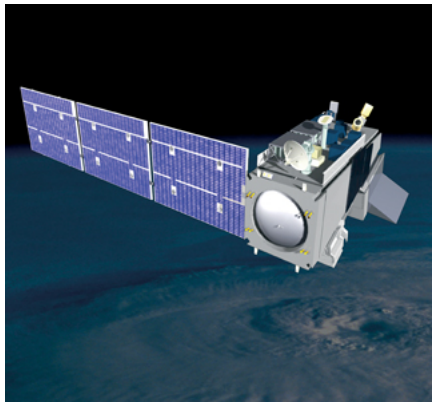
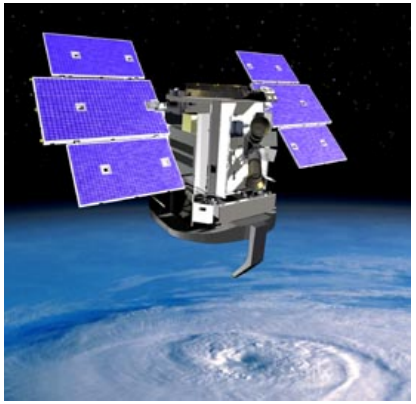
Evaluation of the VIIRS Cloud Base Height (CBH) EDR Using CloudSat





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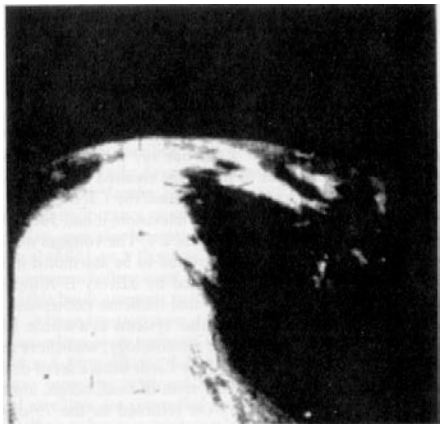
NOAA/NESDIS/Satellite Applications and Research

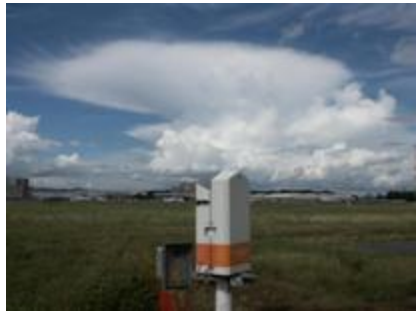
Introduction

- Satellites have been viewing the tops of clouds for 50+ years
- Hutchison (2002) developed algorithm to determine cloud base height (CBH) from VIS/IR observations from MODIS
- VIIRS (CBH) EDR is the first operational algorithm to determine cloud base height
- CBH is important for aviation
- CBH is also important for closure of the Earth's Radiation Budget

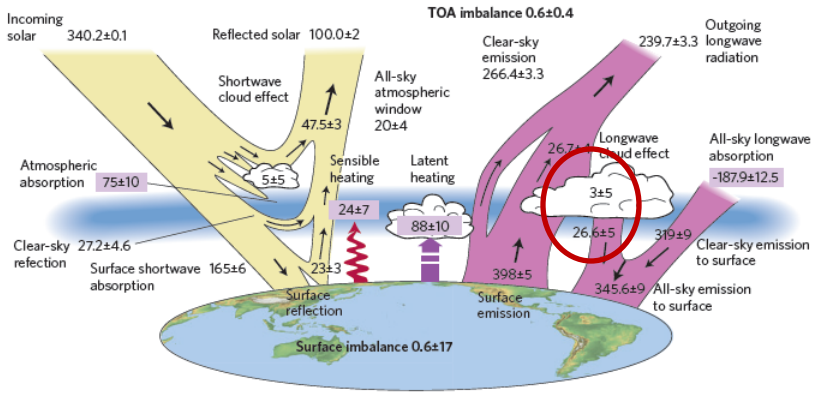


TIROS-1 (1960) [Rao *et al.* (1990)]

VIIRS "Blue Marble" [NASA 2012]



Airport ceilometer [DWD]



[Stephens *et al.* (2012)]

Cloud Base Height Algorithm

The cloud base height for liquid clouds is defined at right. Cloud base height definition for ice clouds is similar, except the average ice water content is temperature dependent.

CBH requires upstream retrievals of cloud top height (CTH), cloud optical depth (τ), effective particle size (r_e) and cloud type, which is used to determine the LWC value to use.

Errors in CBH are directly proportional to errors in each of these values. Issues in upstream retrievals directly impact CBH retrieval.

τ, r_e, cloud type $\longleftrightarrow$ IVPCP

CTH $\longleftrightarrow$ IVPTP

CBH algorithm for liquid clouds:

$$CBH = CTH - \left(\frac{LWP}{LWC}\right)$$

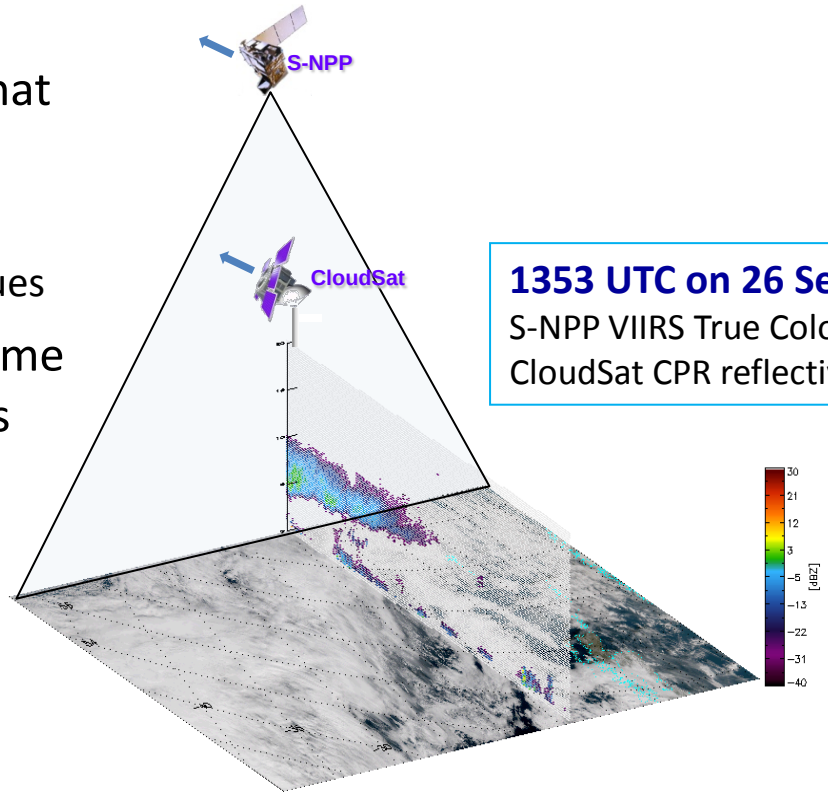
$$LWP = \frac{2\tau\rho r_e}{3}$$

Red variables come from upstream retrievals

LWC is pre-defined average value based on cloud type; cloud type comes from upstream retrieval

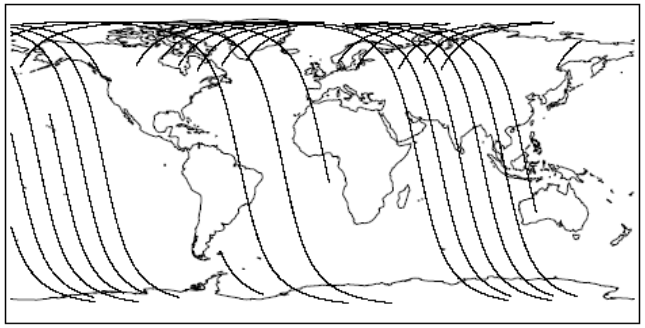
Matching VIIRS with CloudSat

- CloudSat has a cloud-profiling radar that is well suited to observe CBH for most clouds
  - Ground clutter and precipitation are issues
- Suomi-NPP and CloudSat are in the same orbital plane, but at different altitudes
- CloudSat and VIIRS overlap for ~4.5 hours every 2-3 days
  - 8-9 “matchup periods” per month
- Due to battery issues, CloudSat only operates on the daytime side of the Earth
- Use only the closest non-fill VIIRS pixels that overlap CloudSat and have CBH and CTH above 1 km AGL
- Use only CloudSat profiles where precipitation is not present



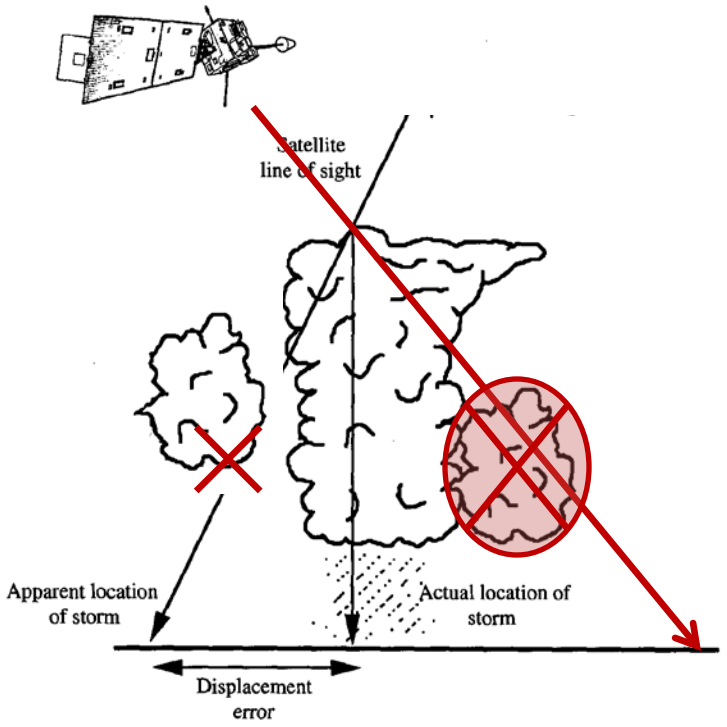
1353 UTC on 26 Sept 2013
S-NPP VIIRS True Color image
CloudSat CPR reflectivity

