Combining GOES-16 and Surface Ceilometer Data to Improve Cloud Ceiling Estimates over the U.S.

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1. Introduction

- Presence of low cloud ceiling affects ability of aircraft to land safely.
- Cloud ceiling is well know in the vicinity of many airports from ASOS, AWOS ceilometer instruments.
- Cloud ceiling away from areas with ground-based ceilometer data (airports) isn't usually well known.
- Satellites such as GOES-16 can be used to estimate cloud base away from airports with ceilometers, but accuracy can be insufficient as they directly infer cloud top, not base.
- Unknown or less accurate cloud ceiling is problematic for smaller aircraft attempting to land at airfields without ceilometer data and for aircraft engaging in medical and rescue operations.
- Cloud ceiling from ground-based ceilometers can be interpolated and combined with satellite-derived cloud base for use as a hybrid (best estimate) product.
- Surface stations are broken up into 2 groups, one for developing the new ceiling product, the other used for validation.
- The new hybrid cloud ceiling is derived with hourly surface observations matched to corresponding GOES-16 retrievals.
- The approach exploits synergy between advanced GOES-16 imager data and ground-based ceilometer data and has the potential to improve cloud ceiling analyses away from surface stations.

2. Methodology

- GOES-16 retrievals of cloud phase, temperature, optical depth (OD), top height are used to estimate cloud ceiling.
- Satellite indicates integrated effect of all cloud layers; low cloud information lost when optically-thick overlying ice clouds are present.
- The station ceiling data are interpolated/extrapolated to each pixel in the GOES-16 view over the central and eastern CONUS (24-49 N, 65-105 W).
- GOES-16 and MERRA-2 data are used to classify clouds into 4 types that normally have similar characteristics/cloud bases: water, supercooled liquid water (SLW), ice, optically thick ice with suspected low-mid cloud.
- MERRA-2 RH >=93% between the surface and 650mb level is used to indicated presence of low-mid cloud.
- Hybrid-1 method: Distance-weighted interpolation with clustering of stations based on distance, cloud ceiling for each cloud type. Uses thin-plate spline interpolated surfaces covering entire image.
- Hybrid-2 method: Single station used to bias-correct GOES-16 up to 20-km from stations. Distance-weighted interpolation with 3 closest stations of the same cloud type used to bias-correct GOES-16 cloud base out to 800-km away from stations. MERRA-2 derived base used for optically thick ice-topped clouds for satellite pixels > 800-km from stations.
- Interpolated station ceiling is set to a height of at least 0.2-km above station elevation for the validation statistics.
- Validation of cloud ceiling product for April 2018 is accomplished using surface data valid at 17 UTC and satellite imagery at 16:45, 17:00 UTC; maximum time offset of 7.5 min between the surface observations and satellite imagery.
- Only stations reporting cloud ceilings with at least 50% valid satellite data surrounding them were used in the matching.
- The surface stations used for validation in a given hour were randomly chosen from half of the full set.

* Surface Obs Interpolation for 2-D mesh:

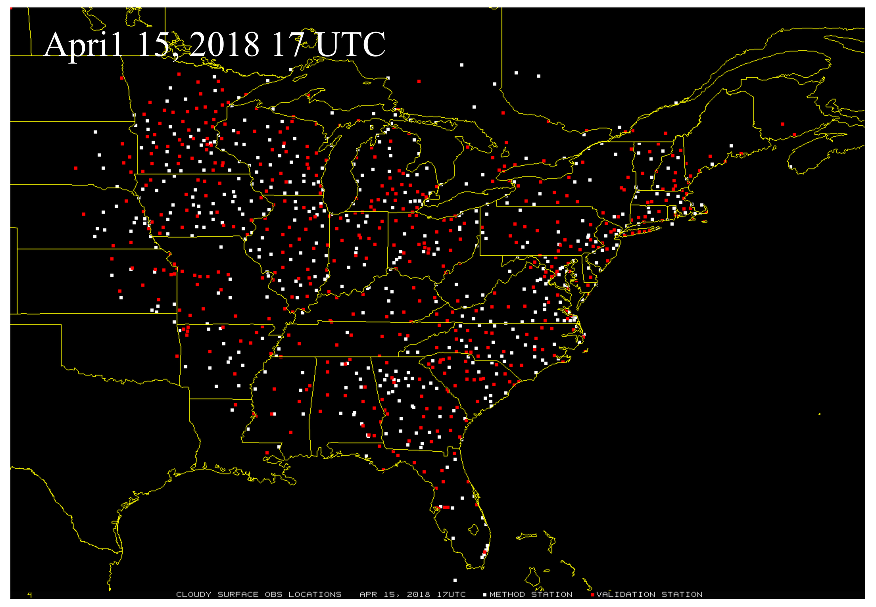
- Interpolation is based on an irregularly-spaced mesh of points (stations).
- Station interpolation was accomplished using a thin-plate spline subset of the polyharmonic spline technique
- Advantages are efficiency and stability, without need for tuning; good for automating.
- Clustering approach was used as an attempt to separate stations into groups based on distance and cloud type, with the equation:

