Aggregation and Uncertainty

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with

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Level–2 versus Level–3

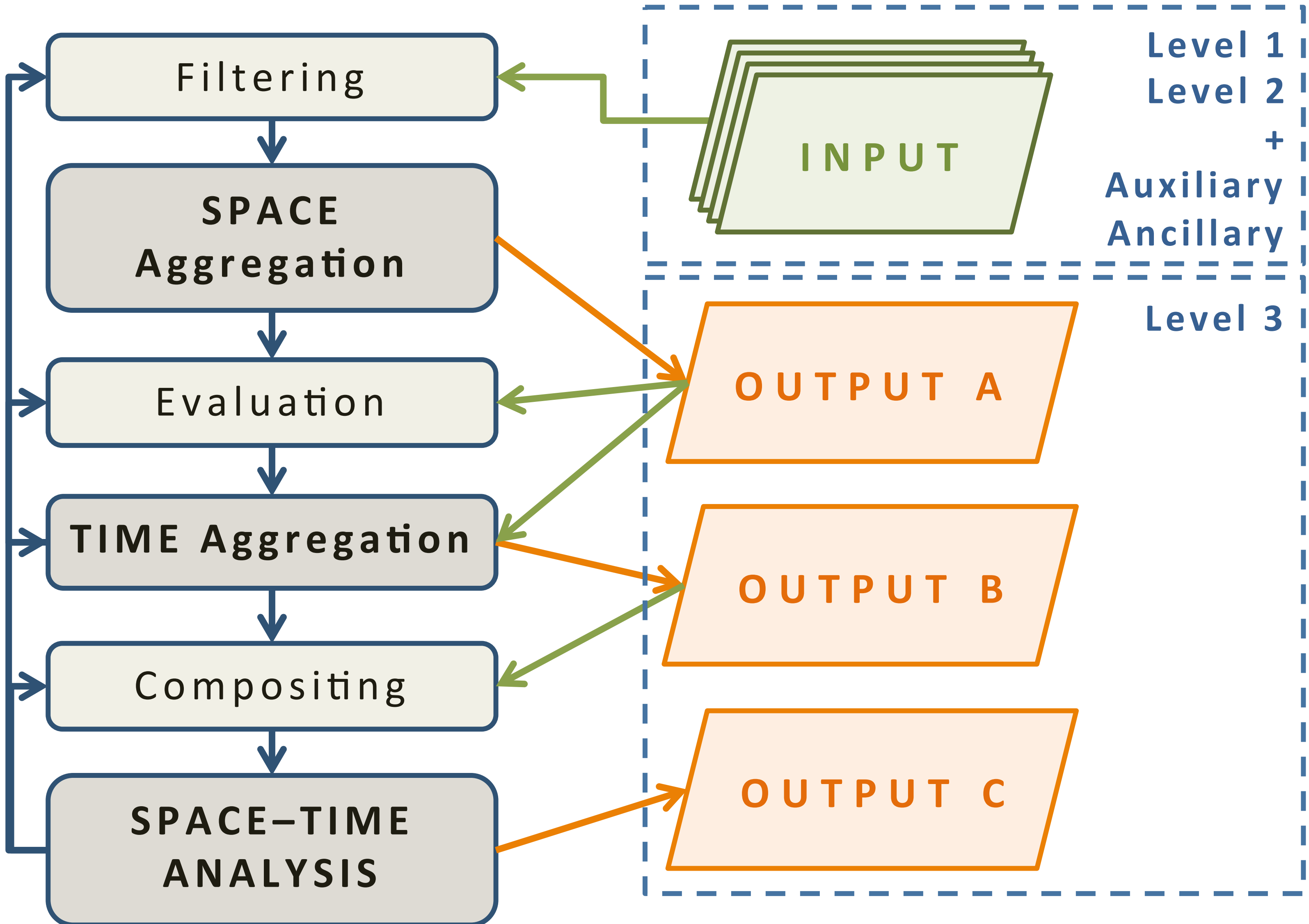
In both cases, y is not measured directly, but is determined from n other quantities $x_1, x_{2,\ldots,}\ x_n$ through a functional relationship f:

$$y = f(x_1, x_{2,\ldots,}\ x_n)$$

Level 2	Level 3
y = atmospheric parameter retrieval (weather observation)	y = atmospheric parameter aggregate (climate observation)
f = retrieval/inversion algorithm	f = aggregation algorithm
x = top of atmosphere measured spectrum. Number of spectral bands/channels determines magnitude of n	x = L2 retrieval parameters. Both L2 pixel size and L3 grid size determines magnitude of n
Sources of uncertainty include forward model, a priori, instrument noise, spectral resolution, inversion algorithm, etc.	Sources of uncertainty include Level 2 retrieval uncertainty, aggregation algorithm, scene intepretation, etc.
Inversion problem ranges from near-linear to non-linear	Aggregation problem range from near-linear to non-linear
Solution is **best estimate** of probability distribution; a mean with SD. Both input and output are *probabilities*	Solution is **best estimate** of probability distribution; a mean with SD. Both input and output are *probabilities*

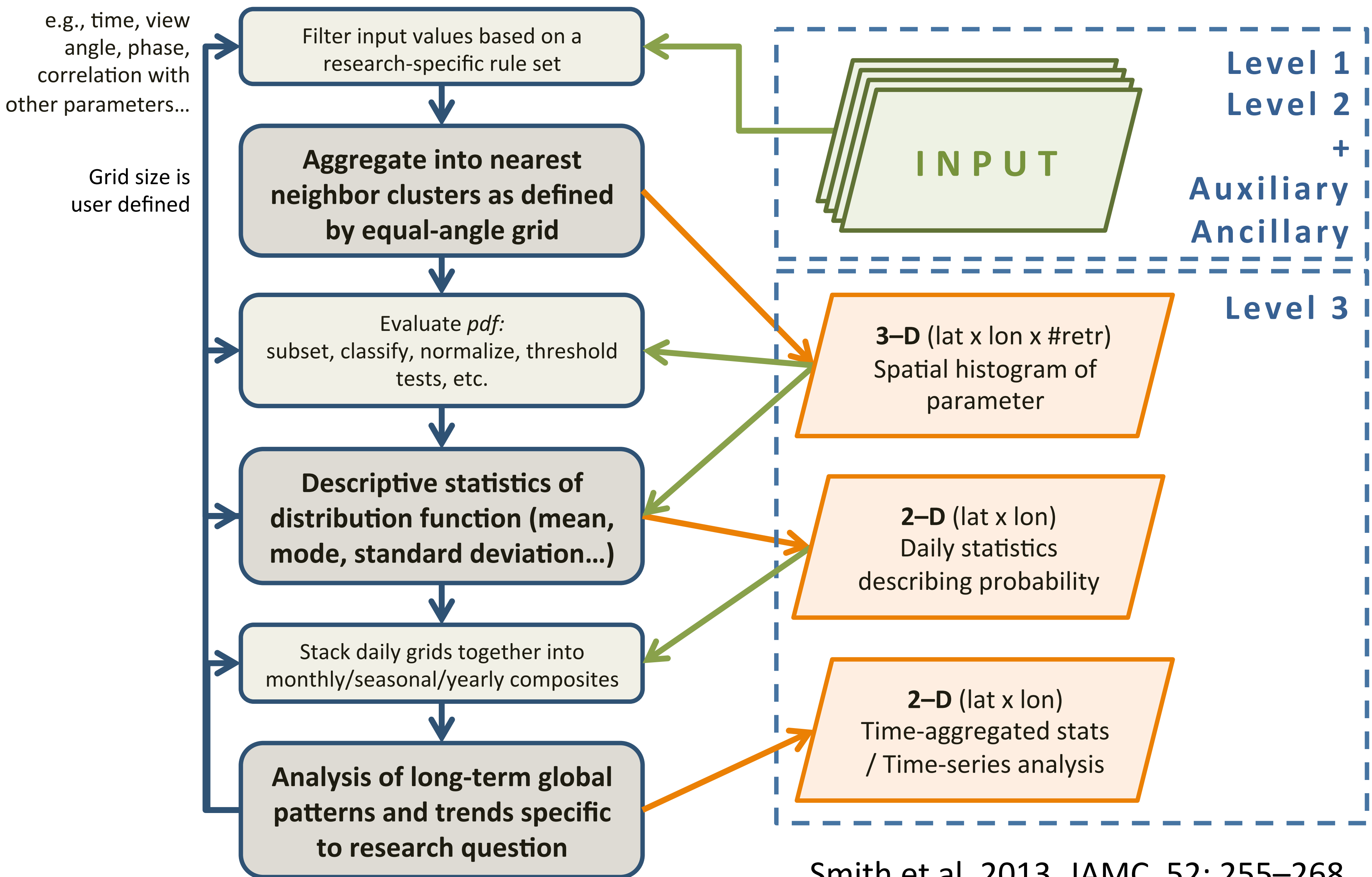
UW Space–Time–Gridding (STG) Framework

Modular design allows ease of processing/experimentation and transparency of data flow



Smith et al. 2013, JAMC, 52: 255–268

UW Space–Time–Gridding (STG) Framework



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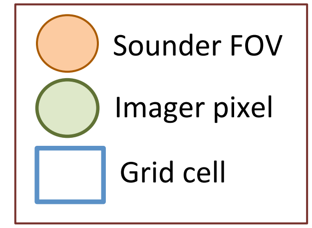
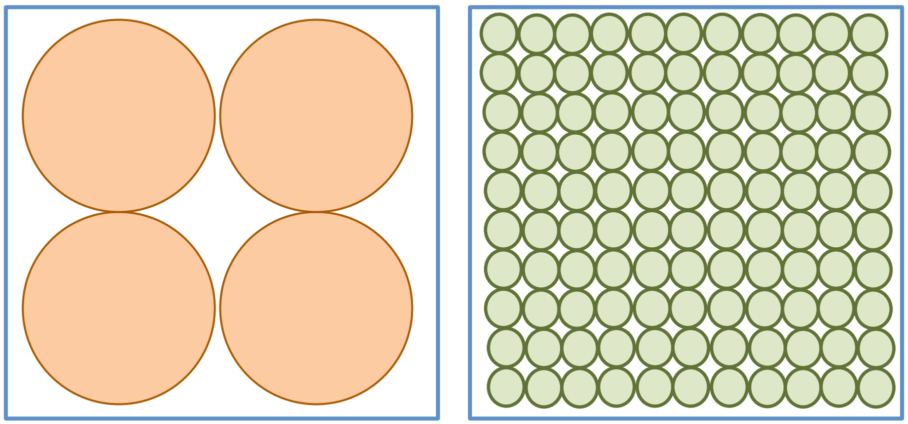
Aggregation as a global co-location scheme

A study in Brightness Temperature (BT): comparing Imagers (VIIRS) and Sounders (CrIS)

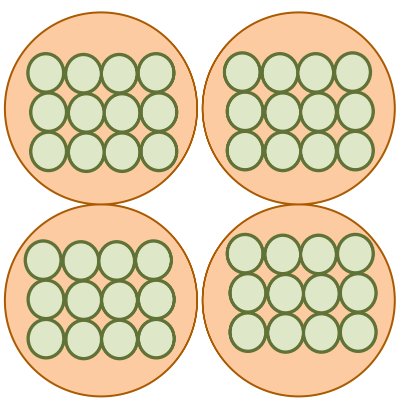
STG method





- Convolve Sounder BT to Imager BT
- Aggregate Sounder BT (avg + stdev)
- Aggregate Imager BT (avg + stdev)
- Select uniform scenes:
  (1) Sounder stdev < threshold 1
  (2) Imager stdev < threshold 2