Match-up locations Sept. 2013

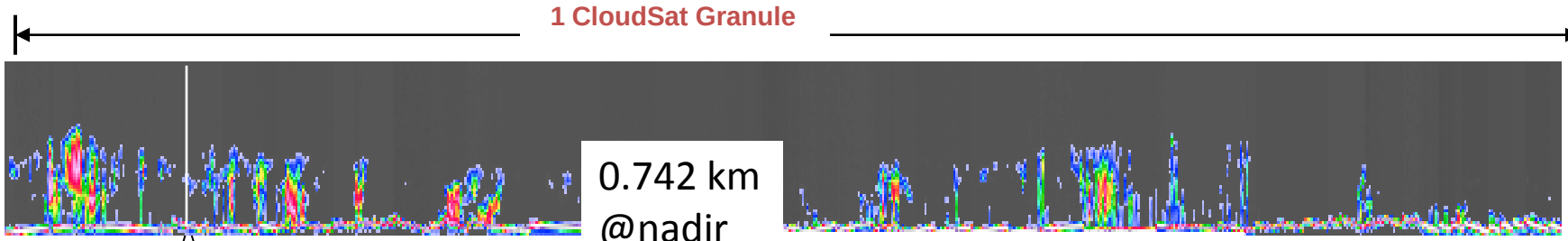


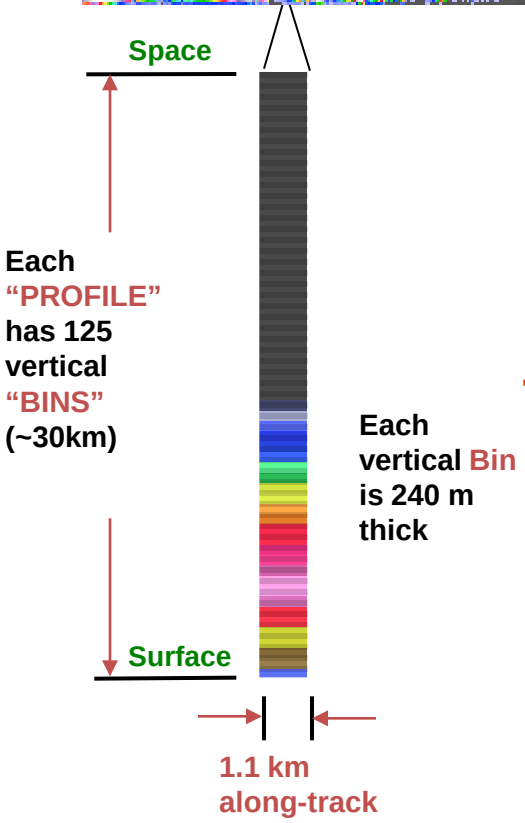
What VIIRS Sees

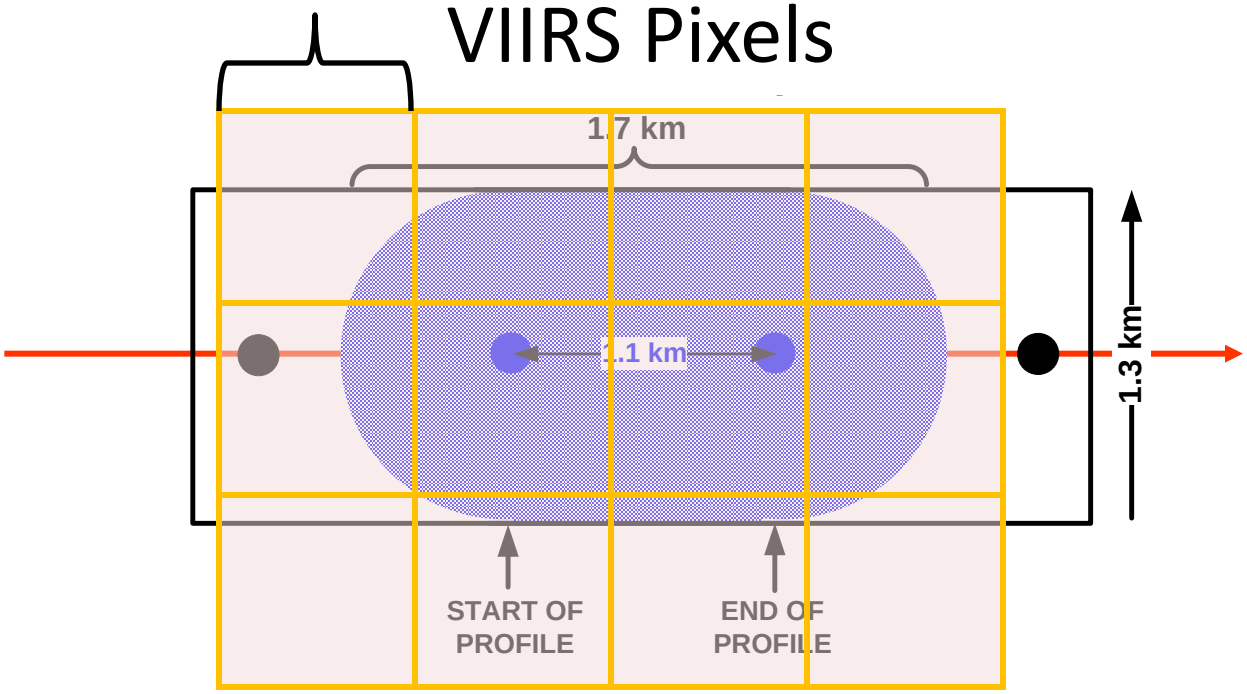
- Intermediate Products (IP) have the same resolution as M-band SDRs
- Parallax-corrected cloud products (IVPTP, IVPCP) are required to properly account for line-of-sight issues
- Parallax means some clouds are missed
- VIIRS does not see through optically thick clouds
- Only the top of the top-most layer



What CloudSat Sees







95 GHz Cloud Profiling Radar (CPR)

CPR samples at 625 kHz = 0.16 sec / burst (called a profile)

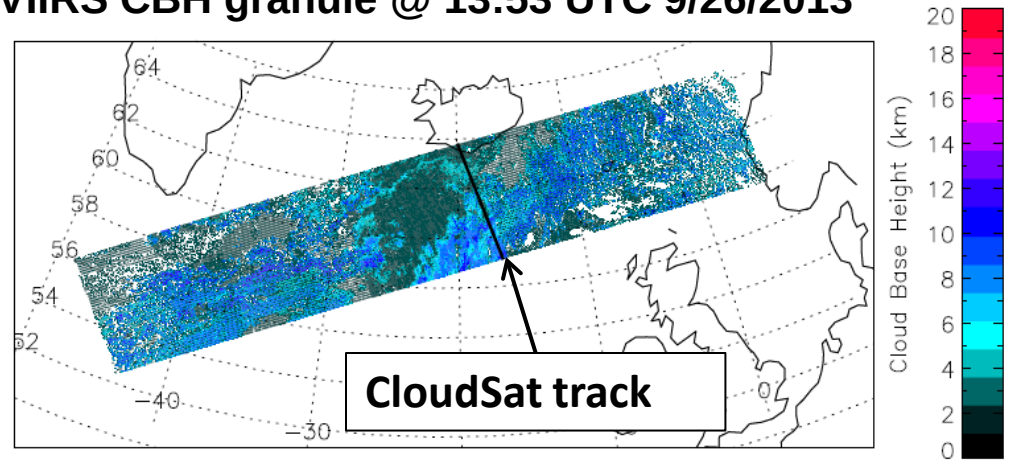
PRF = 4300

(4300 pulses / sec) * (0.16 sec/burst) = 688 pulses/profile

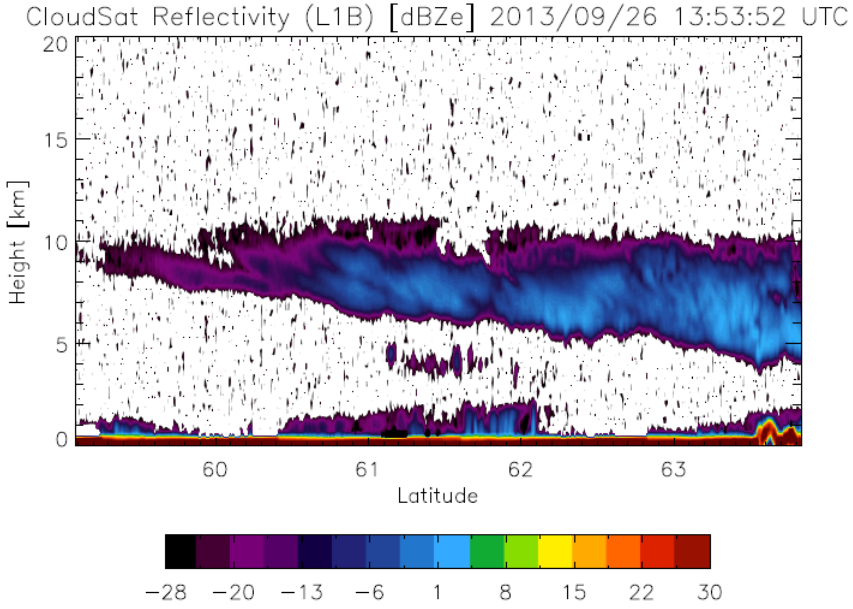
Figures courtesy D. L. Reinke, CIRA

Matchup Example

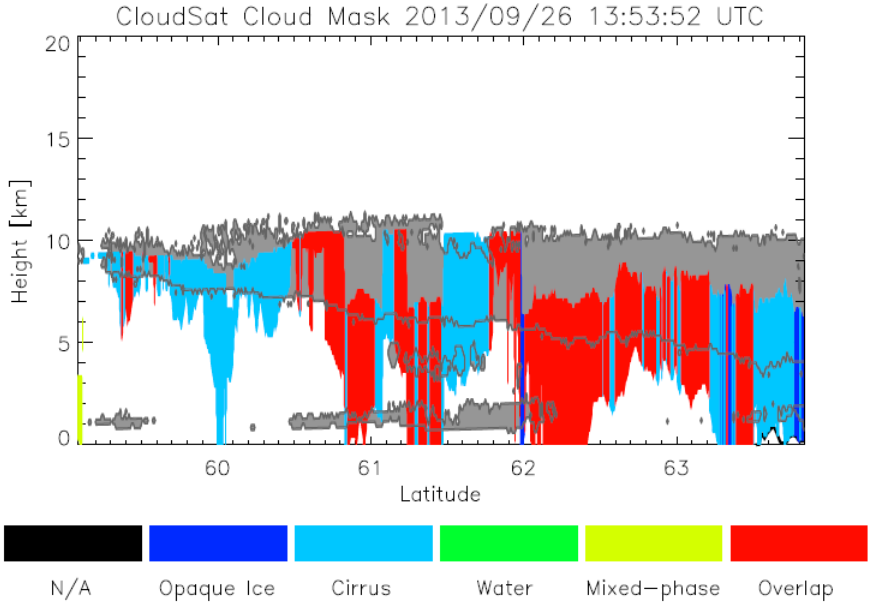
VIIRS CBH granule @ 13:53 UTC 9/26/2013



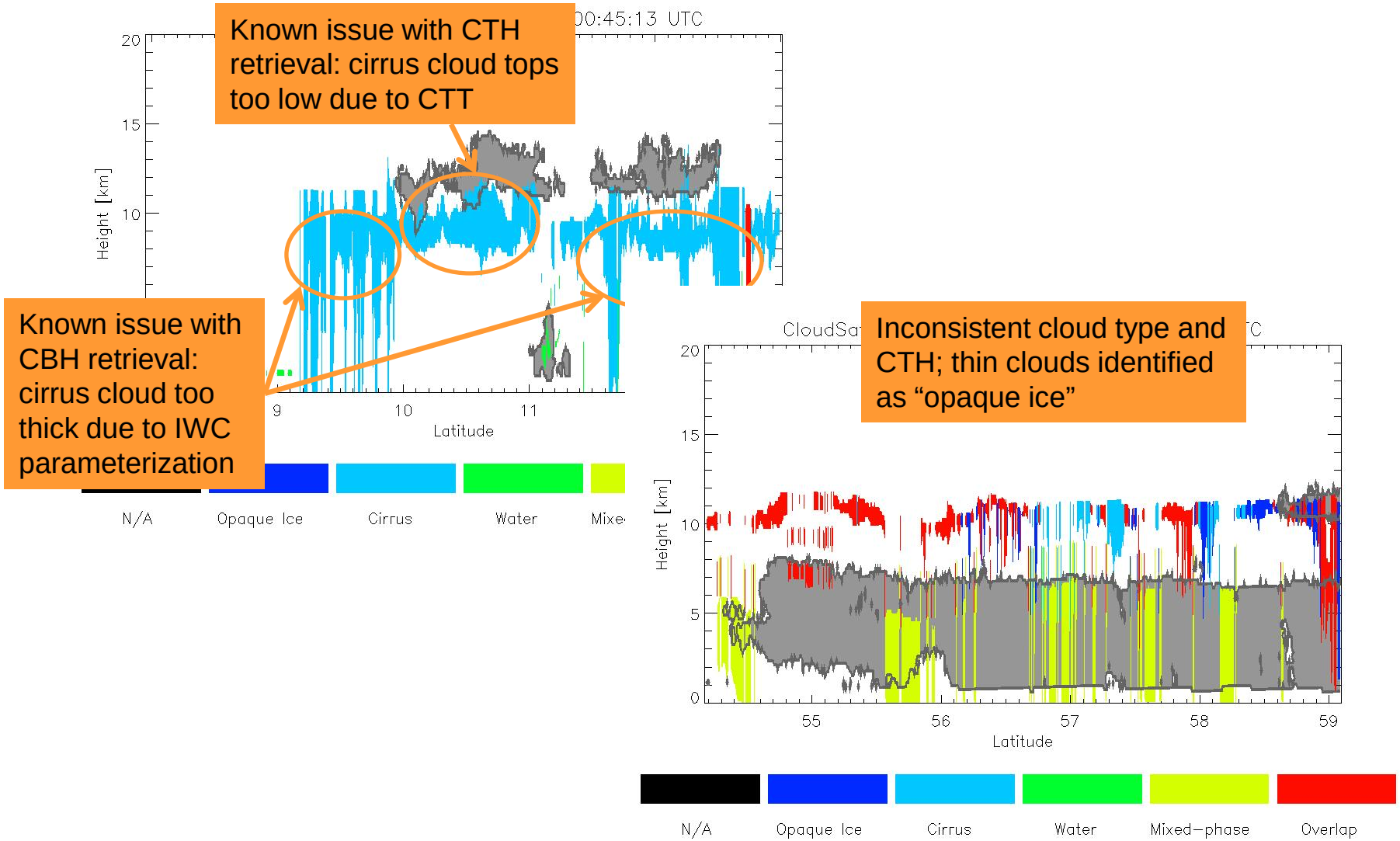
CloudSat 2B-GEOPROF reflectivity



CloudSat Cloud Mask with VIIRS overlayed



Additional Examples



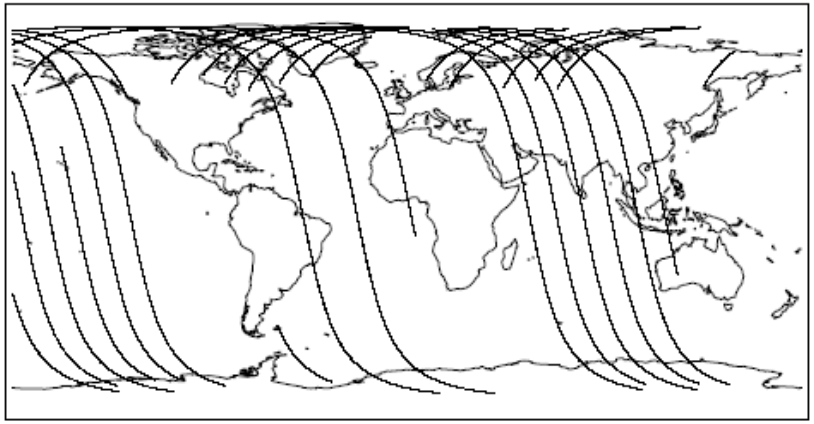
Gray shading represents vertical extent of clouds from CloudSat cloud mask. Colored areas represent vertical extent of clouds from VIIRS CTH and CBH retrievals, sorted by VIIRS cloud type.