$D=(w1*r)+(w2*ceil1/ceil2)+w3*|phase1-phase2|$

D=effective distance between any 2 nearest stations
- r=actual distance between 2 stations
- ceil=station ceiling
- phase=satellite cloud phase reported at the stations
- w=weights for each term

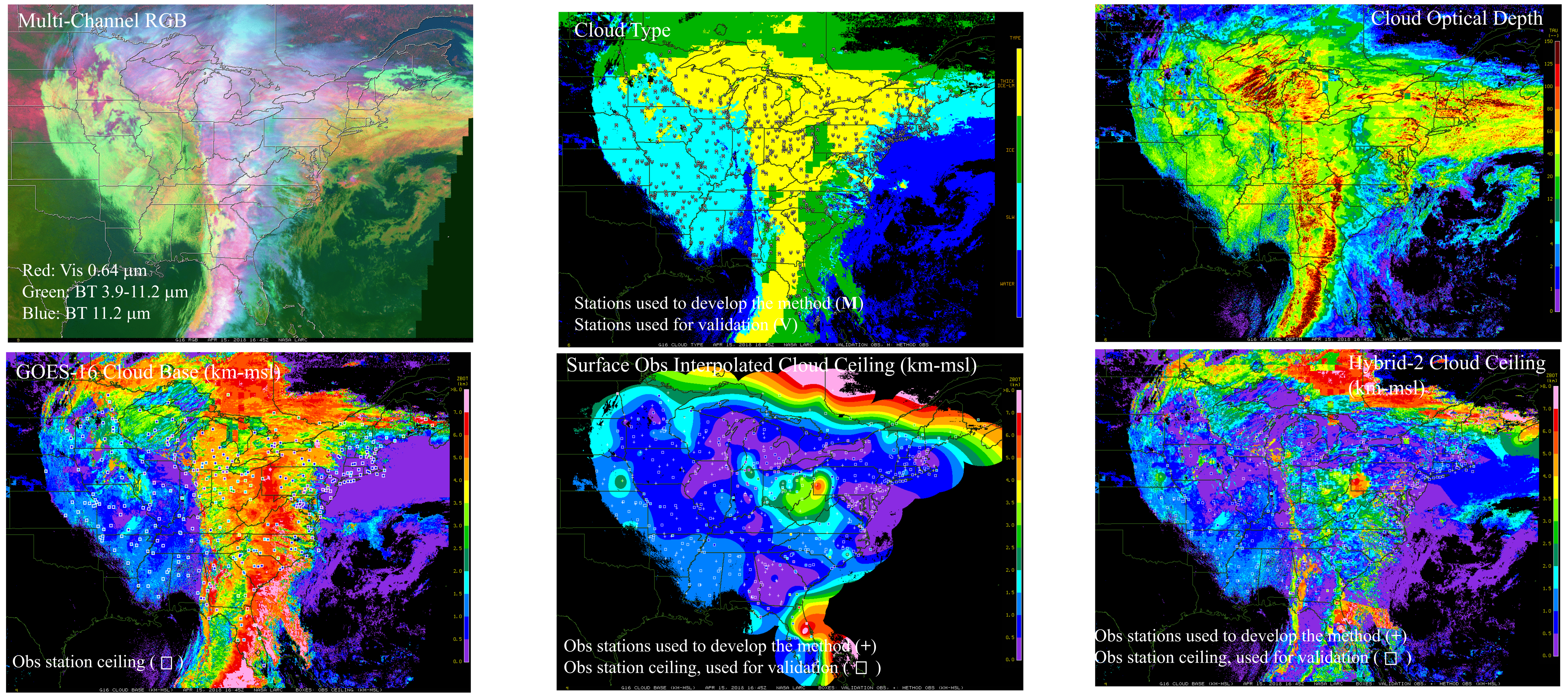
- Polyharmonic thin plate spline interpolation is done independently for each cluster.