Traditional pixel-by-pixel colocation method

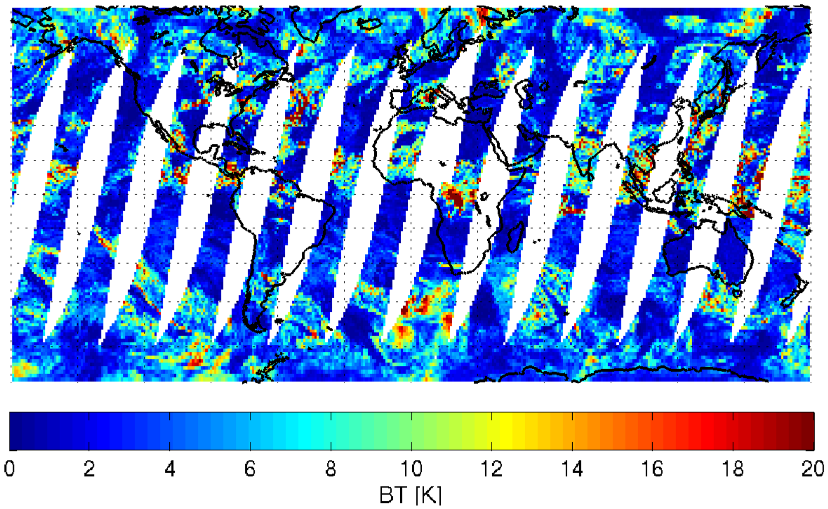


- Convolve Sounder BT to Imager BT
- Colocate Imager BT to sounder FOV (avg + stdev)
- Select uniform scenes:
  (1) Imager stdev < threshold 2

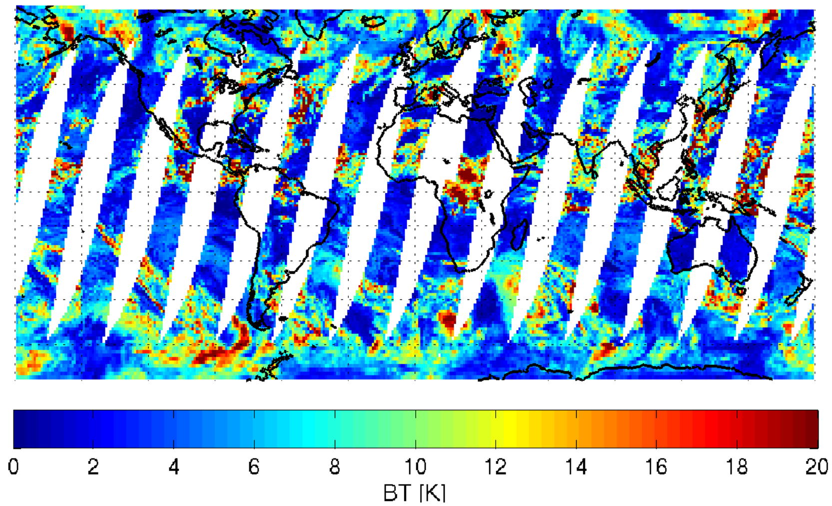
Bias = Average difference of uniform scenes
Error = Standard deviation of difference of uniform scenes

Aggregation as a global co-location scheme

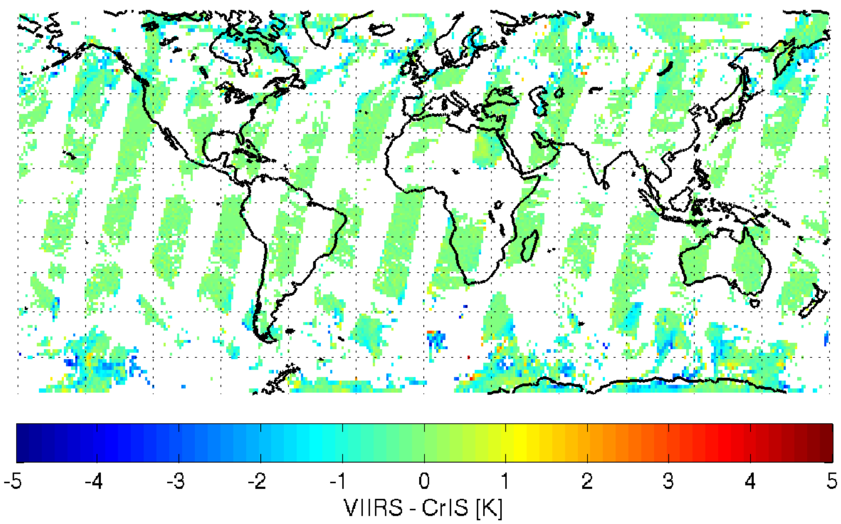
Convolved CrIS BT @ 10.8 µm 1-degree SD



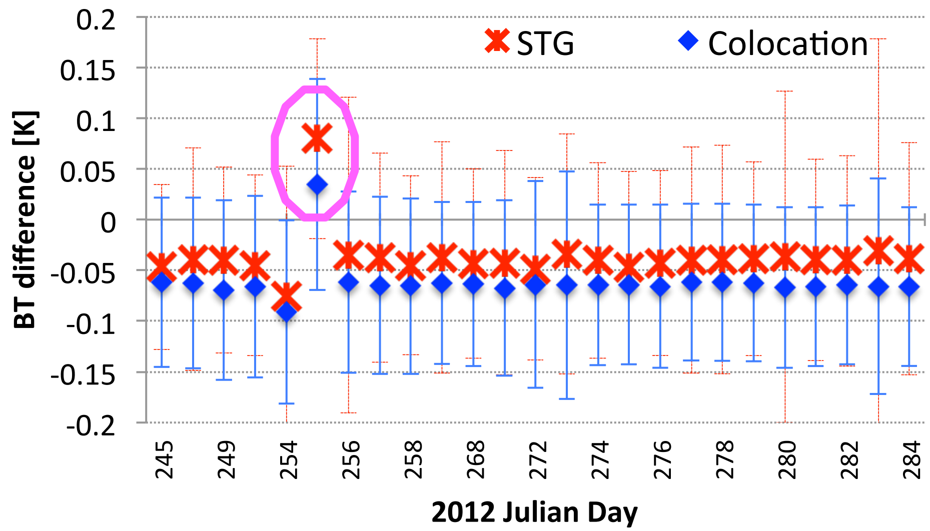
VIIRS BT @ 10.8 µm 1-degree SD



For uniform scenes: VIIRS SD minus CrIS SD



Global average of uniform-scene-differences



For global/zonal statistics, if aggregation is done correctly, co-location error is minimal

Applications

Propagation of L2 uncertainty

Instrument:

MODIS

Retrieval Algorithm:

Coll.5 (C5) & Coll.6 (C6)

Parameter:

Cloud Effective Radius

[µm]

- Daytime only (solar zenith angle)
- Water clouds (cloud phase retrieval)
- Retrieval Quality/Uncertainty flags

↓

1-degree equal-angle grid

↓

Sample size threshold

↓

Arithmetic mean + SD

↓

Monthly stats: September 2012

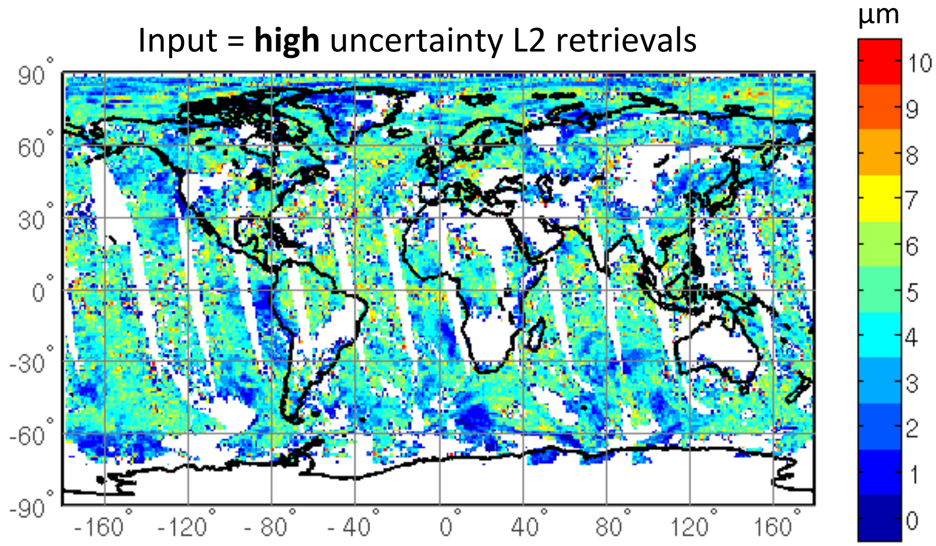
↓

Can the propagation of uncertainty be measured (L2 to L3)? Can uncertainty in L3 be reduced by applying appropriate L2 filters?

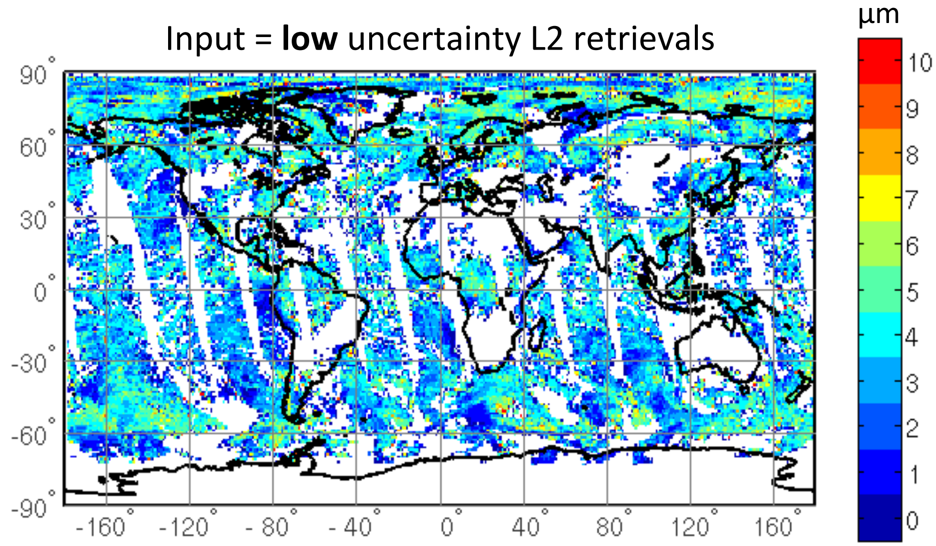
Propagation of L2 uncertainty

Standard deviation (SD) of retrievals on 1-degree grid

Input = **high** uncertainty L2 retrievals



Input = **low** uncertainty L2 retrievals



Does L2 uncertainty affect L3 uncertainty?