"All Clouds" vs. "Within Spec"

- The VIIRS CBH algorithm has been evaluated for two groups:
  - All clouds observed by CloudSat and VIIRS
  - Only those clouds where the VIIRS CTH retrieval is within the error specifications (aka "Within Spec")
    - Error specifications: CTH must be within 1 km if the COT is greater than 1, or within 2 km if the COT is less than 1
- Thus, "**All Clouds**" results show the general performance of the CBH retrieval, "**Within Spec**" results show the performance of the CBH retrieval when the CTH retrieval is accurate
  - CBH accuracy is very closely related to CTH accuracy
  - CBH is within the error specifications if CBH error is less than 2 km

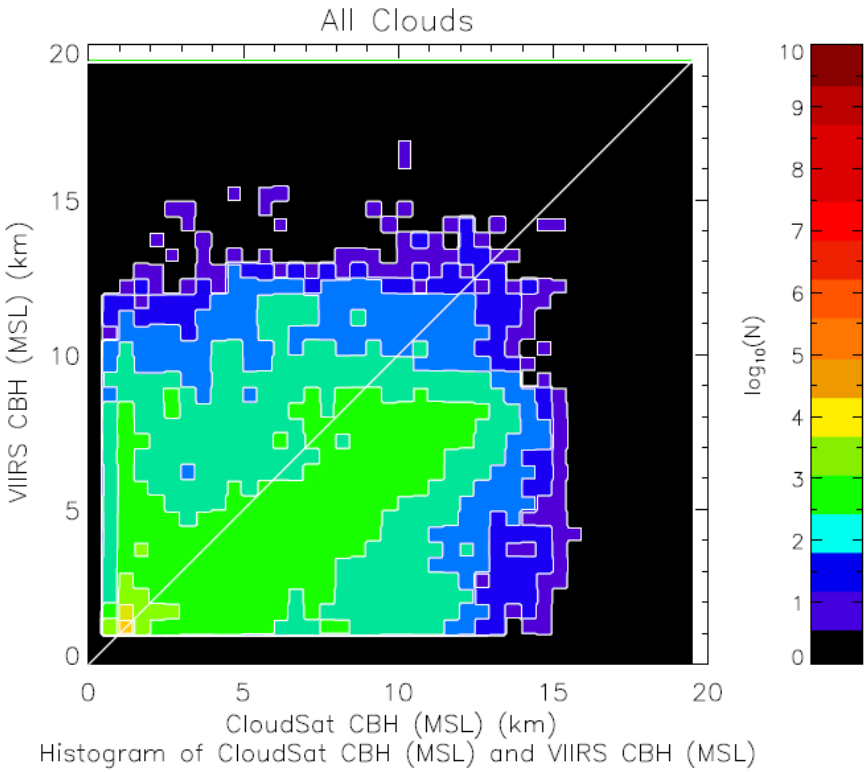
From a Month of Matchups

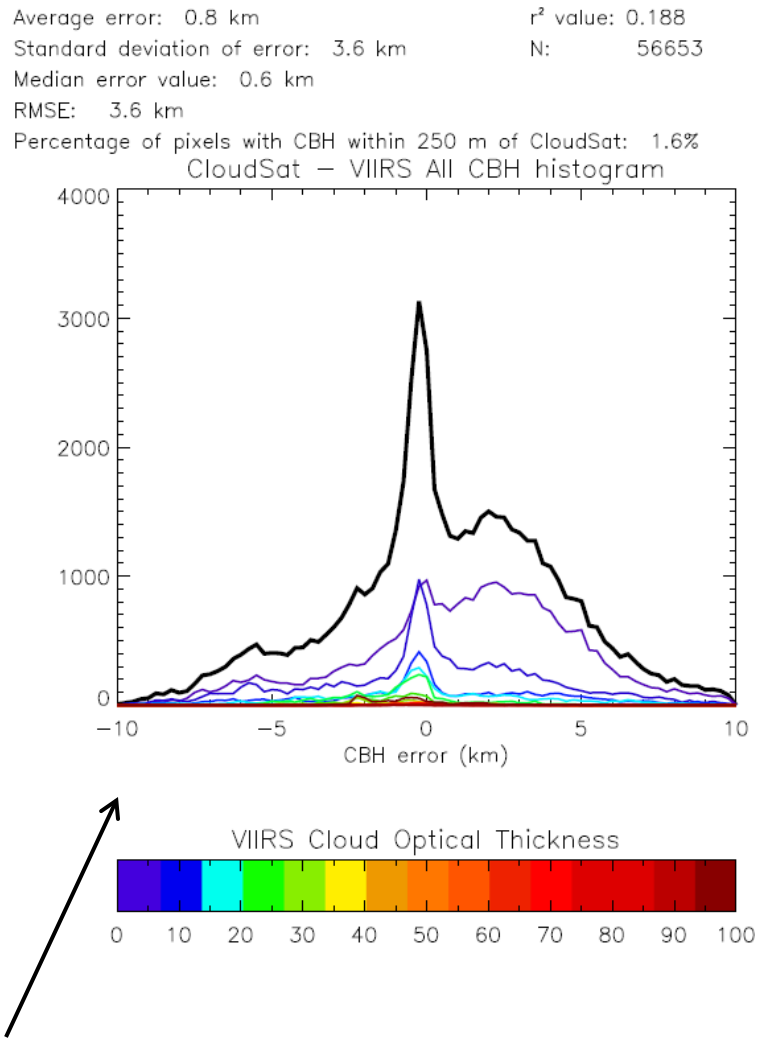
Match-up locations (Sept. 2013)



	September 2013
Matchup periods examined	9
Total matchup profile-pixel pairs	363,499
Valid matchup points	56,655
Percentage of valid points where CTH is “within spec”	37.6%
Percentage of valid points where CBH error < 2 km	44.6%

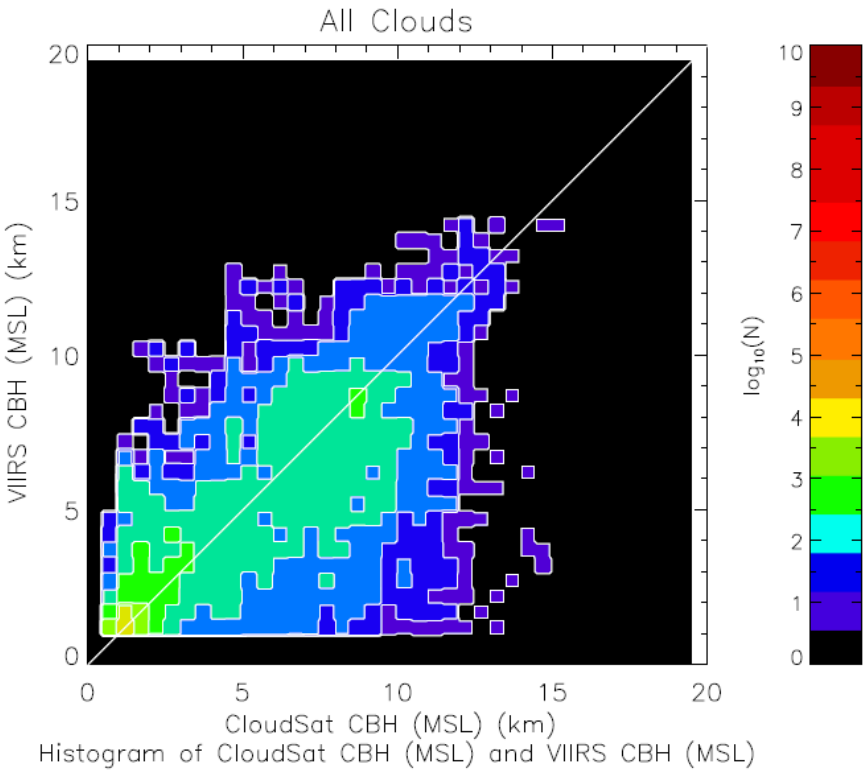
All “Valid Matchups”

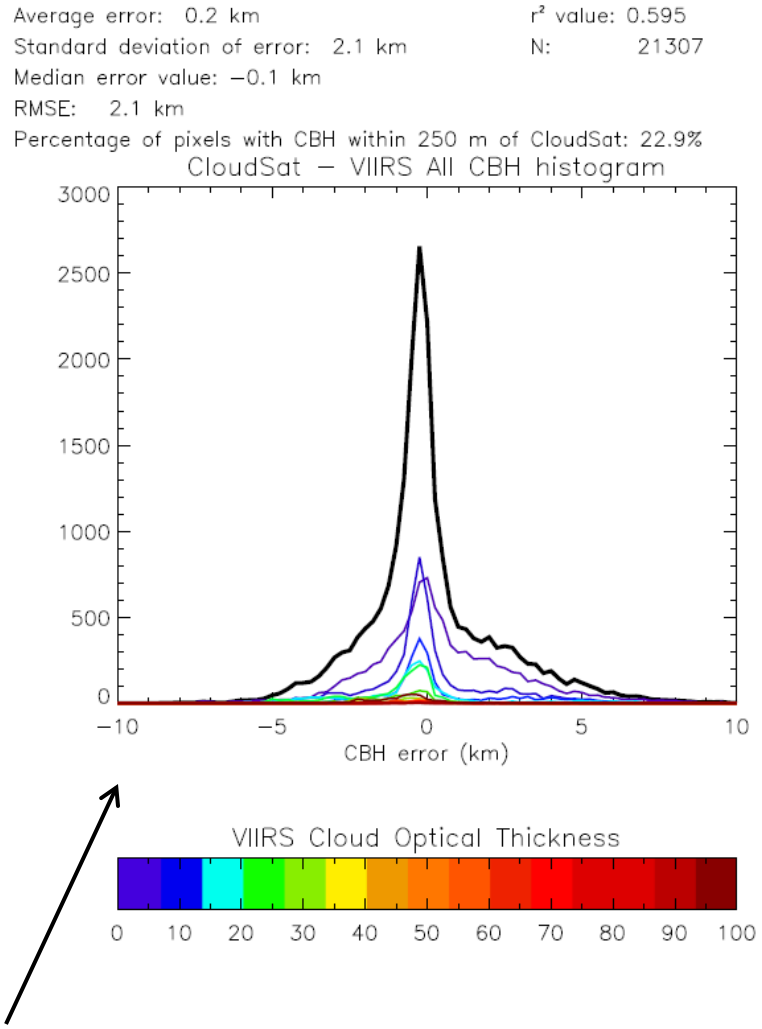




Negative errors indicate CloudSat CBH was lower than VIIRS CBH
(VIIRS biased high relative to CloudSat)

“Within Spec” Matchups





Negative errors indicate CloudSat CBH was lower than VIIRS CBH
(VIIRS biased high relative to CloudSat)

Cloud-type Statistics

When the CTH retrieval is within the error specifications, the CBH retrieval performs better.

CBH retrieval performs best on clouds classified as **liquid water**. The retrieval performs the worst for cirrus and overlap clouds.

All valid matchups

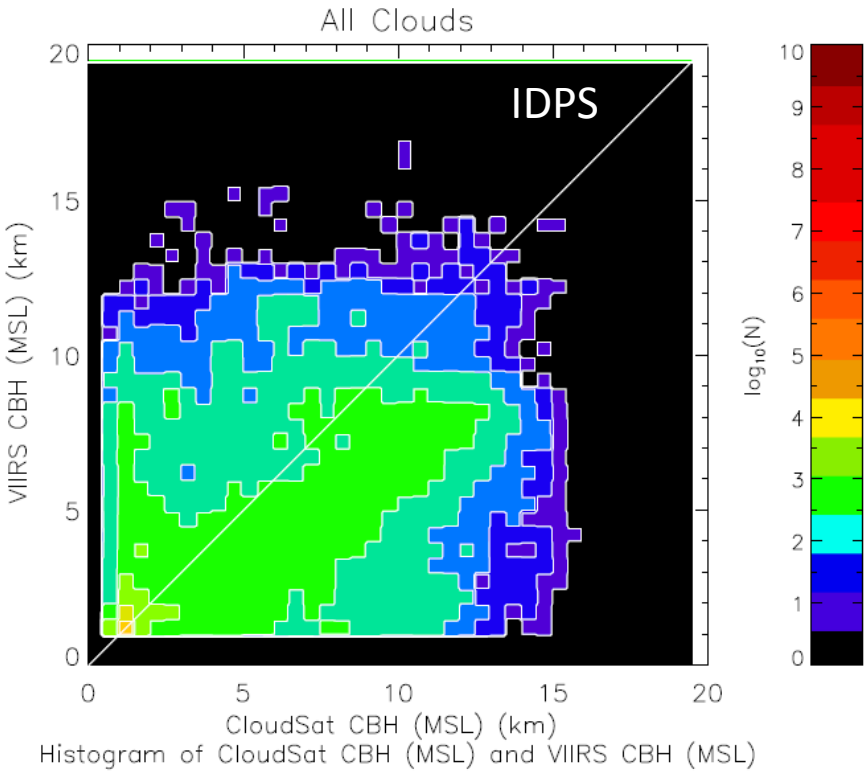
	All Clouds	Opaque Ice	Cirrus	Water	Mixed-phase	Overlap
Percentage of valid points (%)	100	5.5	36.6	18.9	14.4	24.6
Average Error (km)	0.8	-1.1	1.7	0.9	-0.2	0.6
Median Error (km)	0.6	-1.0	2.2	0.0	-0.3	1.2
Standard Deviation (km)	3.6	3.4	3.5	2.9	2.5	4.2
RMSE (km)	3.6	3.6	3.9	3.0	2.5	4.3
Percentage within 250 m (%)	1.6	0.9	1.6	4.3	1.9	1.4
R-squared correlation (-)	0.188	0.030	0.093	0.124	0.066	0.000

