a regularized data environment
- It's about a neutralizing instrument differences.
- Composite data products
- Higher level information – environmental monitoring, indicators of change, etc.

What are the goals of space-time-grid (STG) framework?

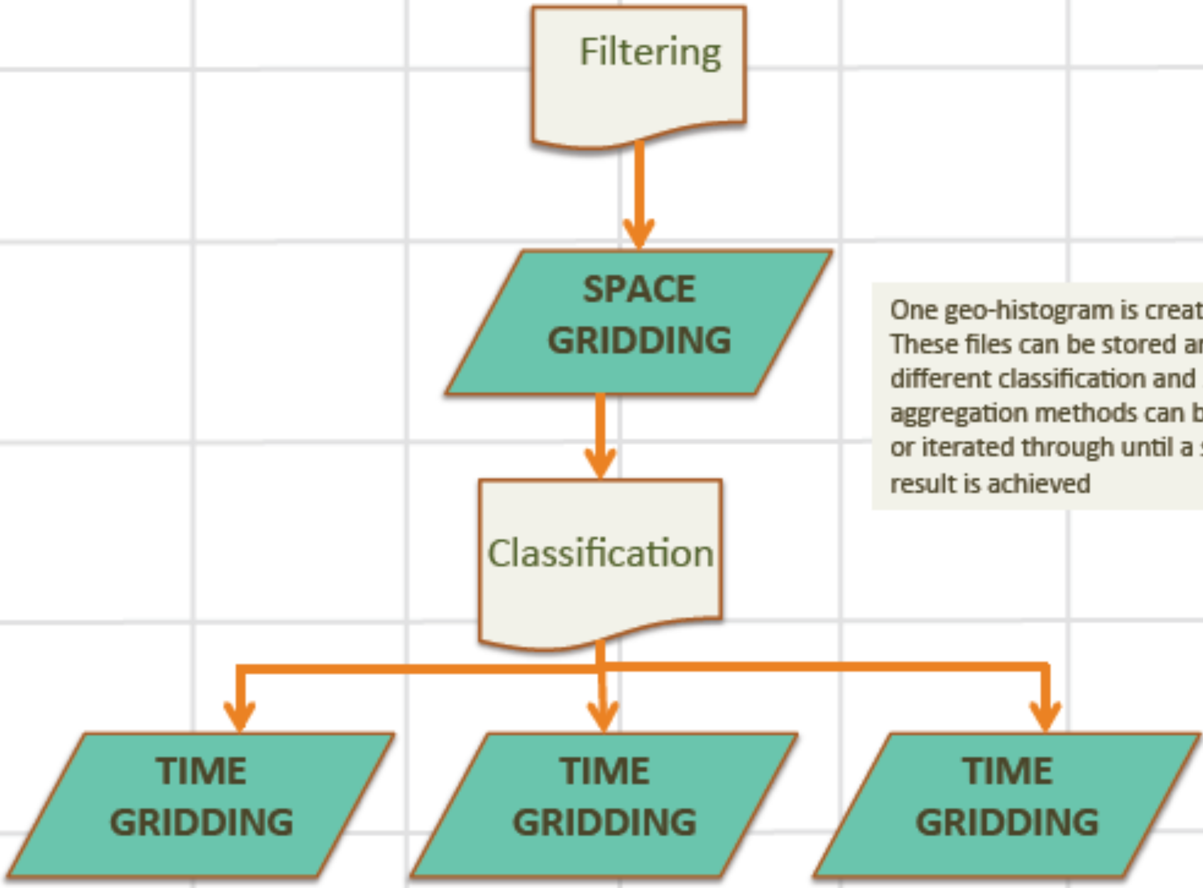
- **Reproducibility**
- Instrument independent (sounders, imagers, etc.)
- **Flexibility**; research specific outcomes
- Allowing both linear and non-linear statistical analysis
- **Data exploration** on a global scale
- Fast/**simple** processing of global data
- Support **research** in grid space


Traditional approach:
Instrument specific algorithms & L2/3 products
L3
L3
?
L2
L2
L2
L1
L1
L1
Single/shared aggregation algorithm
L3
L2
L2
L2
L1
L1
L1
Single/shared retrieval and aggregation
L3
L2
L1
L1
L1
Level 1 to Level 3 directly
L3
L1
L1
L1