High uncertainty L2 = using all retrievals irrespective of value in retrieval uncertainty flag

Low uncertainty L2 = using **only** those retrievals with < 10% in uncertainty flag

L2 uncertainty is a retrieval by-product

L3 uncertainty is measured as the SD of gridded probability distribution (sample of retrievals per grid cell)

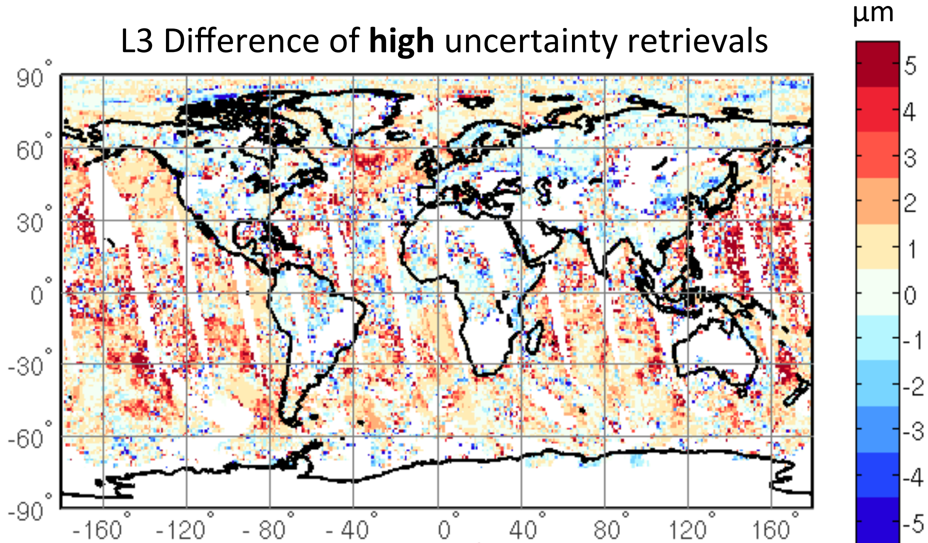
- L3 uncertainty is significantly reduced across the globe when L2 uncertainty is reduced.

- More stringent filtering rules result in less coverage but more reliable results

Propagation of L2 uncertainty

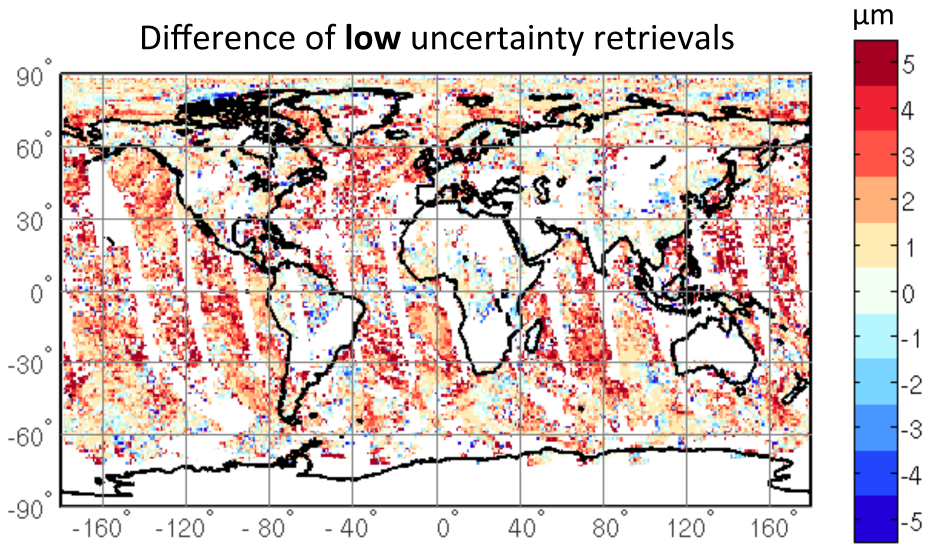
Daily average of retrievals on 1-degree grid

L3 Difference of **high** uncertainty retrievals



Random difference

Difference of **low** uncertainty retrievals



Systematic difference: MODIS C5 detects higher particle size over ocean

How does L2 uncertainty affect product comparisons?

L3 Difference = **C5** minus **C6**

High uncertainty L2 = using all retrievals irrespective of retrieval quality

Low uncertainty L2 = using **only** those retrievals with < 10% uncertainty

L2 uncertainty is a retrieval by-product

L3 uncertainty is measured as the SD of gridded probability distribution (sample of retrievals per grid cell)

- L2 filtering strongly affects differences among data products

- Using only low uncertainty L2 retrievals in L3, highlights systematic differences between two retrieval algorithms

Characterizing uncertainty: random vs. systematic

Instrument:

MODIS

Retrieval Algorithm:

C5 & C6

Parameter:

Cloud Top Pressure

(CTP, [hPa])

Difference:

C5 minus C6

- Daytime only (solar zenith angle)
- Near-nadir (sensor zenith angle)
- Retrieval Quality flags

↓

1-degree equal-angle grid

↓

Sample size threshold
Classify into ordinal classes: low/mid/high

↓

Arithmetic mean + SD

↓

Monthly stats: September 2012

↓

Can aggregation be used to identify systematic differences in L2 products?
How much of the observed difference is random?

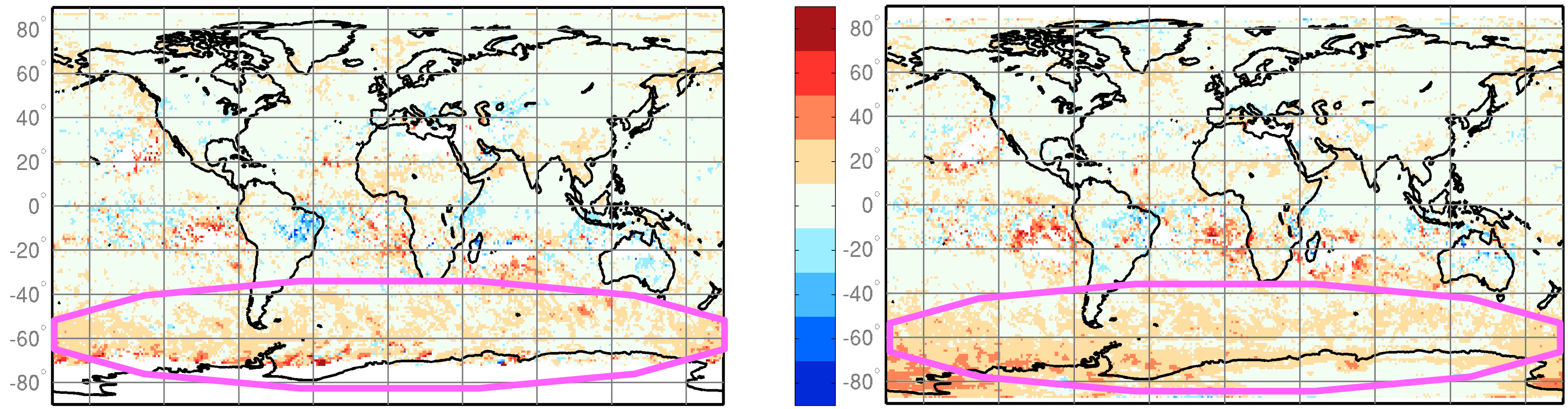
Systematic Differences between two Algorithms

Day Time | **High clouds < 440 hPa** | **Night Time**

MODIS C5 minus C6 avg difference Aug 2012 - Daytime high clouds (9.63 hPa)

[hPa]

MODIS C5 minus C6 avg difference Aug 2012 - Night time high clouds (13.34 hPa)



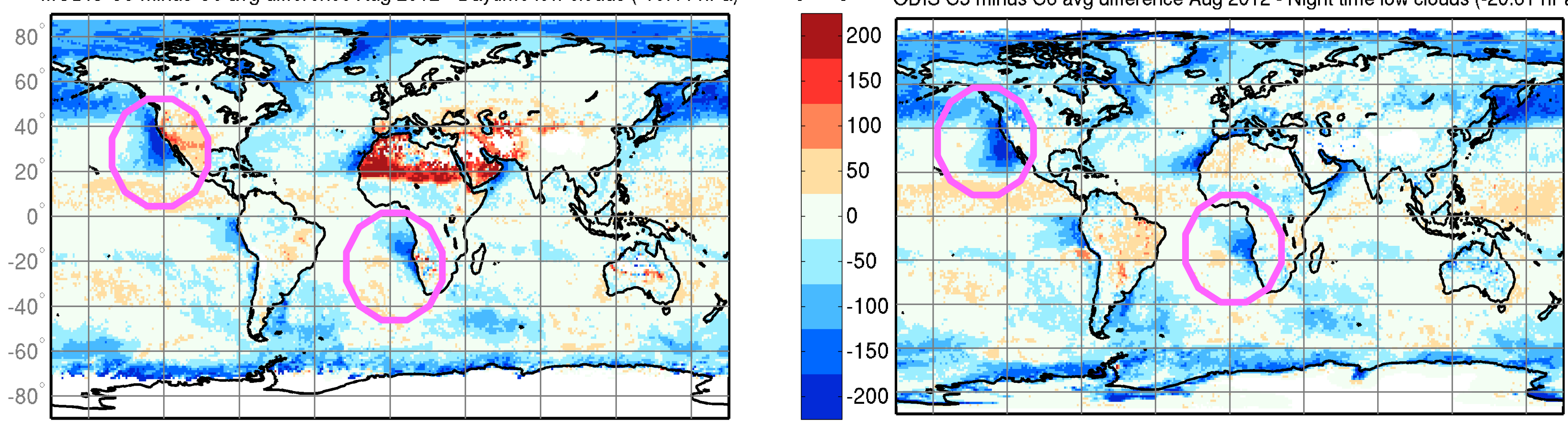
C6 has higher cirrus clouds, day and night

Day Time | **Low clouds > 680 hPa** | **Night Time**

MODIS C5 minus C6 avg difference Aug 2012 - Daytime low clouds (-13.44 hPa)

[hPa]

ODIS C5 minus C6 avg difference Aug 2012 - Night time low clouds (-20.61 hPa)



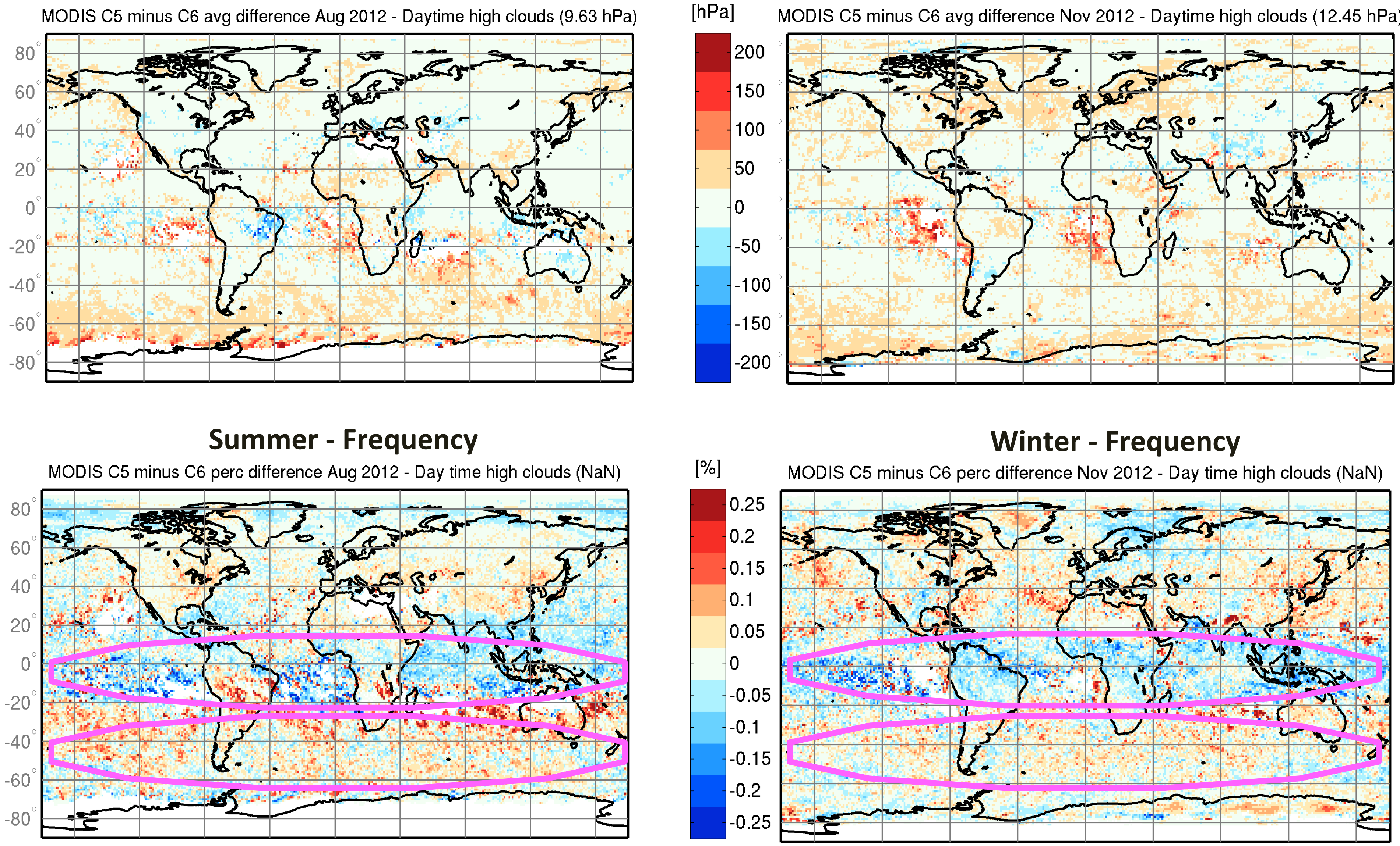
C6 has lower marine stratocumulus clouds, day and night