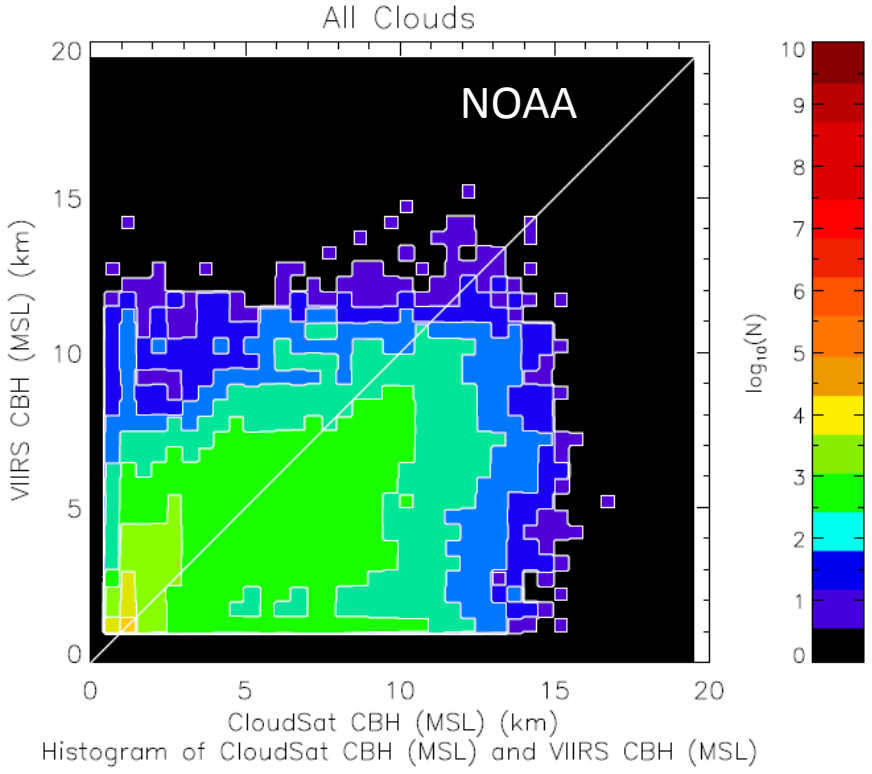
Within Spec matchups

	All Clouds	Opaque Ice	Cirrus	Water	Mixed-phase	Overlap
Percentage of valid points (%)	100	4.2	28.6	31.1	19.3	16.6
Average Error (km)	0.2	0.5	1.0	-0.2	-0.7	0.8
Median Error (km)	-0.1	0.2	0.9	-0.2	-0.4	0.5
Standard Deviation (km)	2.1	2.4	2.7	0.6	1.5	2.8
RMSE (km)	2.1	2.4	2.8	0.7	1.6	2.9
Percentage within 250 m (%)	22.9	10.9	7.3	44.4	26.5	8.1
R-squared correlation (-)	0.595	0.190	0.208	0.814	0.224	0.181

Green values indicate best performer
Red values indicate worst performer

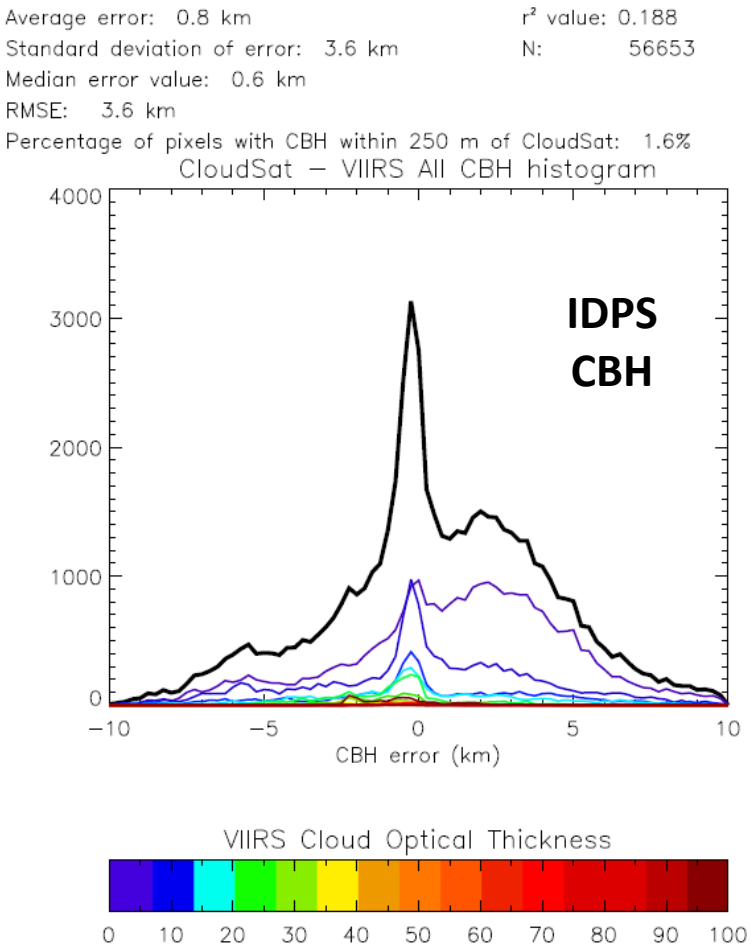
Investigating a Switch of Algorithms

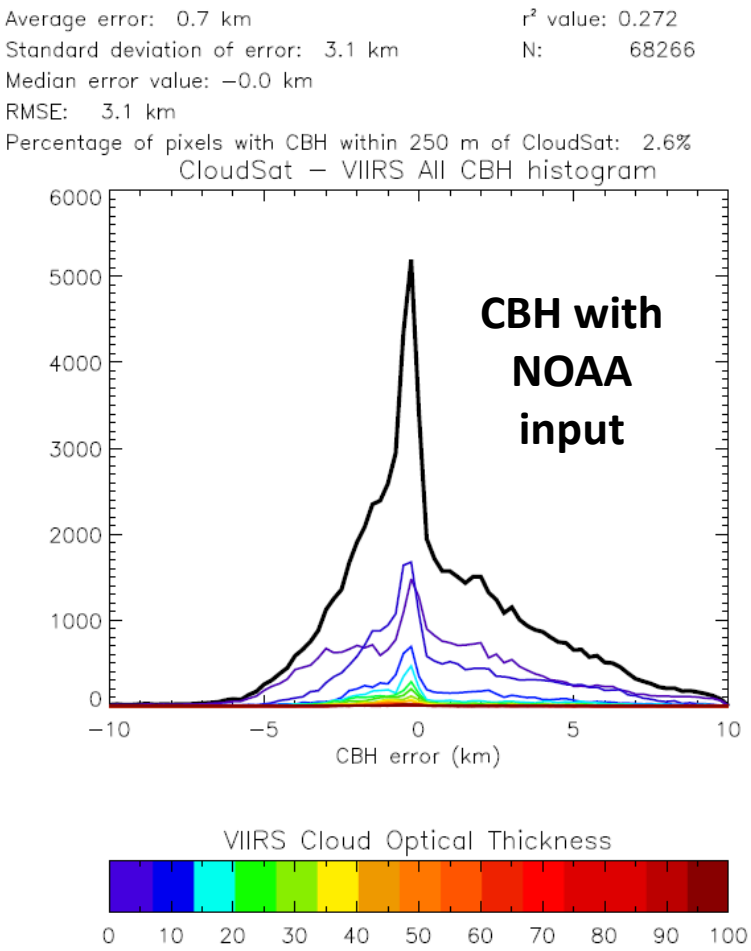




September 2013	IDPS	NOAA
Matchup periods examined	9	9
Valid matchup points	56,653	68,266
Percentage of valid points where CTH is "within spec"	37.6%	52.1%
Percentage of valid points where CBH error < 2 km	44.6%	56.3%

IDPS vs NOAA: **All Valid Matchups**





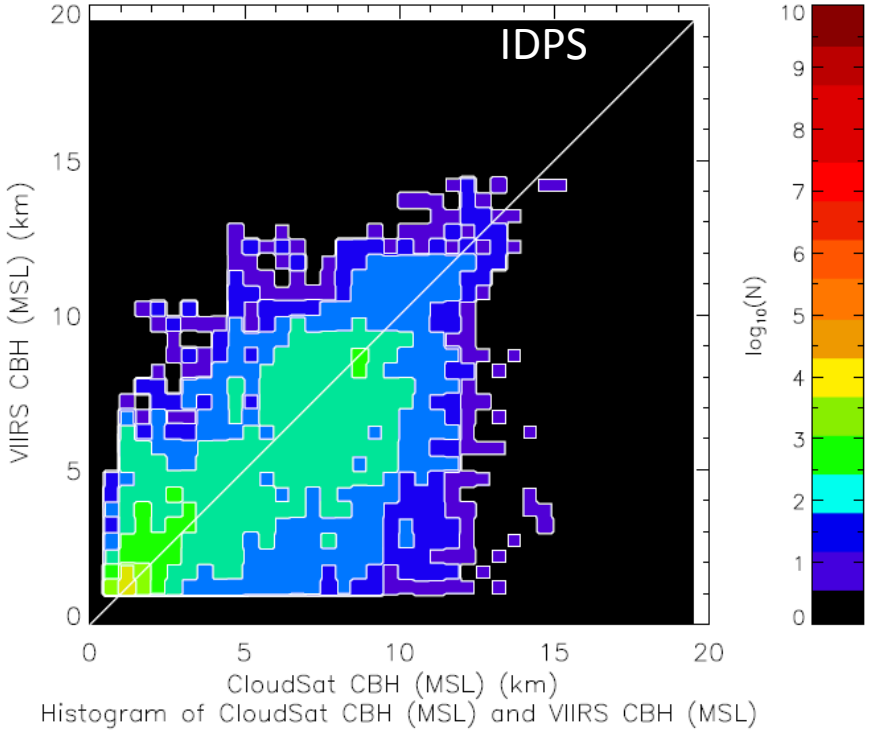
R^2= 0.188, RMSE= 3.6 km, Avg error= 0.8 km
CBHs within 250 m of CloudSat = 1.6 %

R^2= 0.272, RMSE= 3.1 km, Avg error= 0.7 km
CBHs within 250 m of CloudSat = 2.6 %

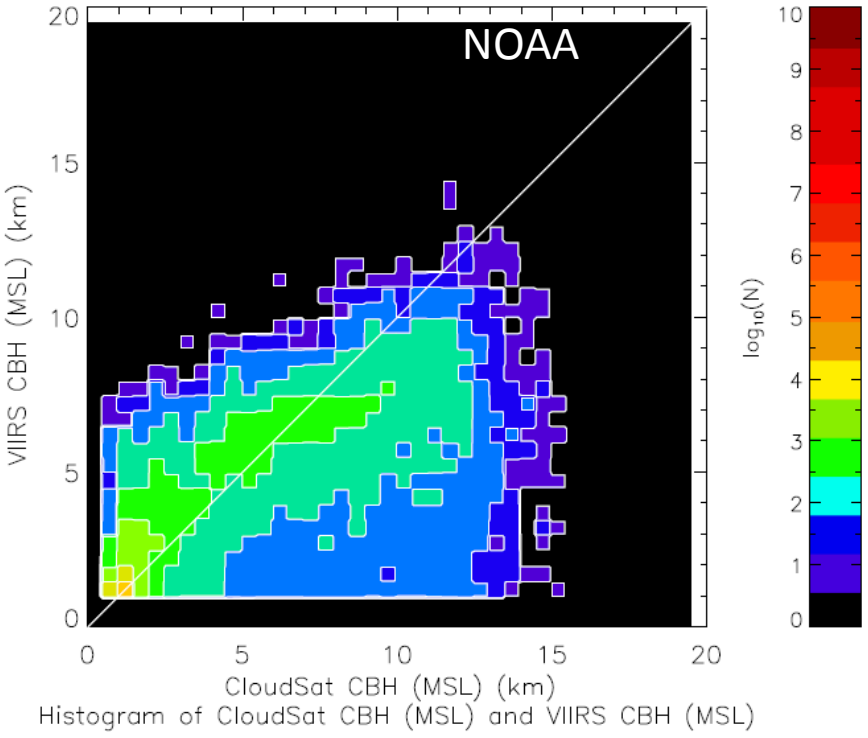
Negative errors indicate CloudSat CBH was lower than VIIRS CBH
(VIIRS biased high relative to CloudSat)