Random grouping of overcast stations used for developing the interpolation methods (white) and for validation (red)

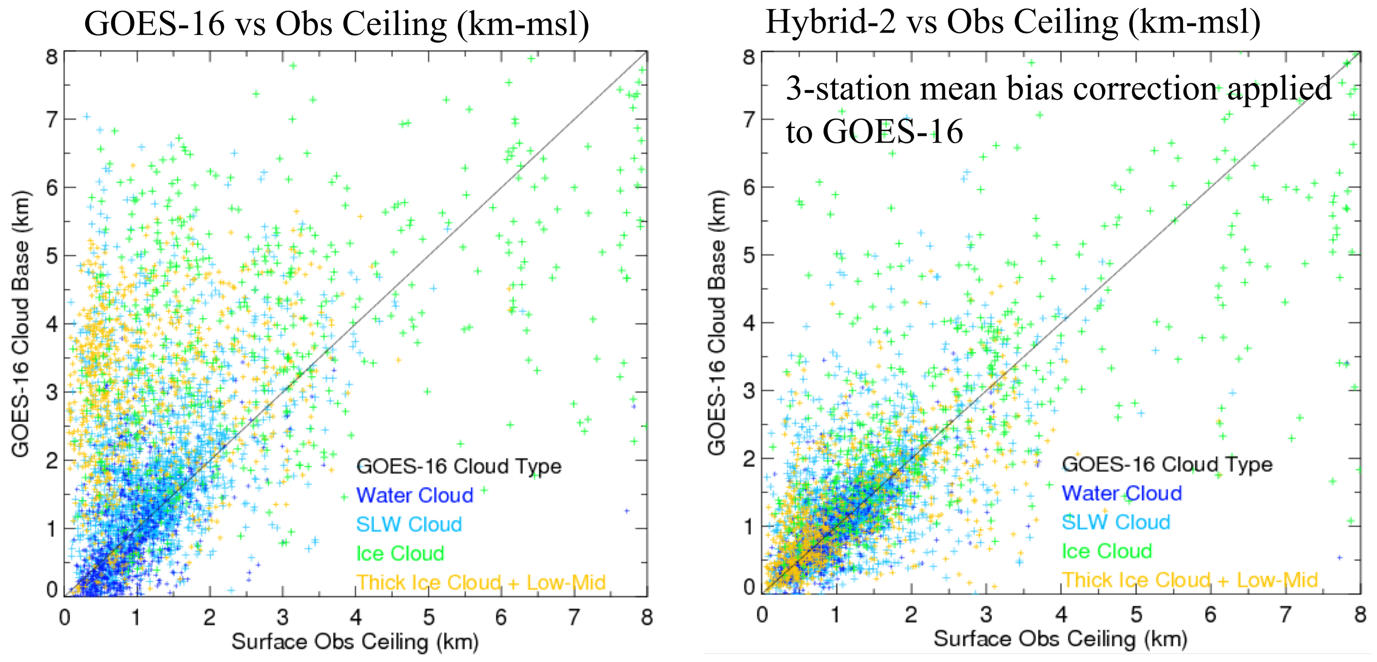


3. Results

GOES-16 Imagery 16:45 UTC Apr 15, 2018



Cloud Ceiling Validation for April 2018, 16:45-17:00 UTC



Cloud Type	N	Surface Ceiling (km)	G-16 Base (km)	Hybrid Base (km)	G-16 Bias (km)	*Hybrid Bias (km)	G16 RMSE (km)	*Hybrid RMSE (km)
Liquid Water	759	0.93	0.90	0.89	-0.03	-0.08 -0.04 0.04	0.77	0.62 0.61 0.51
SLW	1745	1.27	1.88	1.39	0.62	0.07 0.12 0.03	1.33	0.77 0.75 0.56
Ice	502	3.15	4.12	3.35	0.97	0.05 0.20 -0.14	2.40	2.12 1.85 1.69
Ice + Low-Mid	754	1.21	3.02	1.27	1.81	0.10 0.07 0.02	2.27	0.92 0.78 0.83

*Hybrid-1: 2-D mesh interpolation model with clustering
*Hybrid-2: G16 bias correction using 3-station distance-weighted interpolation
*Station interpolation only

4. Summary

- A method is being developed to improve cloud ceiling estimates away from surface stations using a hybrid GOES-16 and surface station approach; original satellite technique is not sufficiently accurate.
- Satellite first guess cloud base calculation uses parameterizations based on OD and cloud top height; method is outdated.
- Hybrid methods for liquid water clouds and thick ice-topped clouds show best agreement with surface observations.
- For ice clouds, the satellite overestimates cloud base by ~1-km with an 0.05-km overestimate for the hybrid-1.
- Satellite-only algorithm overestimates cloud ceiling by 1.8-km in optically-thick ice-topped cloud systems with near 0 bias in the other methods.
- RMS errors were significantly lower in the station interpolated and hybrid methods compared to the satellite alone.
- Using GOES cloud products and MERRA-2 low-level RH, it was difficult to beat station interpolation alone, however, away from stations the satellite and model data is more useful. Satellite base can be modified based on relationships found at stations.
- K-Dimensional Tree method also being considered where station with best matching satellite data is chosen for cloud base.
- Operationally, the process will be run hourly with double the amount of stations used for the ceiling interpolation, improving results.
- It is anticipated that a more accurate cloud ceiling product than can be provided by current satellite algorithms or surface ceilometers alone will be provide the best solution to cloud ceilings needed by the aviation community.

5. References

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