Systematic Differences between two Algorithms

High clouds < 440 hPa

Summer - Average | **Winter - Average**

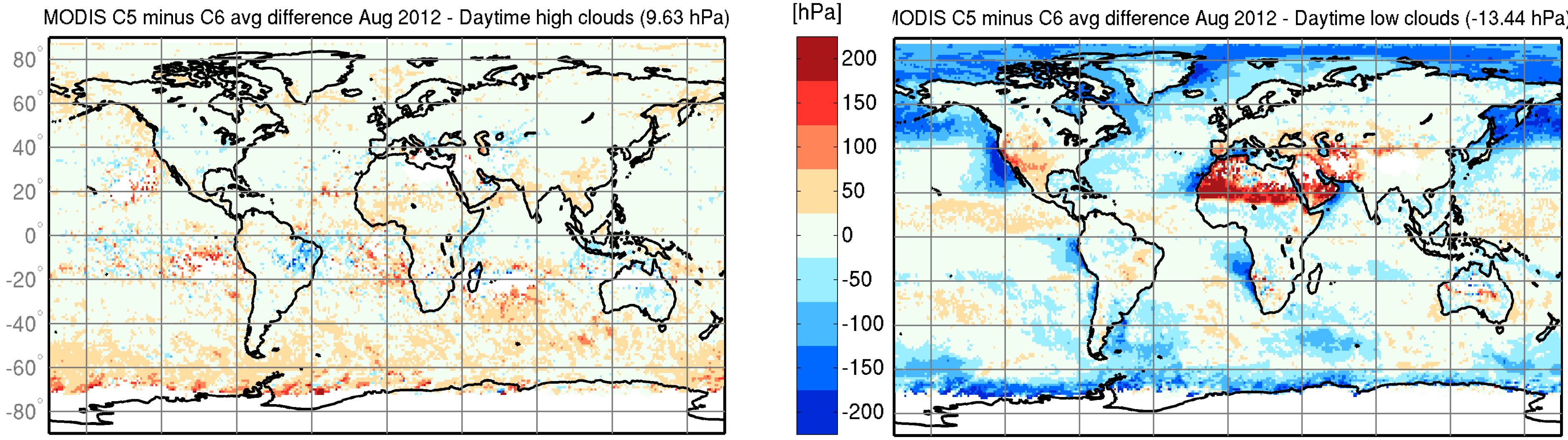
Summer - Frequency | **Winter - Frequency**



C6 frequency of high clouds higher in Tropics and lower over Southern Ocean; Generally a lower frequency over mid-latitude Land

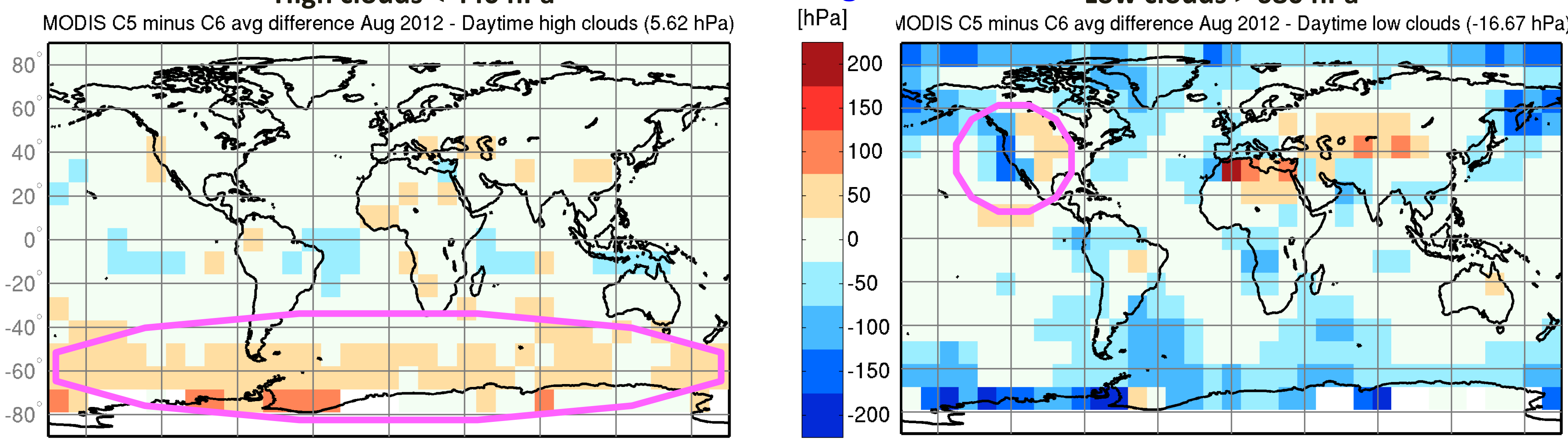
How much of the observed difference is random?

High clouds < 440 hPa **1-degree** **Low clouds > 680 hPa**



Increase grid resolution by an order of magnitude to remove random differences

High clouds < 440 hPa **10-degree** **Low clouds > 680 hPa**

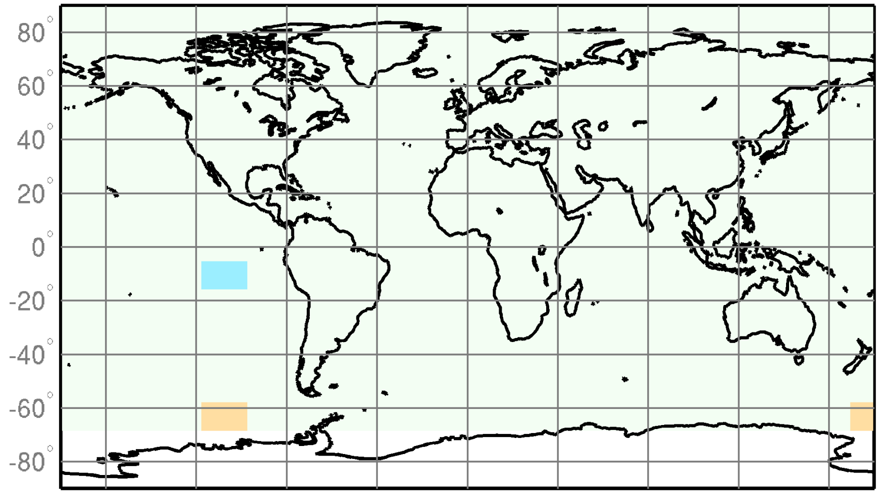


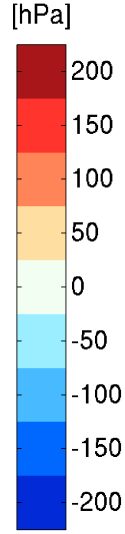
How seasonal is systematic differences?

High clouds < 440 hPa
C5 CTP monthly mean

Spring (August 2013)

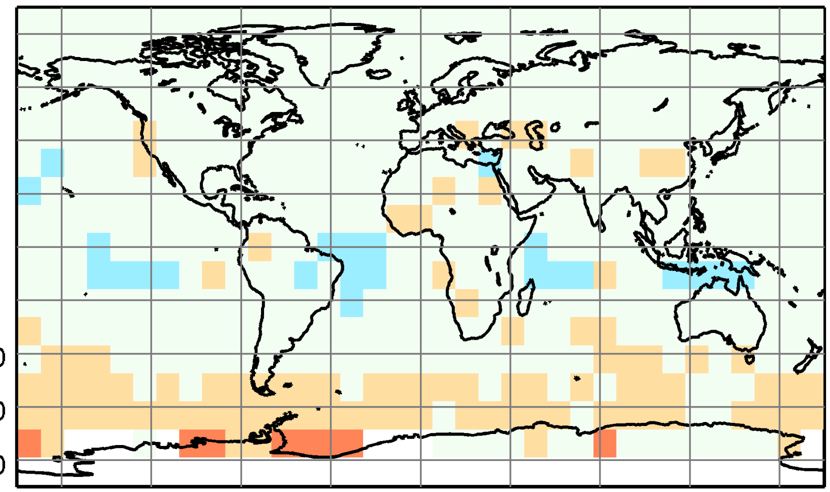
MODIS C5 minus C6 avg difference May 2012 - Daytime high clouds (1.95 hPa)





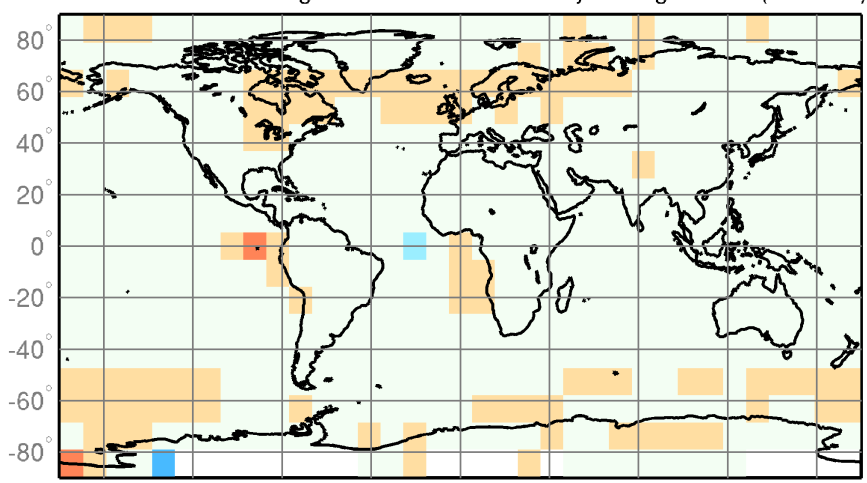
Summer (August 2013)

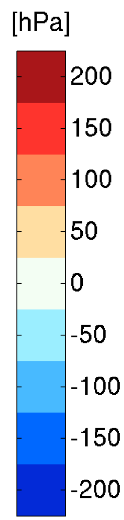
MODIS C5 minus C6 avg difference Aug 2012 - Daytime high clouds (5.62 hPa)



Autumn (November 2012)