IDPS vs. NOAA:**"Within Spec"**

All Cloud Types



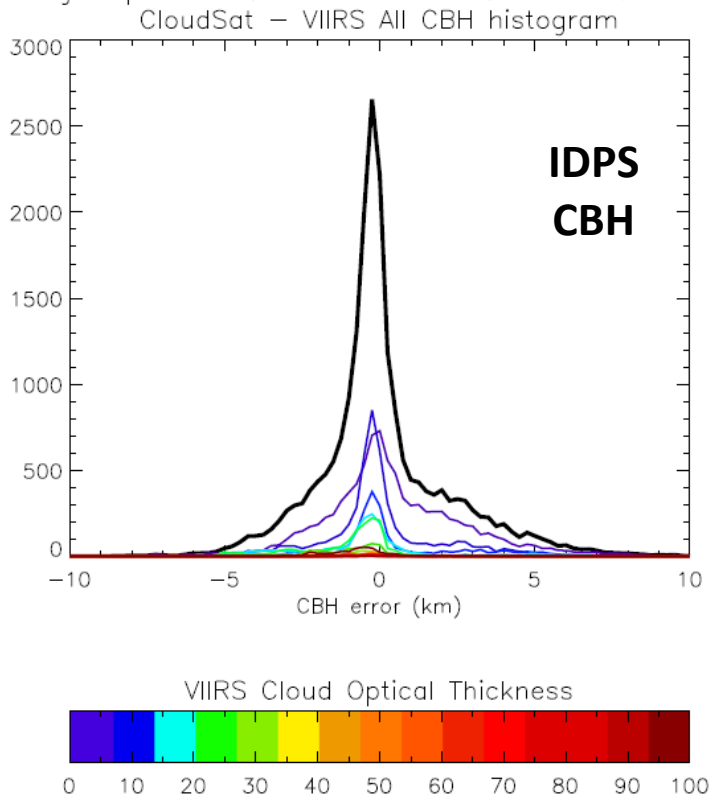
All Cloud Types



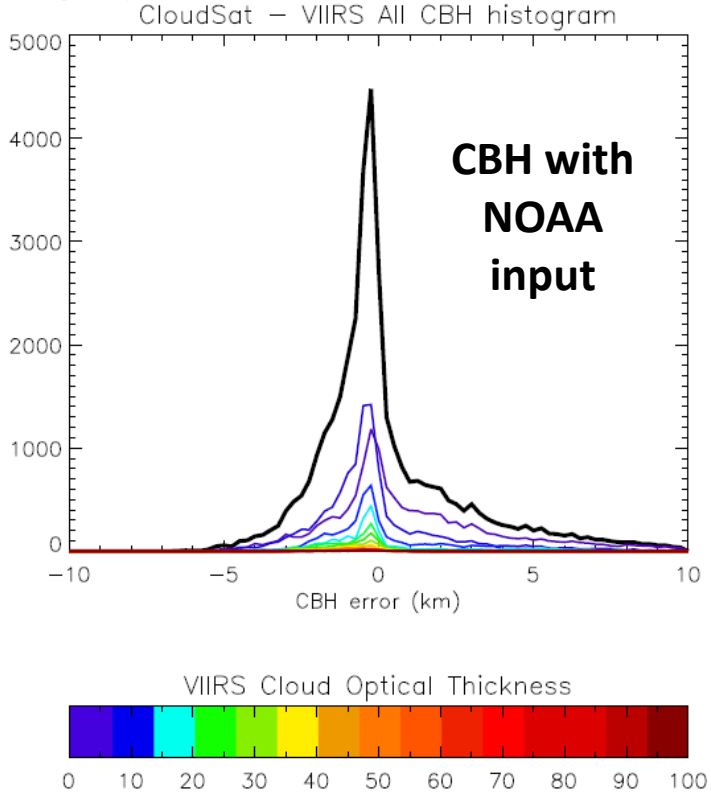
CBH calculations with NOAA upstream input are ongoing.

IDPS vs. NOAA: **"Within Spec"**

Average error: 0.2 km
Standard deviation of error: 2.1 km
Median error value: −0.1 km
RMSE: 2.1 km
Percentage of pixels with CBH within 250 m of CloudSat: 22.9%
r^2 value: 0.595
N: 21307



Average error: 0.4 km
Standard deviation of error: 2.5 km
Median error value: −0.2 km
RMSE: 2.5 km
Percentage of pixels with CBH within 250 m of CloudSat: 20.2%
r^2 value: 0.527
N: 35586



R^2= 0.595, RMSE= 2.1 km, Avg error= 0.2 km
CBHs within 250 m of CloudSat = 22.9 %

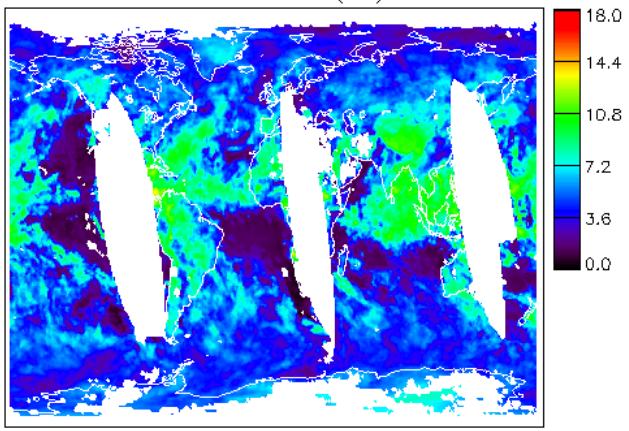
R^2= 0.527, RMSE= 2.5 km, Avg error= 0.4 km
CBHs within 250 m of CloudSat = 20.2 %

Negative errors indicate CloudSat CBH was lower than VIIRS CBH
(VIIRS biased high relative to CloudSat)

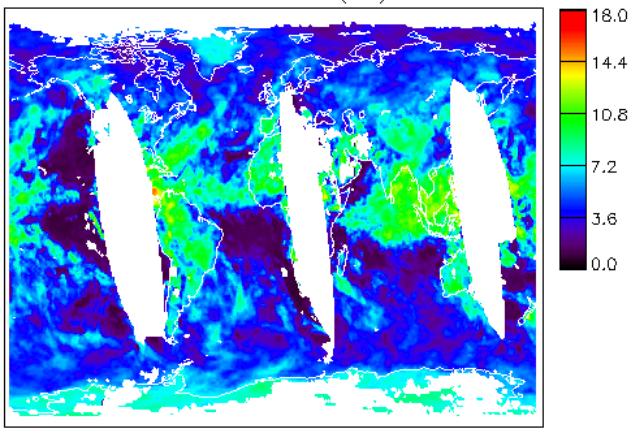
Mean CTH & CBH of Sept-Oct 2013 VIIRS-CloudSat matchups (1^o x 1^o)

CLAVR-x Supercooled cloud type as water phase to CBH calculation

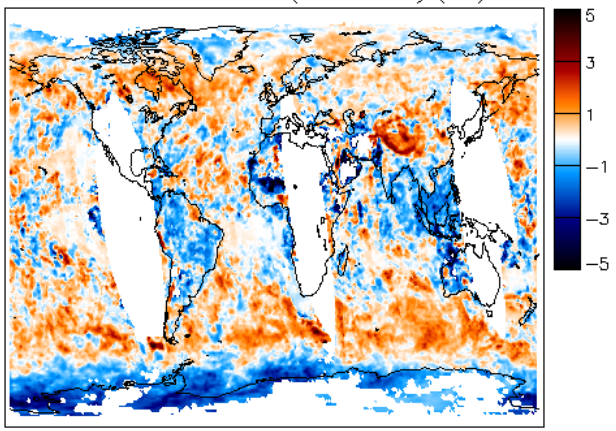
VIIRS IDPS CTH



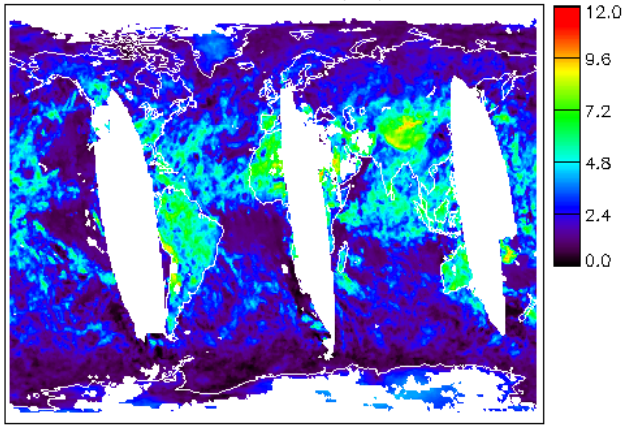
NOAA CTH



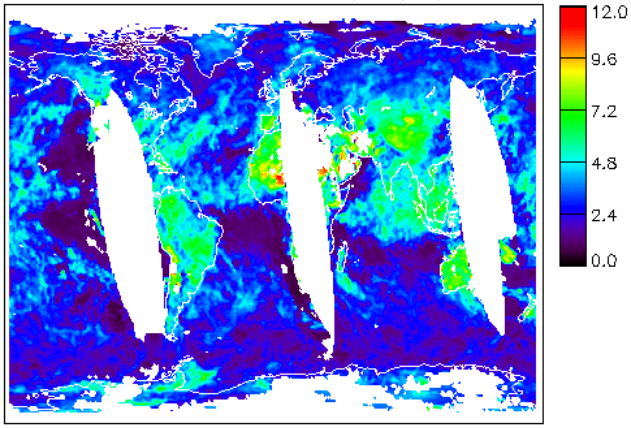
Δ CTH



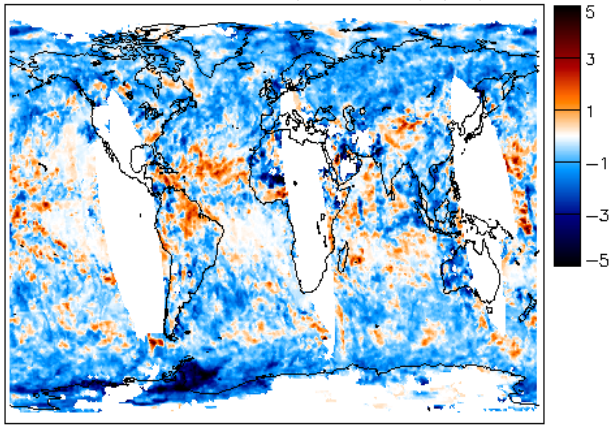
VIIRS IDPS CBH



CBH with NOAA input

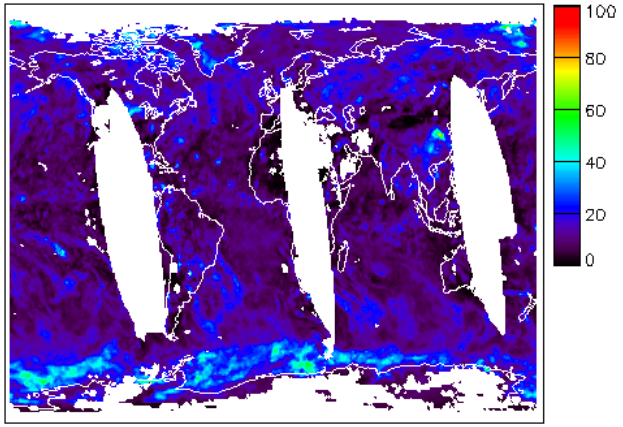


Δ CBH

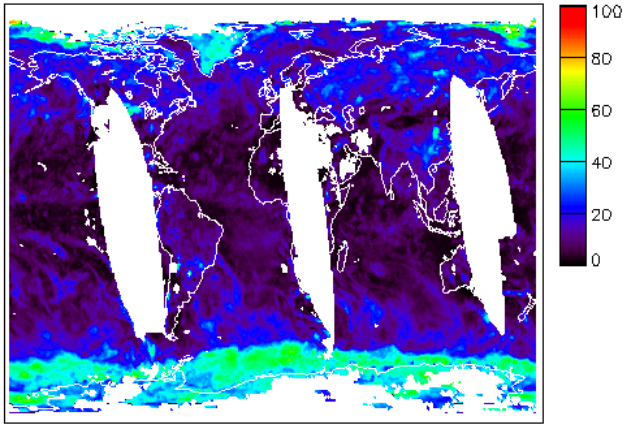


Mean COT and EPS of Sept-Oct 2013 VIIRS-CloudSat matchups (1º x 1º)