Different approaches to STG

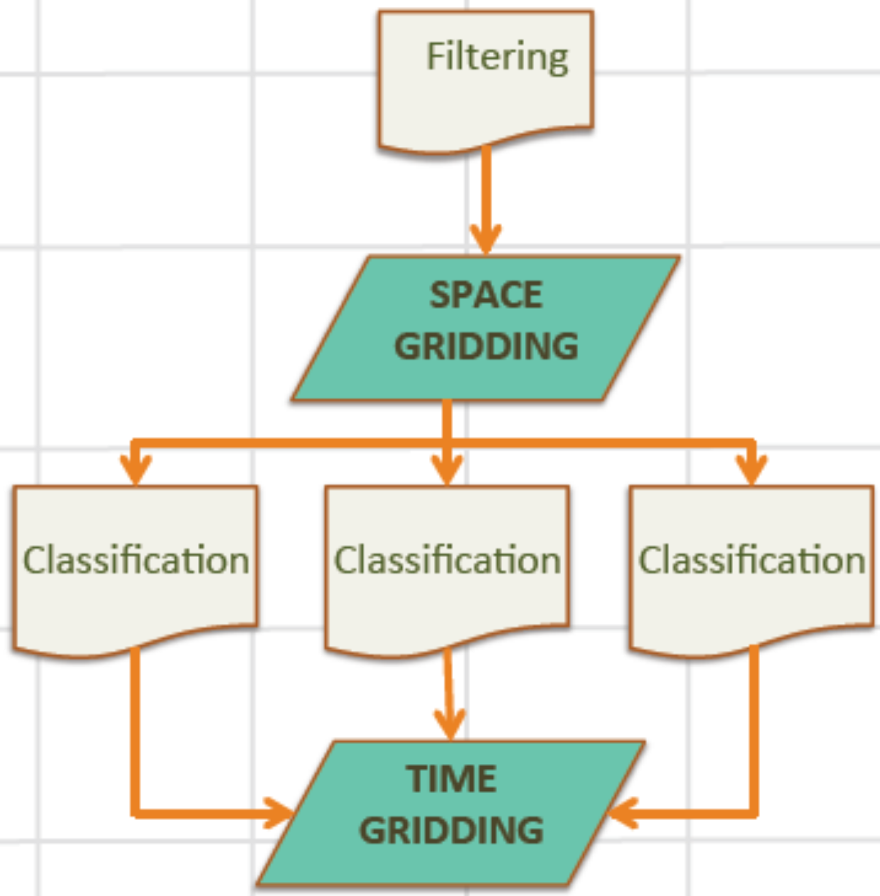


Different approaches to STG

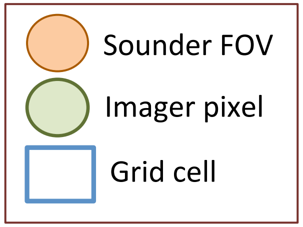


One geo-histogram is created per day. These files can be stored and a number of different classification and statistical aggregation methods can be implemented or iterated through until a suitable final result is achieved

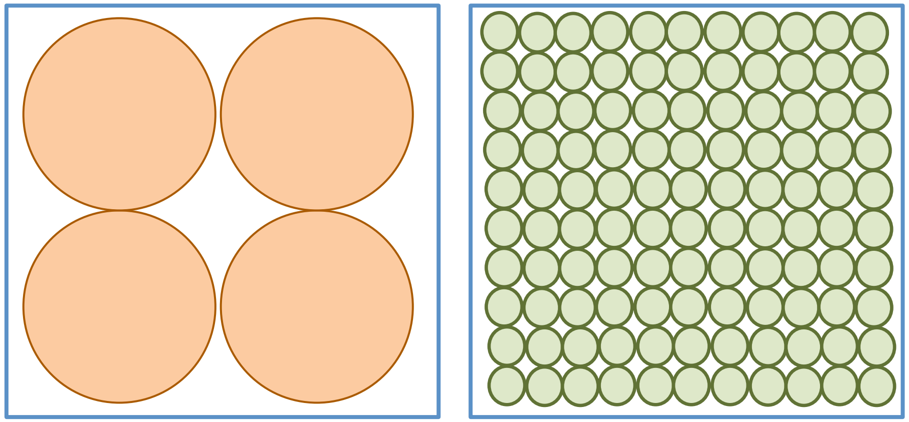
Different approaches to STG



How to determine uniformity given two different approaches

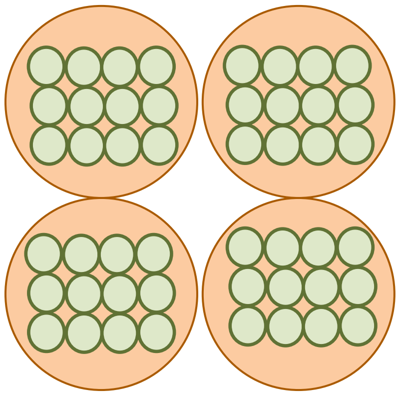


STG method



When I compare the STD of different grid cells, I compare their variance

Traditional colocation method



Imager pixels are colocated to sounder FOV.
Uniformity test consists of testing the imager standard deviation within each FOV for falling below a certain threshold. This is all. If the scene is uniform