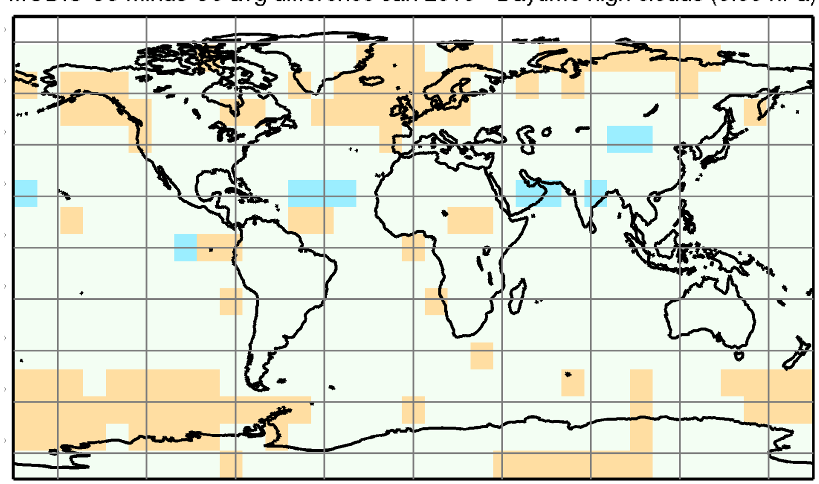
MODIS C5 minus C6 avg difference Nov 2012 - Daytime high clouds (9.76 hPa)





Winter (January 2013)

MODIS C5 minus C6 avg difference Jan 2013 - Daytime high clouds (6.36 hPa)



Analyzing Systematic Differences

Instrument:

AIRS + IASI + CrIS

Retrieval Algorithm:

UW Dual-Regression

Parameter:

Temperature Profile

[K]

Using model fields
(from GDAS)
as reference

None

↓

10-degree equal-angle grid

↓

None

↓

Arithmetic mean

↓

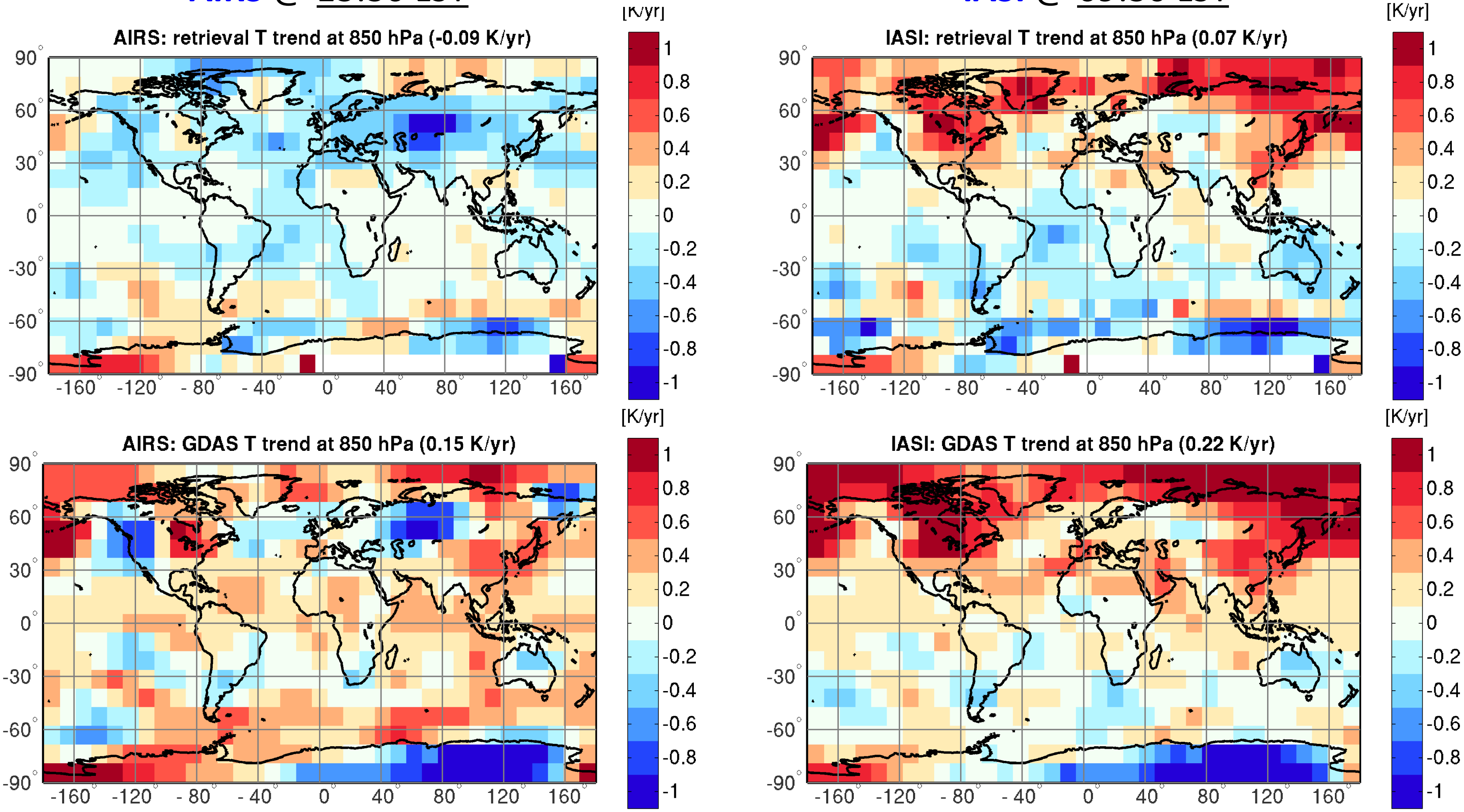
Annual average: 2012
5-year trend: 2008 – 2012

↓

How does systematic differences (due to diurnal sampling and instrumentation) change with height?

5-yr Trend (2008–2012) at 850 hPa (K/yr)

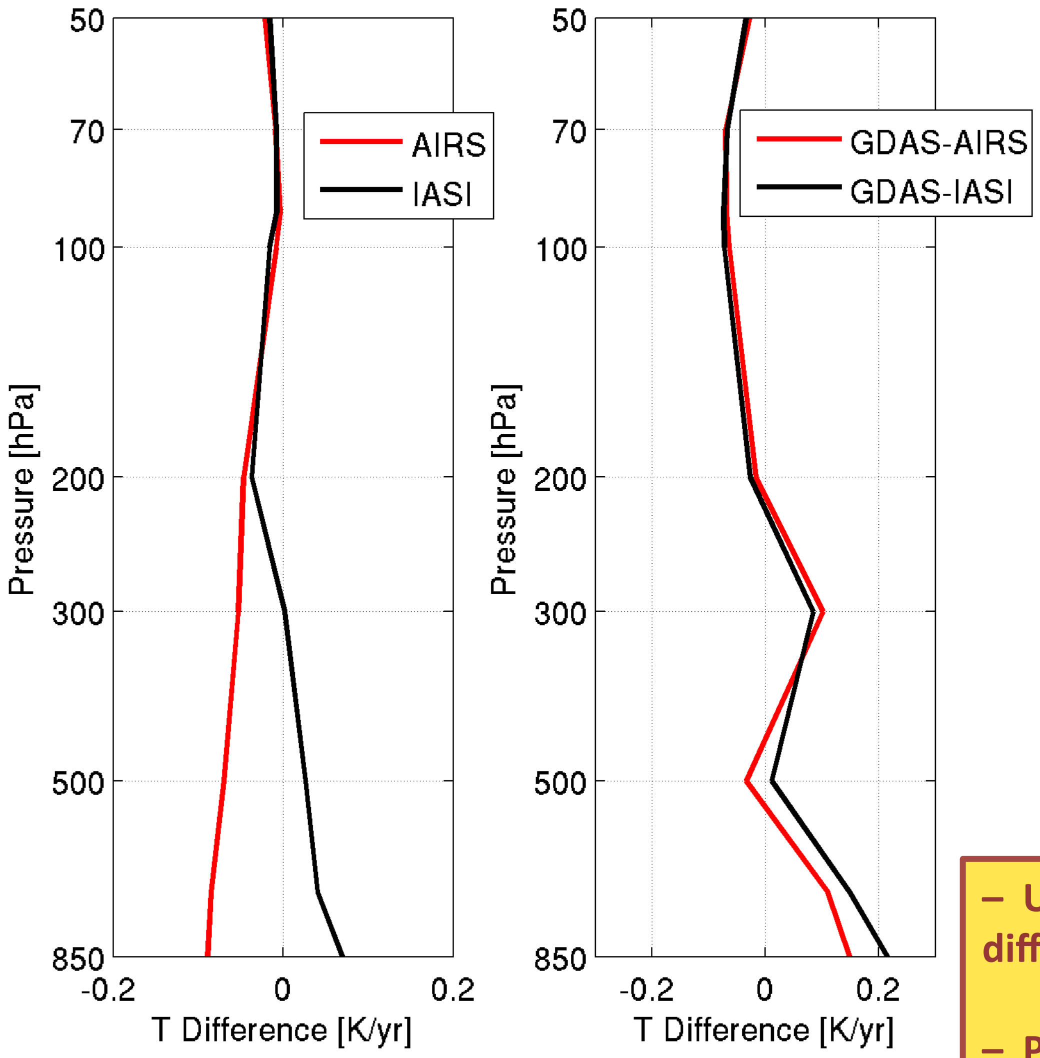
AIRS @ 13:30 LST | **IASI** @ 09:30 LST



IASI-AIRS Trend difference is 0.16 K/yr while GDAS Trend difference is 0.07 K/yr

At 850 hPa half of the observed difference between AIRS & IASI is due to diurnal sampling differences

Analyzing Systematic Differences



How does diurnal sampling differences affect product comparisons at different heights?

Global weighted (by cosine of the latitude) mean along a pressure profile.

Isolating two sources of systematic differences by comparison with model data (as reference)

(1) Diurnal sampling
(2) instrument

– **Uncertainty due to diurnal sampling differences affects tropospheric retrievals only**

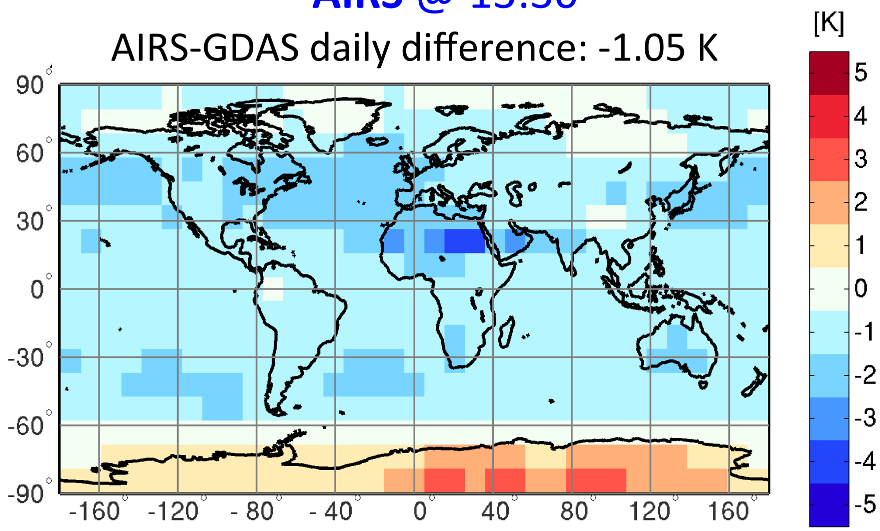
– **Possible implications for evaluating/ analyzing multi-instrument low-cloud retrievals**