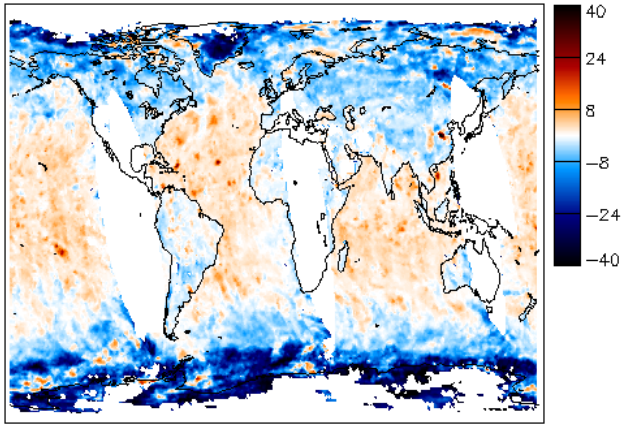
VIIRS IDPS COT



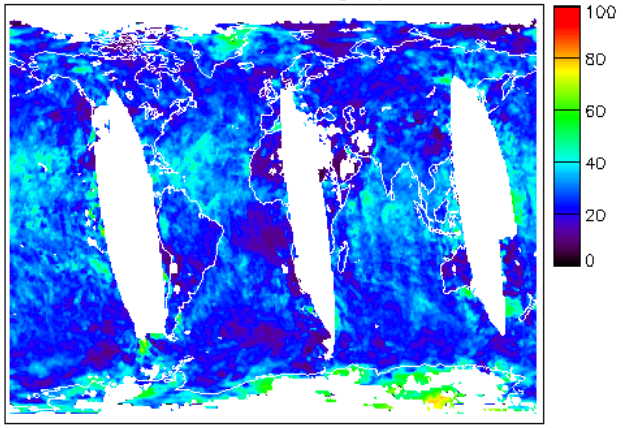
NOAA COT



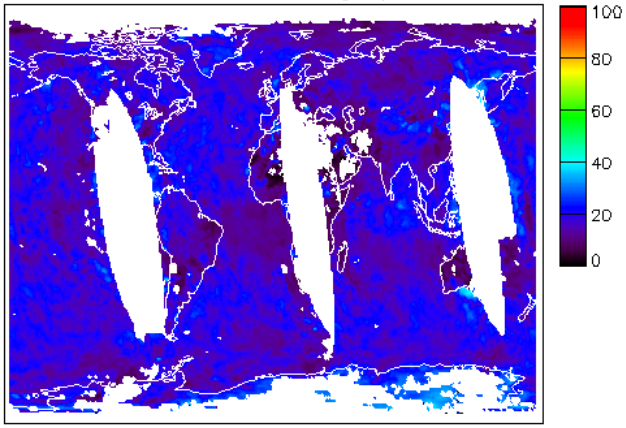
Δ COT



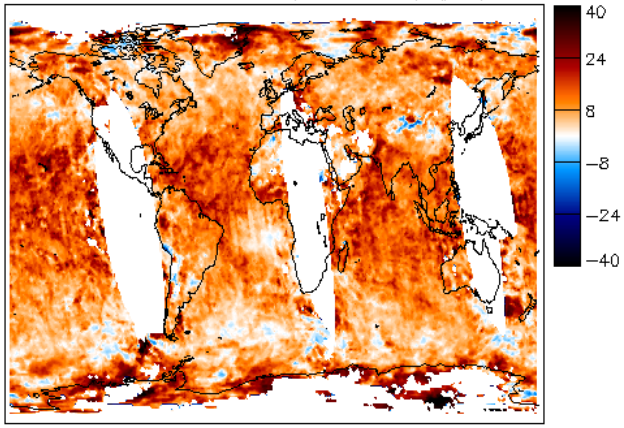
VIIRS IDPS EPS



NOAA EPS



Δ EPS



Summary

- Retrieving CBH from VIS/IR information is difficult
  - VIIRS CBH EDR is the first to attempt this on a large scale
- Errors in upstream retrievals all directly impact CBH
  - IWC parameterization results in very low CBH values for high clouds
  - Cloud type errors impact CBH
  - Very low effective particle size and optical depths observed
  - Difficult to retrieve CTH for optically thin ice clouds
- VIIRS and CloudSat do not always agree on where the upper-most cloud layer is
  - Results in large CBH errors
- CBH has some skill when CTH is “within spec”
- In general, the NOAA algorithms perform better than IDPS when compared to CloudSat for all valid matchups
  - Similar performance for “within spec” matchups
- CBH retrieval performs best for low, liquid water clouds; worst on thin cirrus and overlap
- Large differences in EPS and COT between IDPS and NOAA algorithms - This feeds back into CBH

For the Future

- Errors in CTH, COT and EPS need to be fixed
- Average LWC values used by CBH algorithm are constant across the globe
  - Use latitude/temperature dependent LWC
- Investigate fix for poor IWC parameterization
  - Eliminate cirrus CBH at ground level
- Different cloud types form under different dynamic conditions
  - Use lifted condensation level for convective cloud CBH, e.g.
- Use 5+ years of CloudSat statistics on cloud thickness to improve CBH

Backup Slides

September 2013 Matchups

Total number of CloudSat granules included in this matchup: 26
Total number of VIIRS granules included in this matchup: 716
Number of matchup profiles examined: 363499

Number of profiles with VIIRS N/A fill value: 3468 (1.0%)
Number of profiles with VIIRS missing fill value: 205 (0.1%)
Number of profiles with VIIRS pixel trim fill value: 12171 (3.3%)
Number of profiles with VIIRS error fill value: 101824 (28.0%)
Number of profiles with VIIRS VDNE fill value: 0 (0.0%)
Number of profiles with VIIRS flagged as out-of-range: 1 (0.0%)
Number of profiles with valid CBH retrieval and invalid CTH retrieval: 14849 (4.1%)

Clouds obscured by parallax effect

Cloud-free pixels

CloudSat profiles removed due to ground clutter: 120954 (33.3%)
CloudSat profiles removed due to precipitation: 31379 (8.6%)

Profiles where CloudSat detected cloud VIIRS did not: 18866 (5.2%)
Profiles where VIIRS detected cloud CloudSat did not: 53374 (14.7%)
Profiles where CloudSat and VIIRS both detected cloud: 56653 (15.6%)
Profiles where CloudSat and VIIRS did not detect cloud: 234606 (64.5%)

"Valid matchup" pixels

CTH Error specifications: CTH must be within 1 km if the COT is greater than 1, or within 2 km if the COT is less than 1

Profiles where VIIRS is within spec: (CTH) 21308 (5.9%)
Percentage of pixels where both detected cloud and VIIRS was within spec: 37.6%

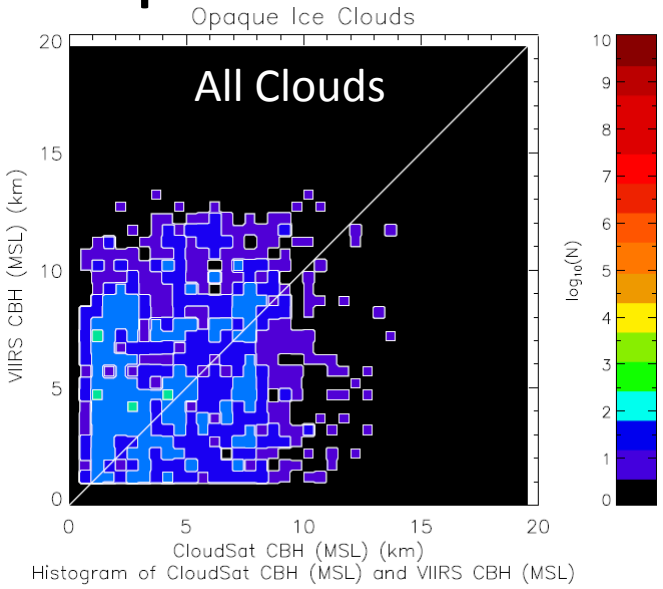
"Within Spec" pixels

CBH Error specifications: CBH must be within 2 km

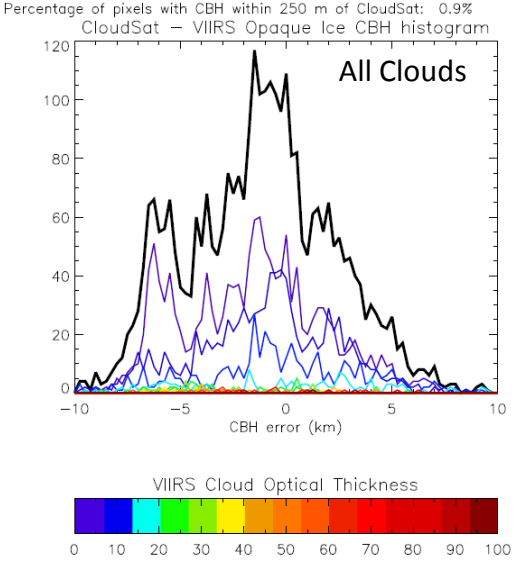
Profiles where VIIRS is within spec: (CBH) 25266 (7.0%)
Percentage of pixels where both detected cloud and VIIRS was within spec: 44.6%

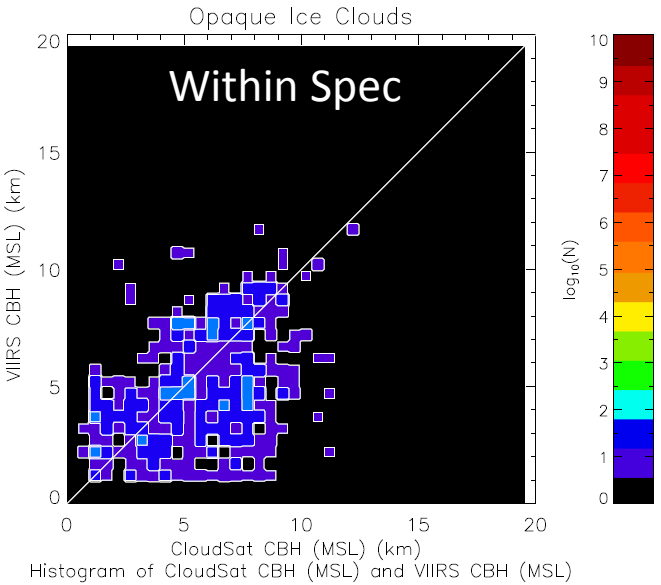
CBH performance – Opaque Ice

September 2013

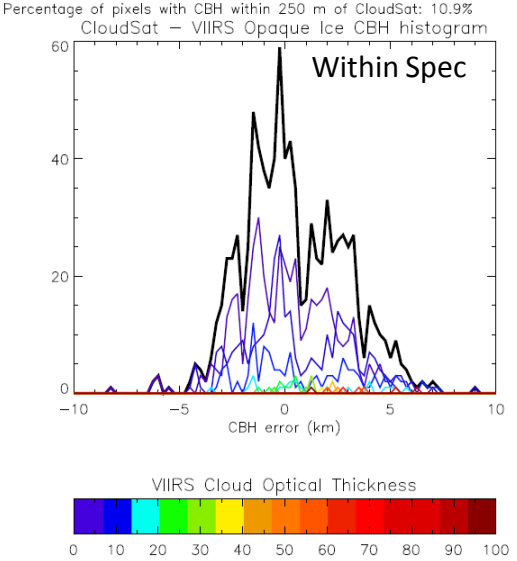


Average error: −1.1 km
Standard deviation of error: 3.4 km
Median error value: −1.0 km
RMSE: 3.6 km
Percentage of pixels with CBH within 250 m of CloudSat: 0.9%
r² value: 0.030
N: 3092



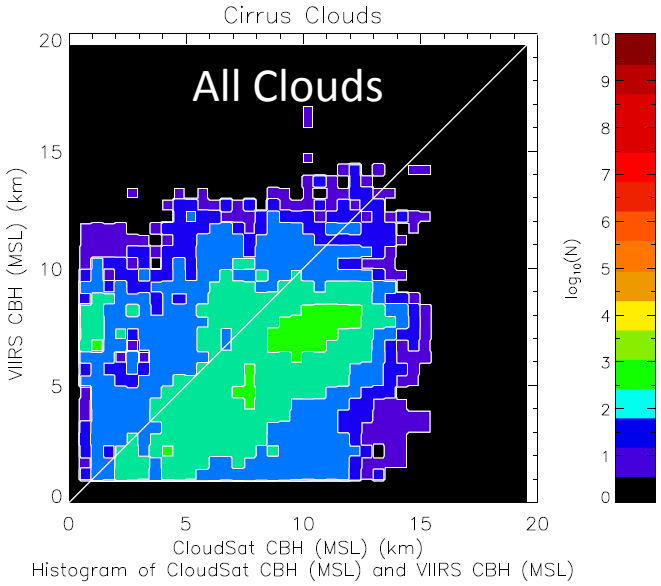


Average error: 0.5 km
Standard deviation of error: 2.4 km
Median error value: 0.2 km
RMSE: 2.4 km
Percentage of pixels with CBH within 250 m of CloudSat: 10.9%
r² value: 0.190
N: 911