Systematic difference caused by instrument alone

300 hPa

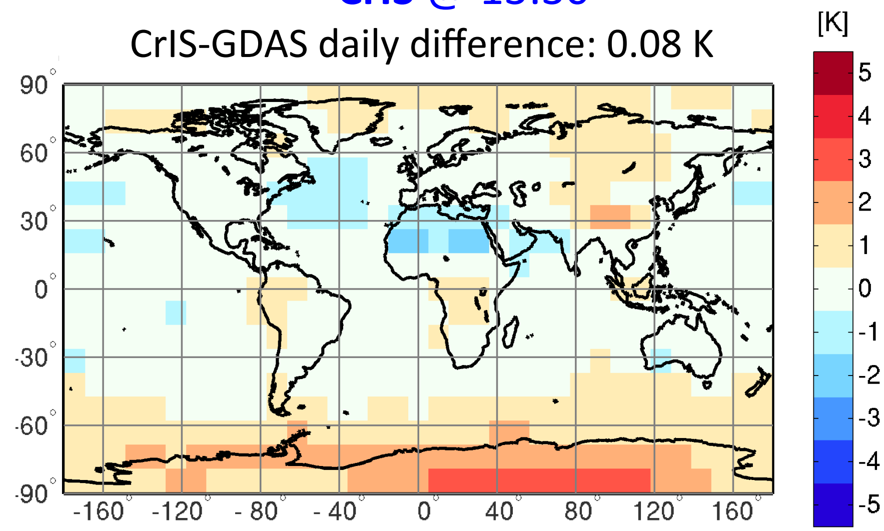
AIRS @ 13:30

AIRS-GDAS daily difference: -1.05 K



CrIS @ 13:30

CrIS-GDAS daily difference: 0.08 K



Annual mean of daily differences

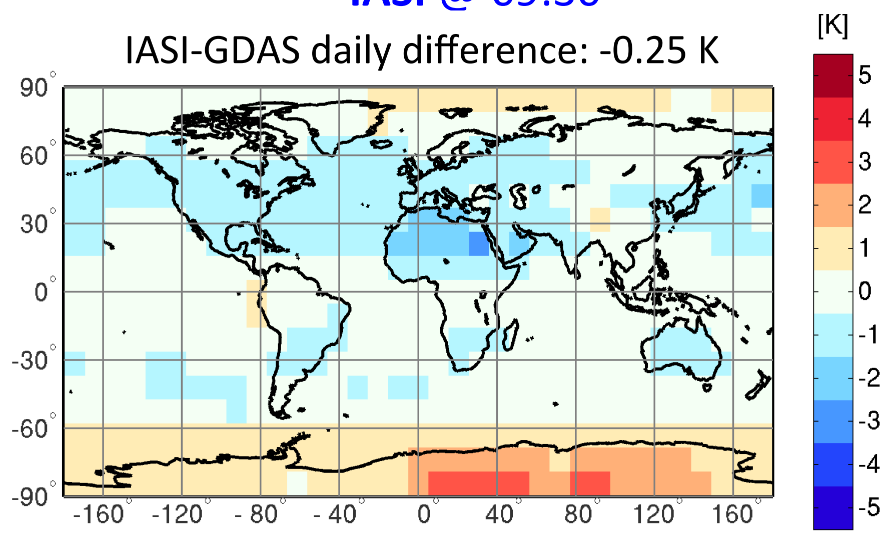
Daily difference = Instrument minus Space-Time-Interpolated Model Field (diurnal sampling effect removed)

AIRS is a grating spectrometer
IASI + CrIS are Michelson Interferometers

IASI and CrIS have stronger correlation with each other than with AIRS

IASI @ 09:30

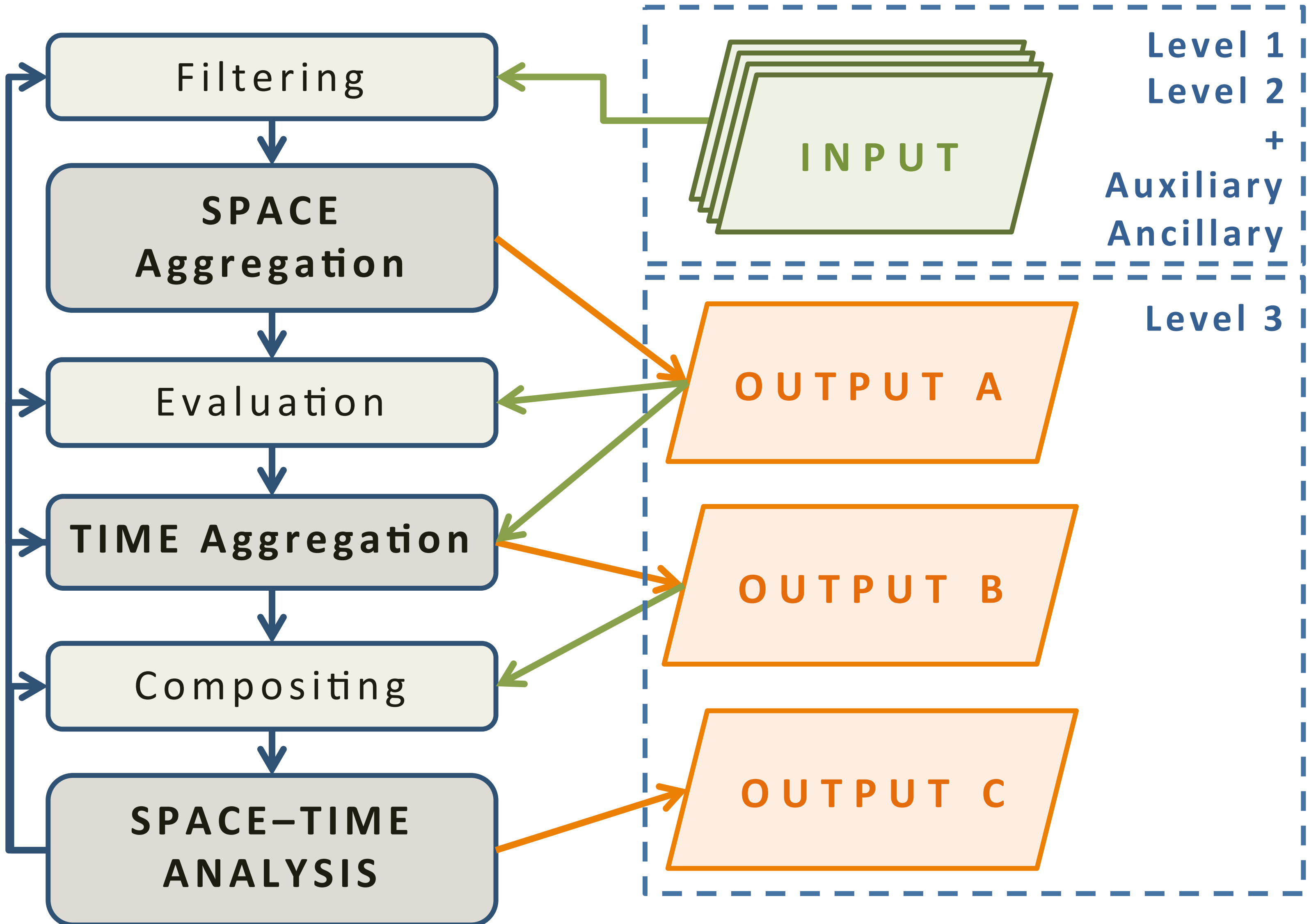
IASI-GDAS daily difference: -0.25 K



Uncertainty caused by L-3 methods

UW Space–Time–Gridding (STG) Framework

Modular design allows ease of processing/experimentation and transparency of data flow



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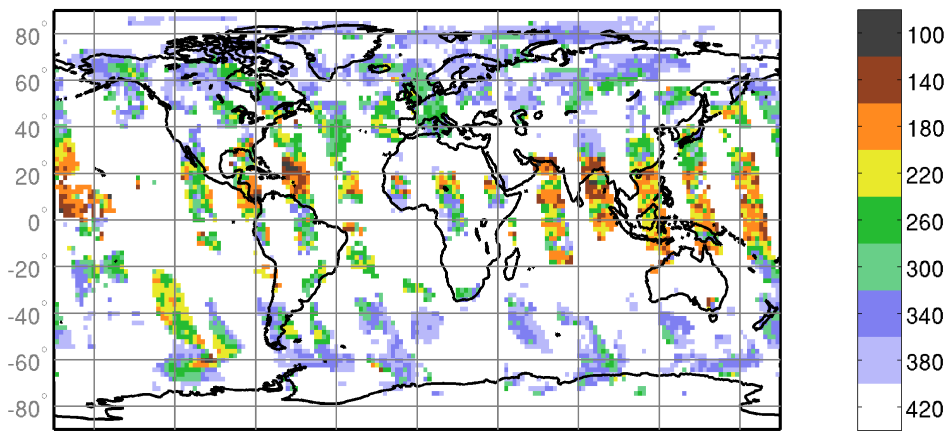
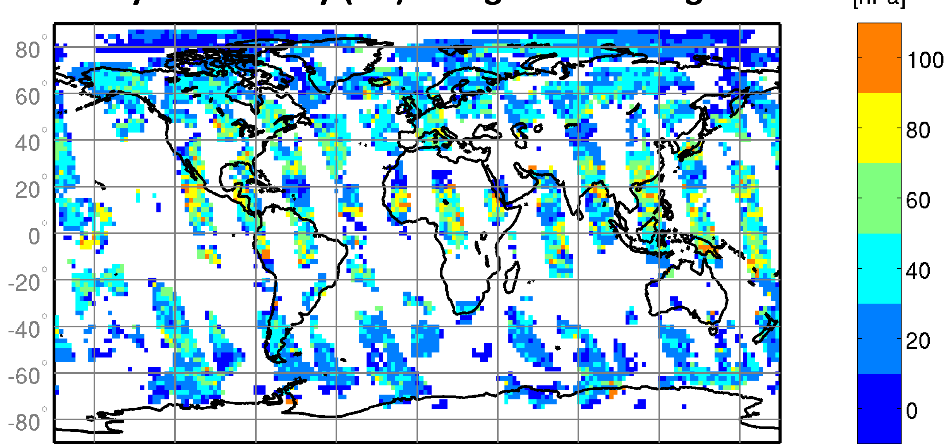
Propagation of L3 Uncertainty: Spatial Scale

MODIS C5: Daily (3 Sep 2012) high CTP difference on different resolution grids

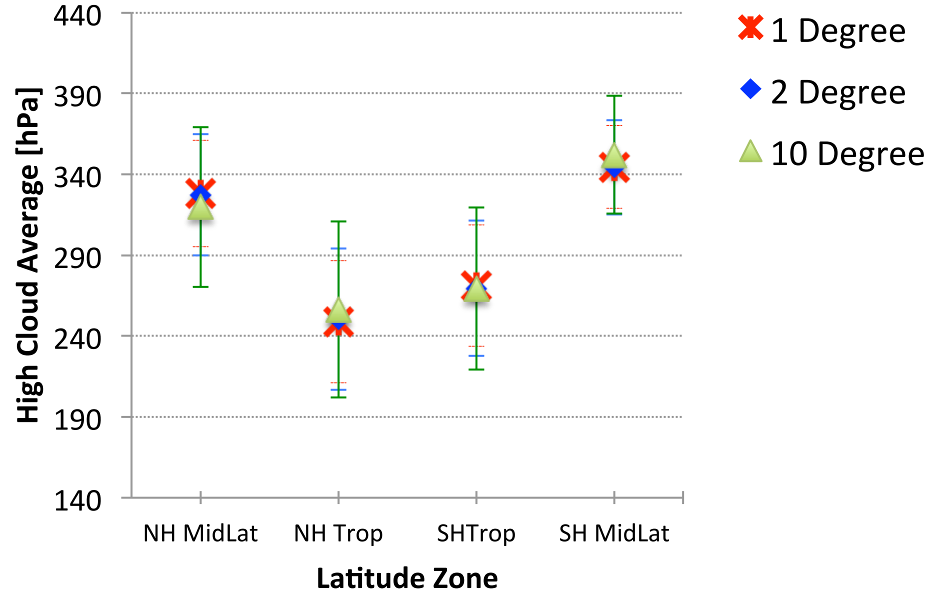
Daily average of high CTP on 2˚ grid



Daily uncertainty (SD) of high CTP on 2˚ grid



How critical is grid-cell size to global/zonal statistics?