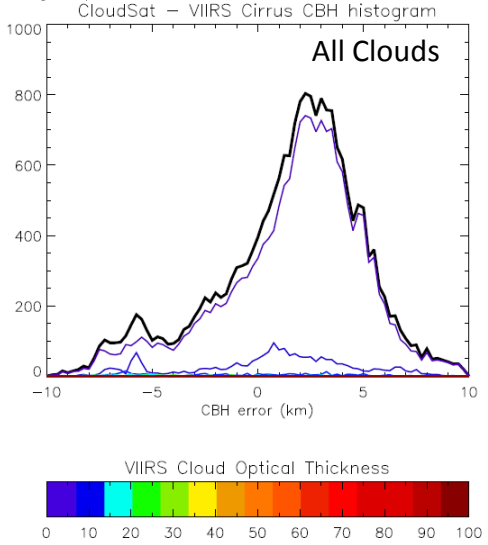


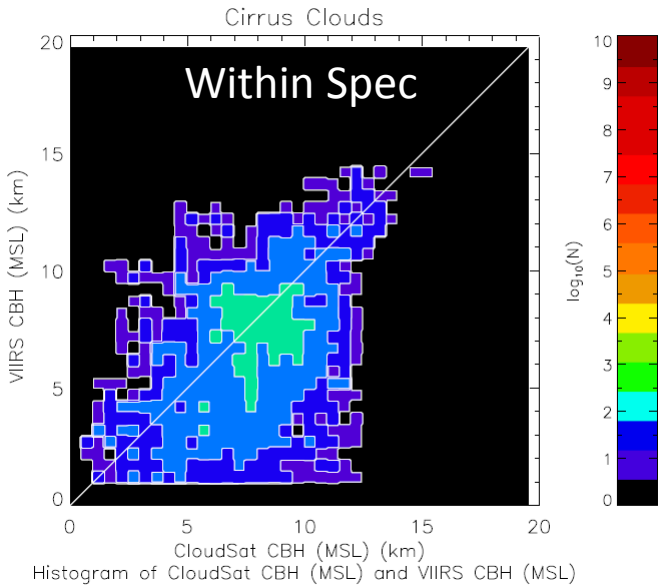
CBH performance – Cirrus

September 2013

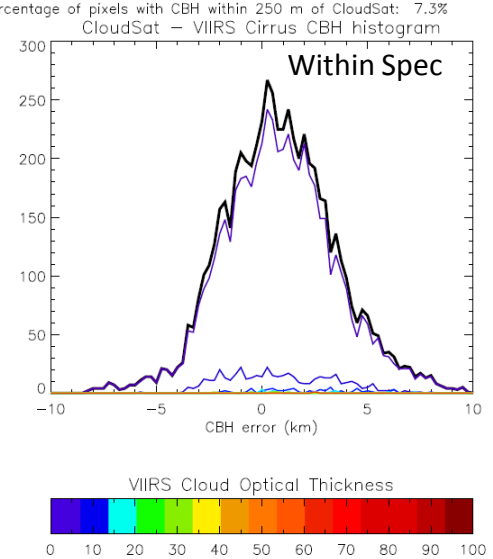


Average error: 1.7 km
Standard deviation of error: 3.5 km
Median error value: 2.2 km
RMSE: 3.9 km
Percentage of pixels with CBH within 250 m of CloudSat: 1.6%
r^2 value: 0.093
N: 20741



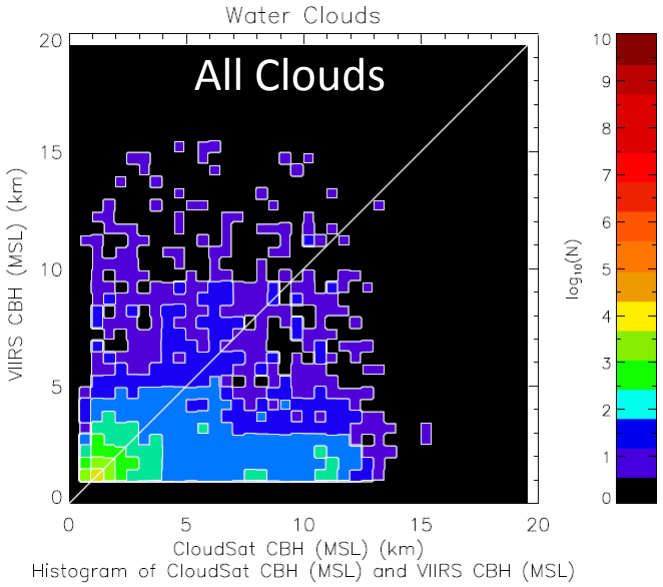


Average error: 1.0 km
Standard deviation of error: 2.7 km
Median error value: 0.9 km
RMSE: 2.8 km
Percentage of pixels with CBH within 250 m of CloudSat: 7.3%
r^2 value: 0.208
N: 6098

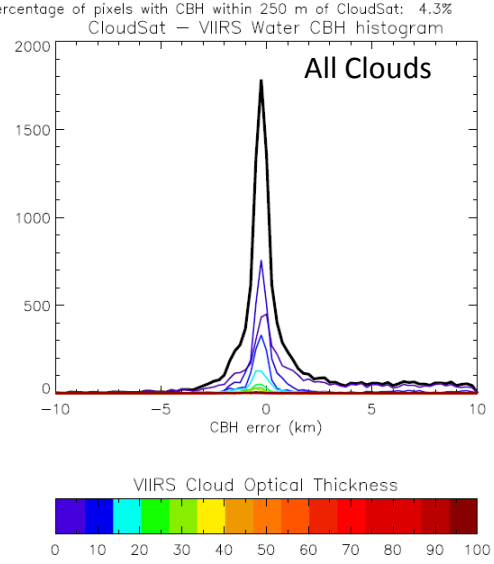


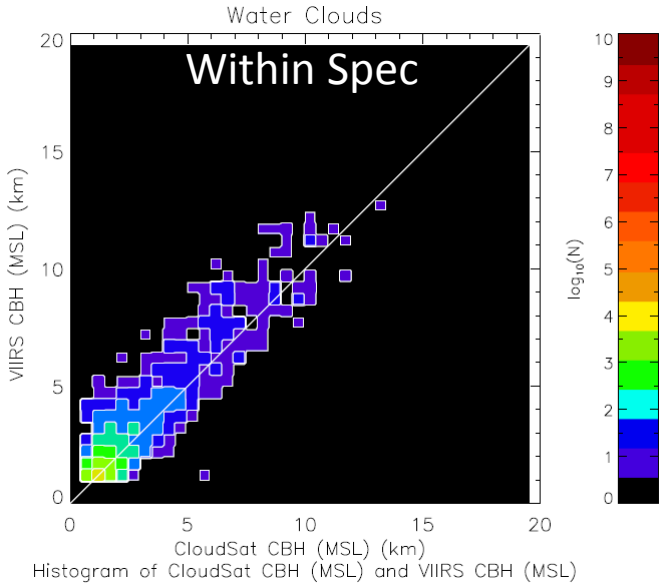
CBH performance – Water

September 2013

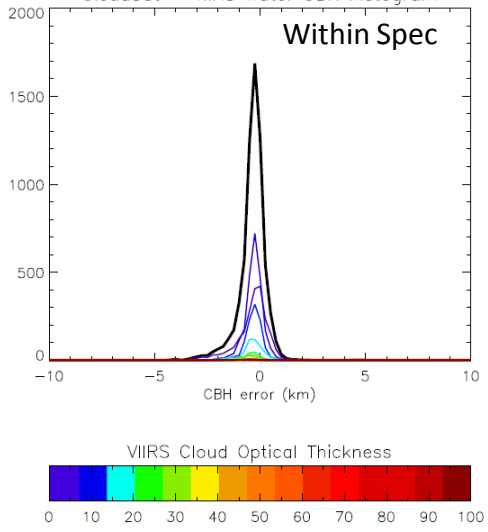


Average error: 0.9 km
Standard deviation of error: 2.9 km
Median error value: −0.0 km
RMSE: 3.0 km
Percentage of pixels with CBH within 250 m of CloudSat: 4.3%
r² value: 0.124
N: 10712



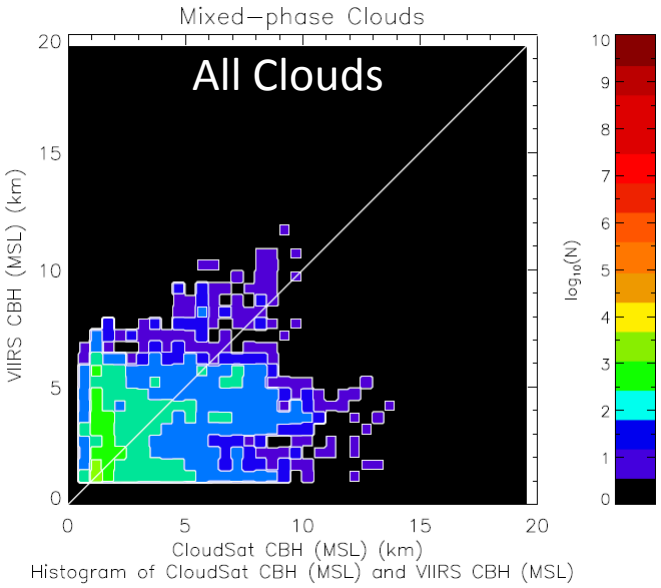


Average error: −0.2 km
Standard deviation of error: 0.6 km
Median error value: −0.2 km
RMSE: 0.7 km
Percentage of pixels with CBH within 250 m of CloudSat: 44.4%
r² value: 0.814
N: 6636

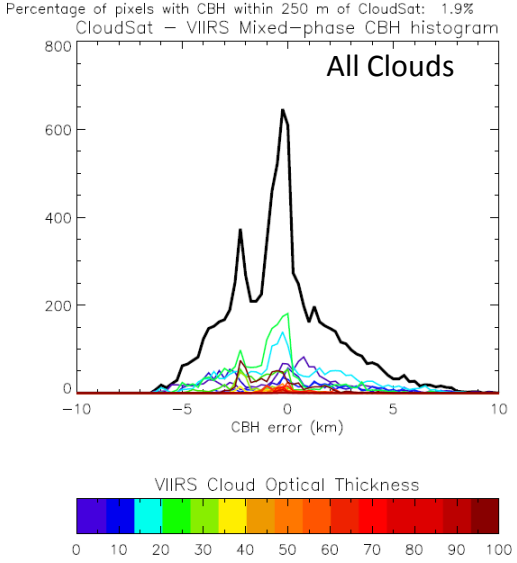


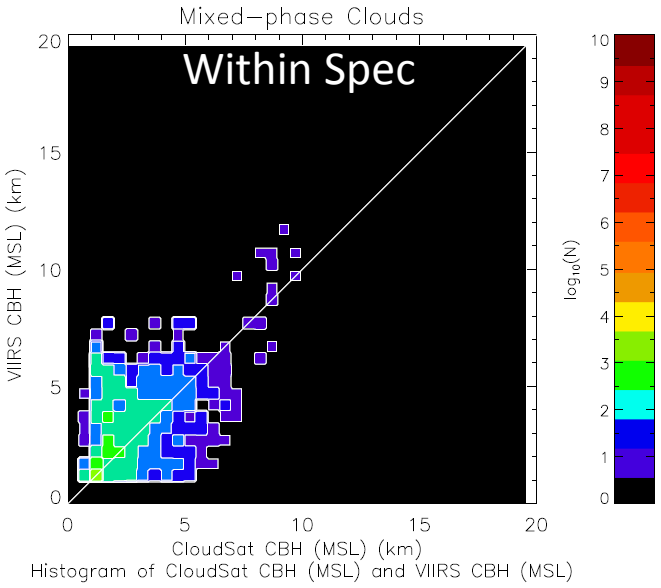
CBH performance – Mixed-phase

September 2013

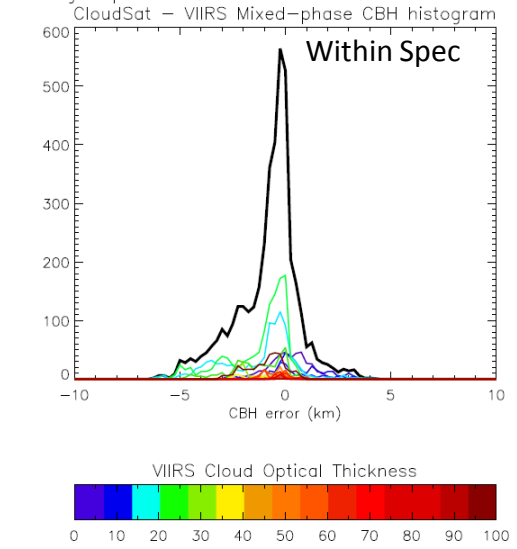


Average error: −0.2 km
Standard deviation of error: 2.5 km
Median error value: −0.3 km
RMSE: 2.5 km
Percentage of pixels with CBH within 250 m of CloudSat: 1.9%
r² value: 0.066
N: 8186



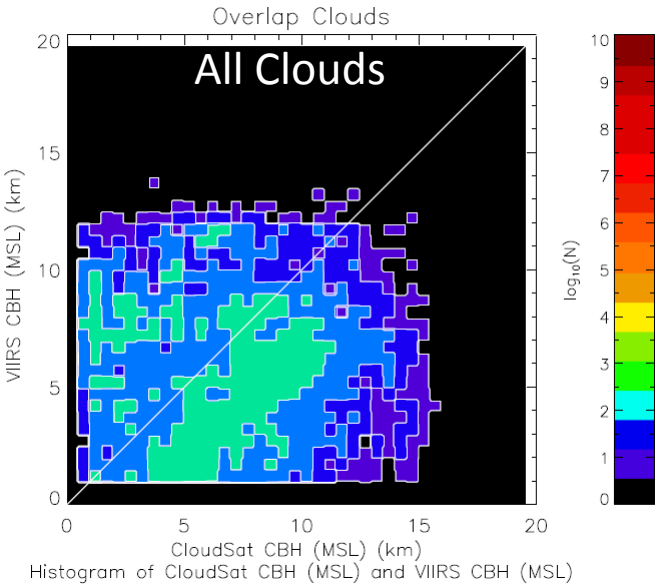


Average error: −0.7 km
Standard deviation of error: 1.5 km
Median error value: −0.4 km
RMSE: 1.6 km
Percentage of pixels with CBH within 250 m of CloudSat: 26.5%
r² value: 0.224
N: 4112