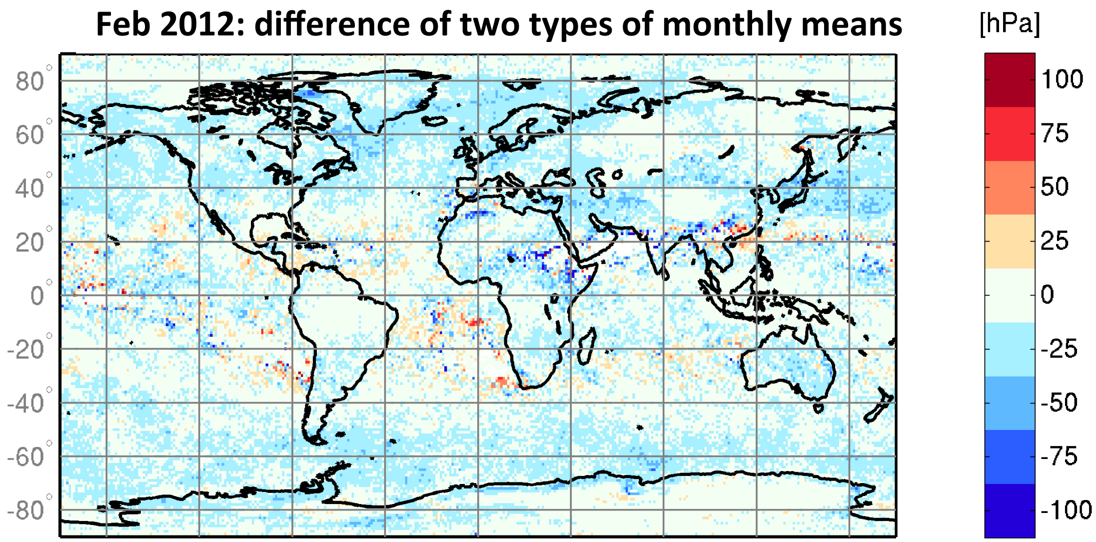
Mean = mean of grid cell means
Error bars = mean of grid cell uncertainties (SD)

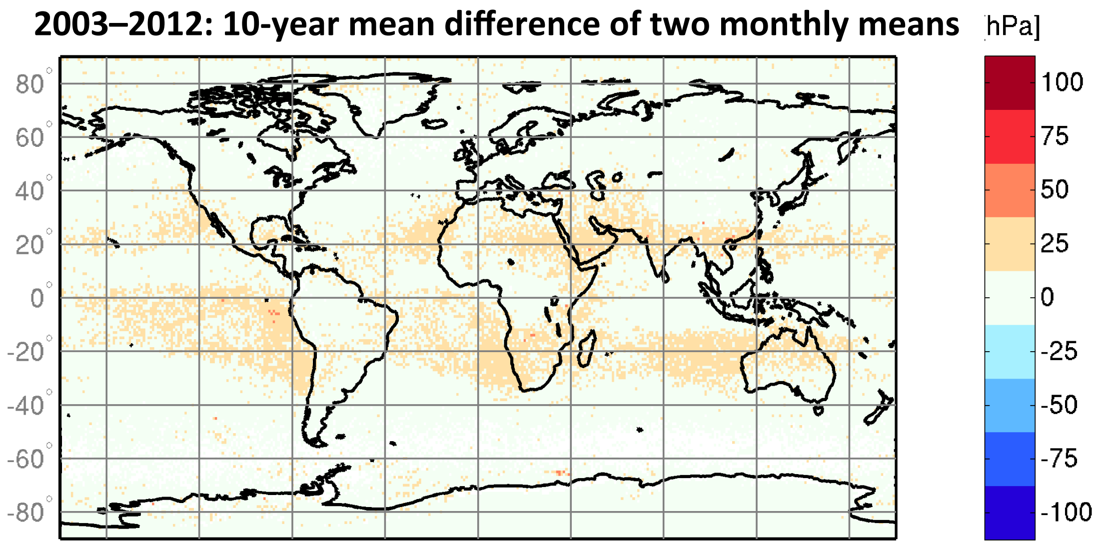
For zonal statistics of CTP, spatial resolution of L3 product (daily space-time aggregate) is not critical

Note: a larger spatial scale will affect the rate at which the probability in each cell changes, i.e. a 10-degree (1-degree) cell will require a higher (lower) degree of change across space before a change in the daily estimate (mean of pdf) is observed

Propagation of L3 Uncertainty: Temporal Scale

AIRS DR: Monthly high CTP difference on 1-degree grid





How does L3 aggregation affect product comparisons?

How much of the L3 product differences smooth out over time? (i.e., how much of the L3 product differences are random?)

Type 1 monthly mean = monthly mean of daily means

Type 2 monthly mean = weighted (by % cloudiness) monthly mean of daily means

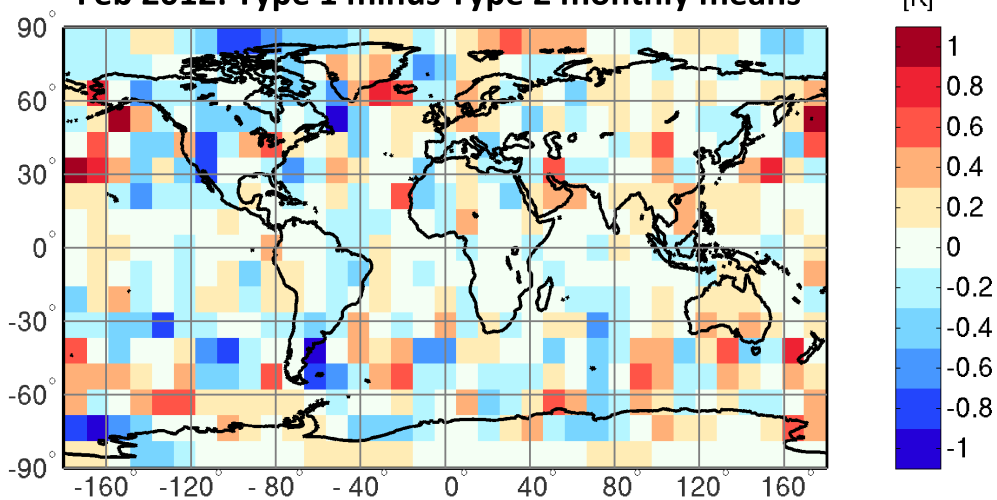
Difference = Type 1 minus Type 2

Uncertainty due to systematic effects becomes evident once temporal scale is increased

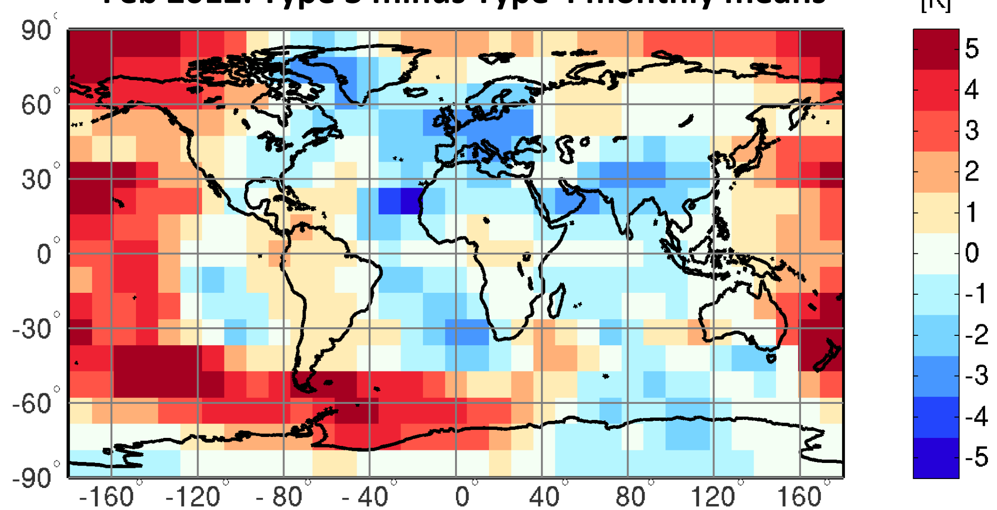
Propagation of L3 Uncertainty: Temporal Scale

AIRS DR Temperature @ 300 hPa difference on 10-degree grid

Feb 2012: Type 1 minus Type 2 monthly means



Feb 2012: Type 3 minus Type 4 monthly means



What constitutes a monthly mean?

Does it matter which combination of days we use?

Type 1 = monthly mean of 15 even-numbered days

Type 2 = monthly mean of 15 odd-numbered days

Type 3 = monthly mean of first 15 days

Type 4 = monthly mean of last 15 days

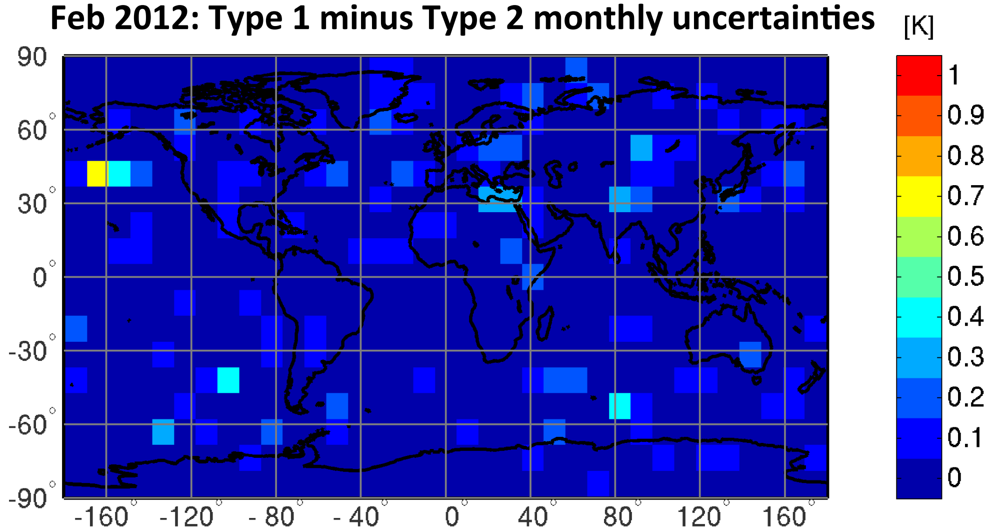
A Monthly mean is sensitive to the combination of daily means.

An even distribution of days across a month (irrespective of exact matching) results in **random differences** only. Two different cluster distribution of days across a month can result in **systematic difference**s.

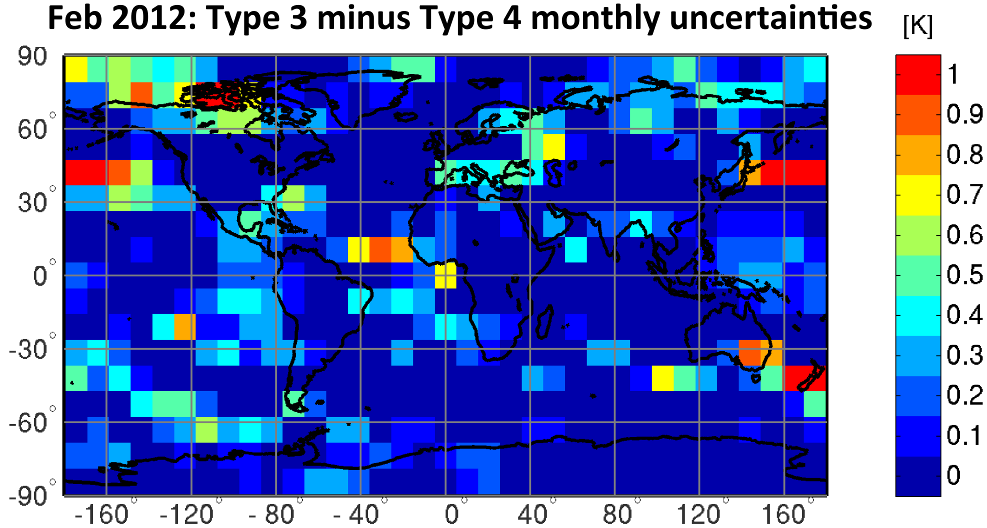
Propagation of L3 Uncertainty: Temporal Scale

AIRS DR Temperature @ 300 hPa difference on 10-degree grid

Feb 2012: Type 1 minus Type 2 monthly uncertainties



Feb 2012: Type 3 minus Type 4 monthly uncertainties



What causes these observed differences in monthly means?

How can daily L-3 uncertainties help clarify differences?

Average monthly uncertainty = Average of daily SD per grid cell

A high average uncertainty indicates a high variability in parameter state (due to weather events). If a time-aggregate sample of daily averages is not evenly distributed, but clustered around weather events, L-3 uncertainty can no longer be attributed to random effects alone.

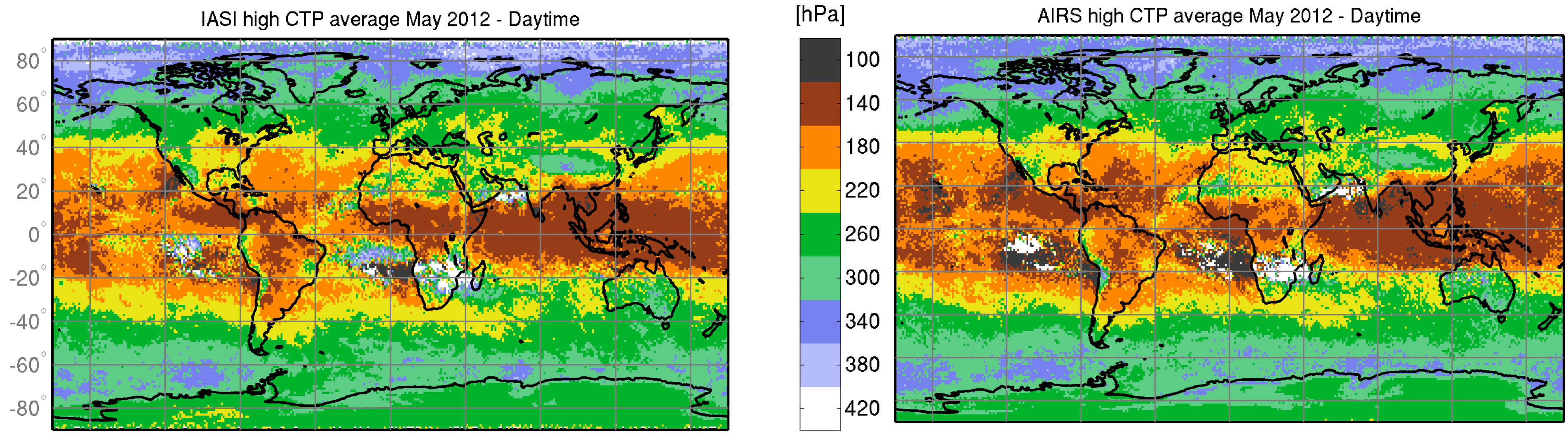
L-3 uncertainty metrics can help design aggregation strategies

Multi-source Multi-instrument Global comparisons

Multi-Instrument Global Comparisons

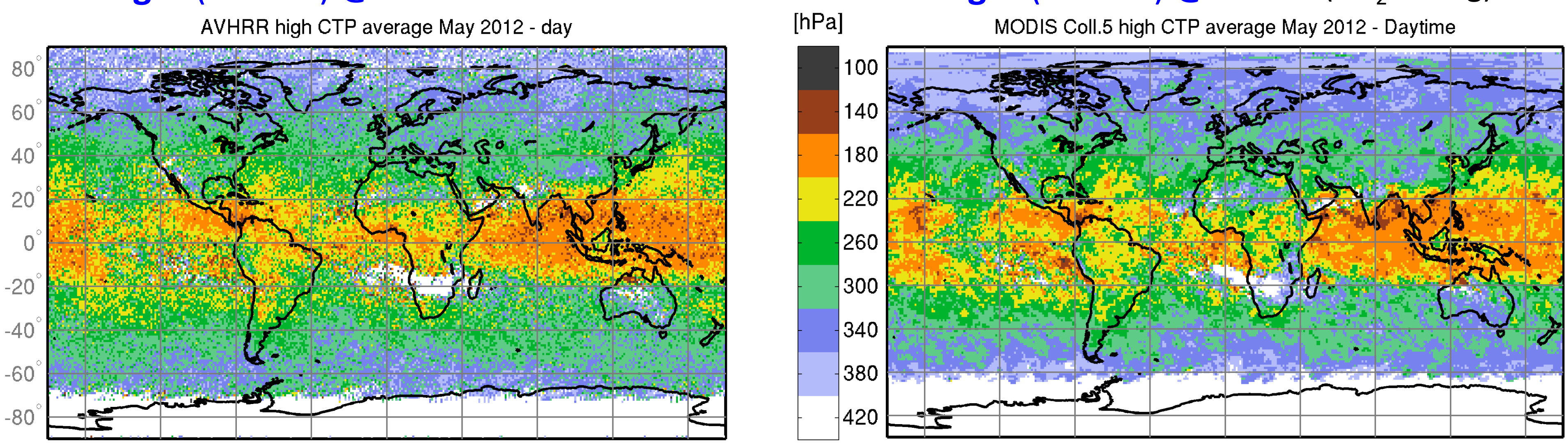
Sounder (IASI) @ **09:30** (UW DR)

Sounder (AIRS) @ **13:30** (UW DR)

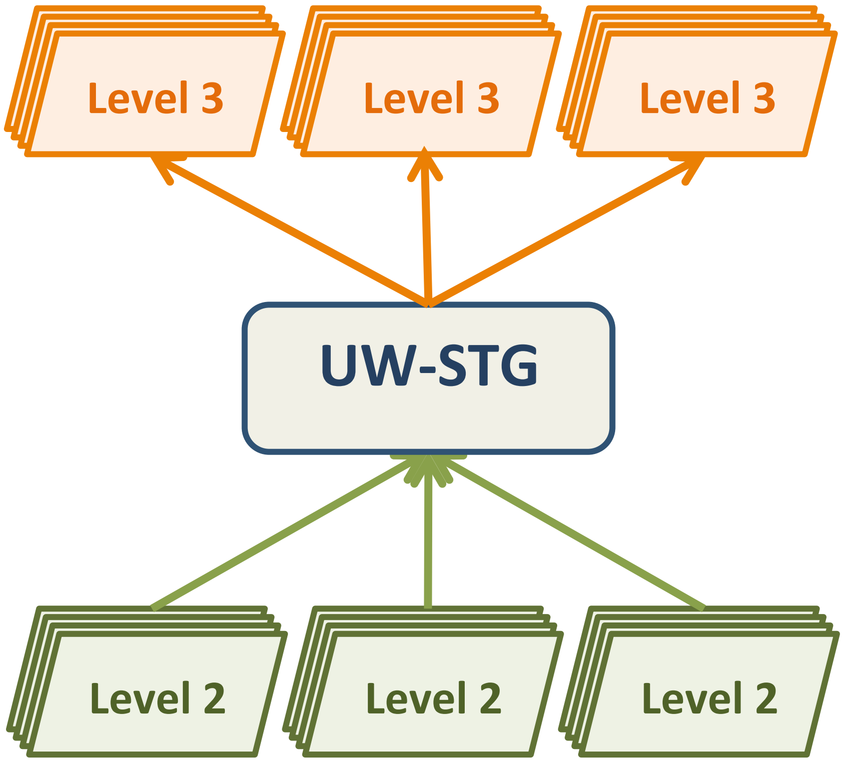


Imager (AVHRR) @ **09:30** (Optimal Estimation)

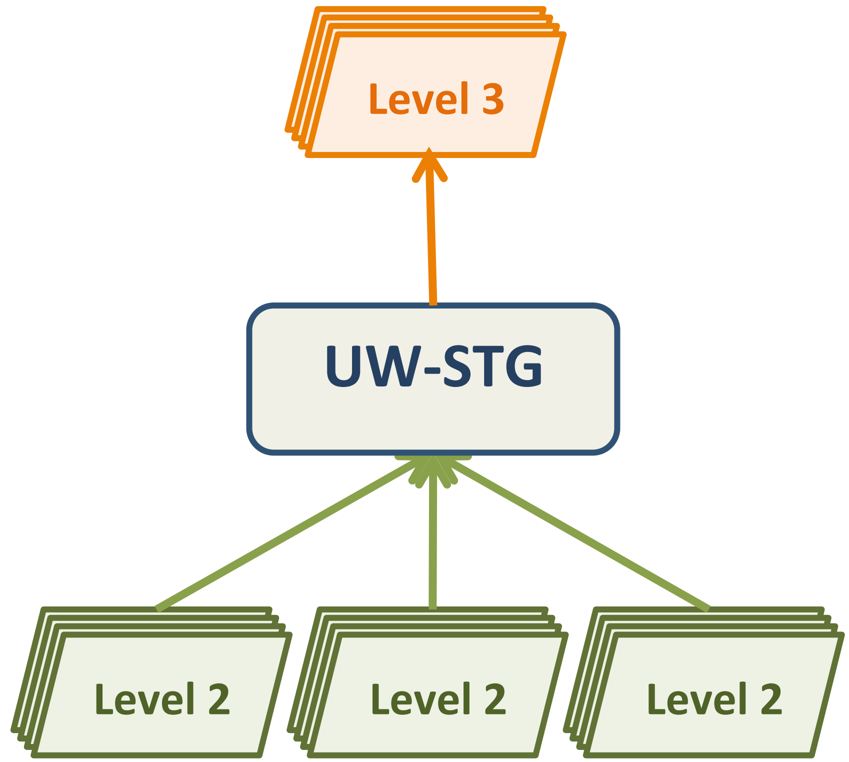
Imager (MODIS) @ **13:30** (CO_2 slicing)



STG supports different approaches to production of aggregated products



Simple products from single sources



Composite product with (weighted) input from multiple sources

SUMMARY and FUTURE WORK

- Uncertainty can be traced, characterized, understood and managed. It can be used to help design aggregation algorithms.
- STG is transparent, iterative, fast, independent of instrument and dynamic (allows implementation of user-defined aggregation strategies).
- A modular approach to aggregation facilitates a systematic and traceable investigation into the behavior of data and geophysical properties over space-time
- Aggregation can be used to
  - Better understand L2 differences/algorithms/uncertainties
  - Make user-specific L3 products with high information content and good uncertainty estimates
- Aggregation is not limited to the averaging of L2 pixels. L3 can be higher level information products that draw on data from multiple parameters/sources)

- Continue to characterize sources of uncertainty
- Investigate methods for working with multiple observations at different times.
- Evaluate cloud parameter differences between Imager-Sounder pairs (MODIS/AIRS, AVHRR/IASI, VIIRS/CrIS). Develop composite imager-sounder cloud products
- Build long-term sounder (HIRS/AIRS/CrIS/IASI) cloud record
- Investigate the effect of ancillary data resolution on L-3 products