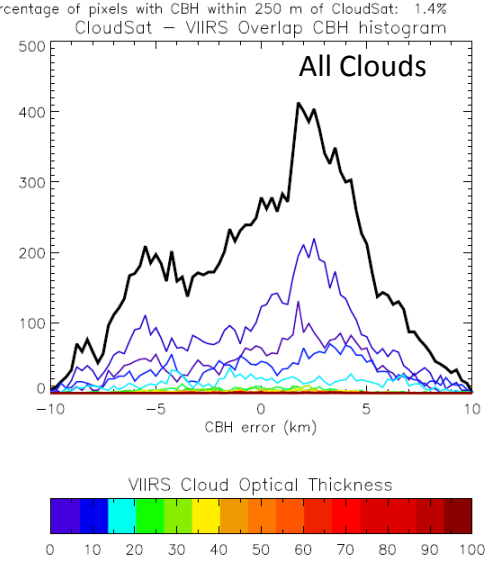


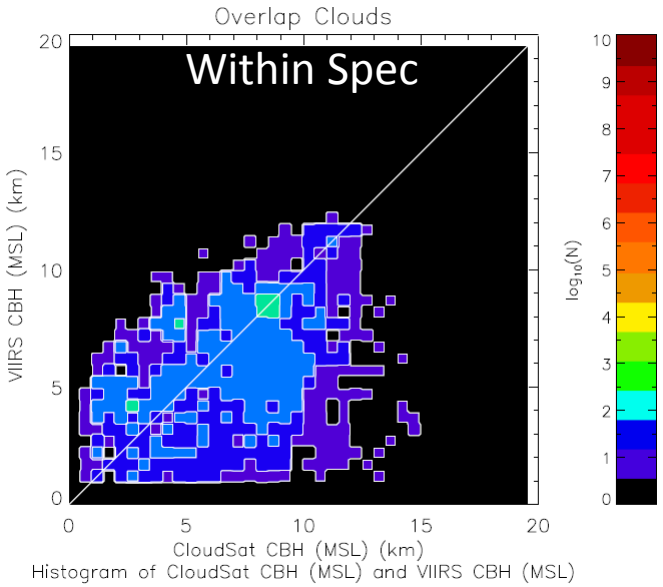
CBH performance – Overlap

September 2013

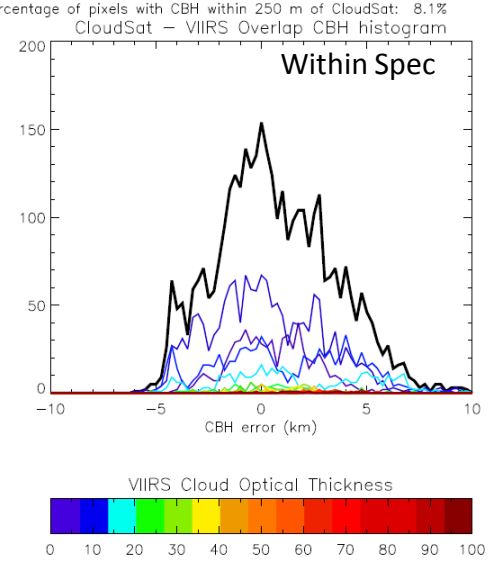


Average error: 0.6 km
Standard deviation of error: 4.2 km
Median error value: 1.2 km
RMSE: 4.3 km
Percentage of pixels with CBH within 250 m of CloudSat: 1.4%
r^2 value: 0.000
N: 13922

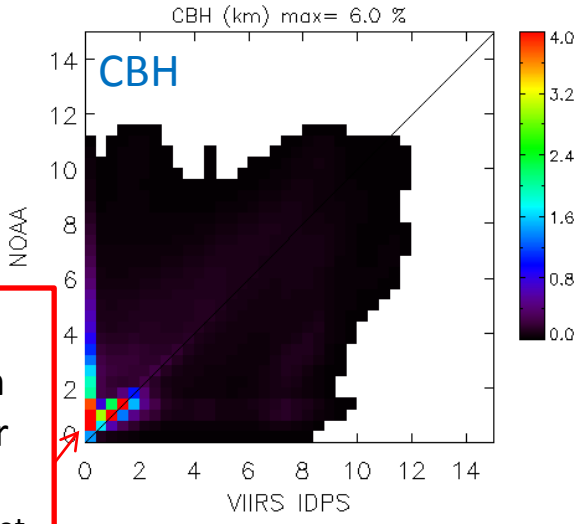


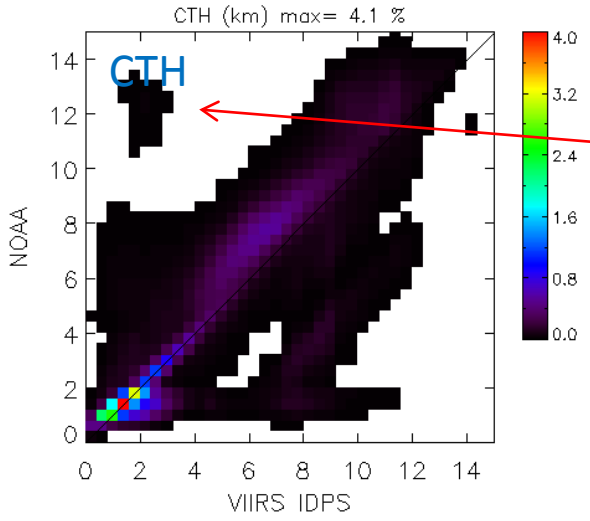


Average error: 0.8 km
Standard deviation of error: 2.8 km
Median error value: 0.5 km
RMSE: 2.9 km
Percentage of pixels with CBH within 250 m of CloudSat: 8.1%
r^2 value: 0.181
N: 3550



Comparisons between IDPS and NOAA (%) over the globe



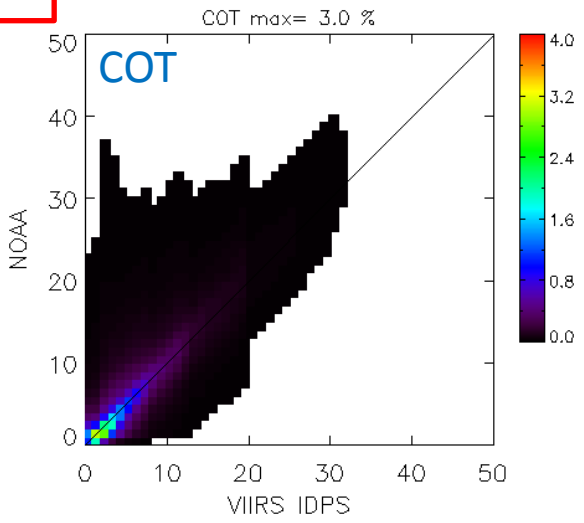


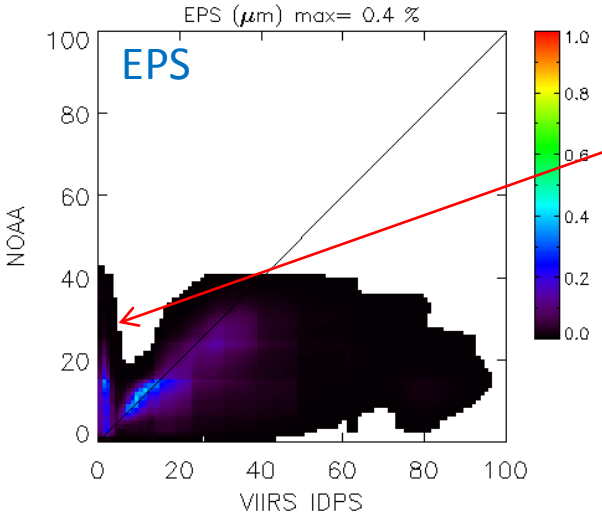
NOAA

VIIRS IDPS

Some very high CTHs from NOAA over desert areas?

Different lWC value selection for some water cloud pixels?
(Very low CBHs are not included in comparisons with CloudSat)



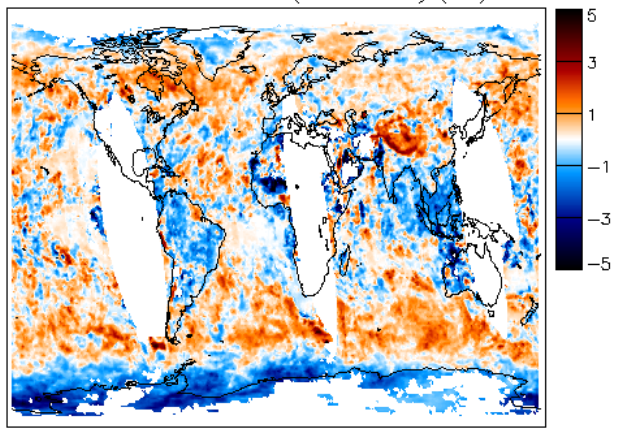


Extremely small VIIRS IDPS EPS

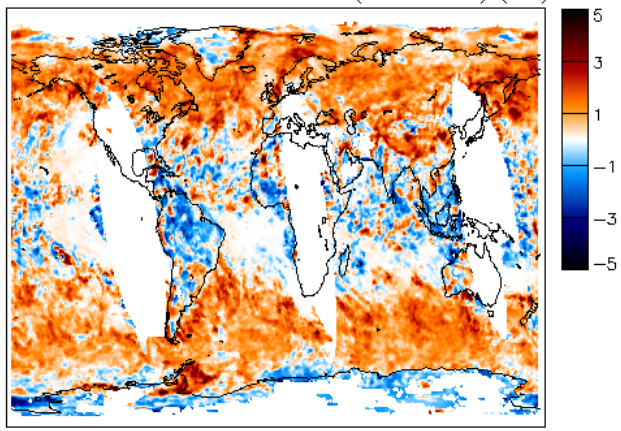
Sept-Oct 2013 matchup cases (daytime granules only)

Differences between **IDPS** and **NOAA** mean cloud properties

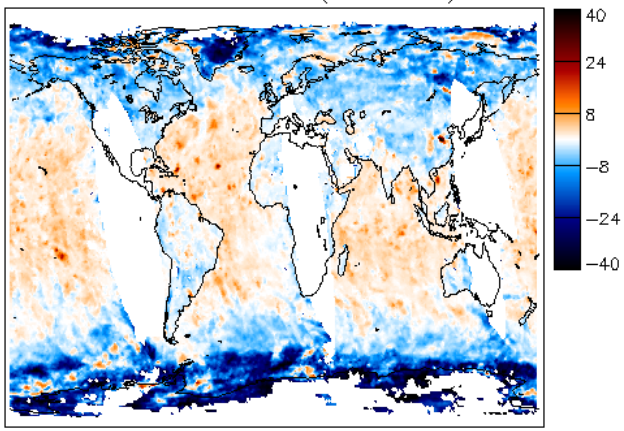
Δ CTH



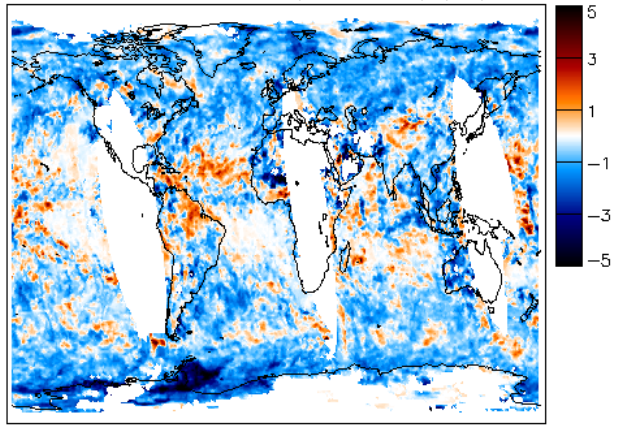
Δ Geometric Thickness



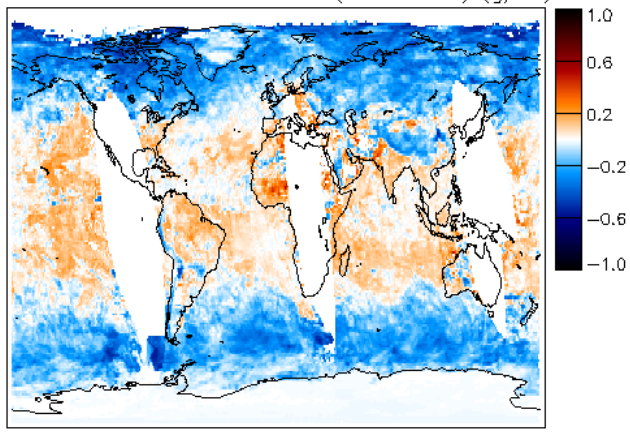
Δ COT



Δ CBH



Δ Water Content



Δ EPS