Combining Satellite and Ground-Based Ceilometer Data over the U.S. to Improve Cloud Ceiling Estimates away from Surface Stations

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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 to each pixel in the GOES-16 view over the central and eastern CONUS (24-49 N, 65-105 W).
- Distance-weighted interpolation only is used as a first method (M1*).
- Distance-weighted interpolation with clustering of stations based on distance, cloud ceiling, and satellite cloud phase is done as a second method (M2*).
- Each station's ceiling data is extended out to a maximum distance of 200-km.
- 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.
- Averaging satellite pixels within 20-km of the surface stations is done for 3 cloud types: water, optically thin ice, optically thick ice.
- 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.

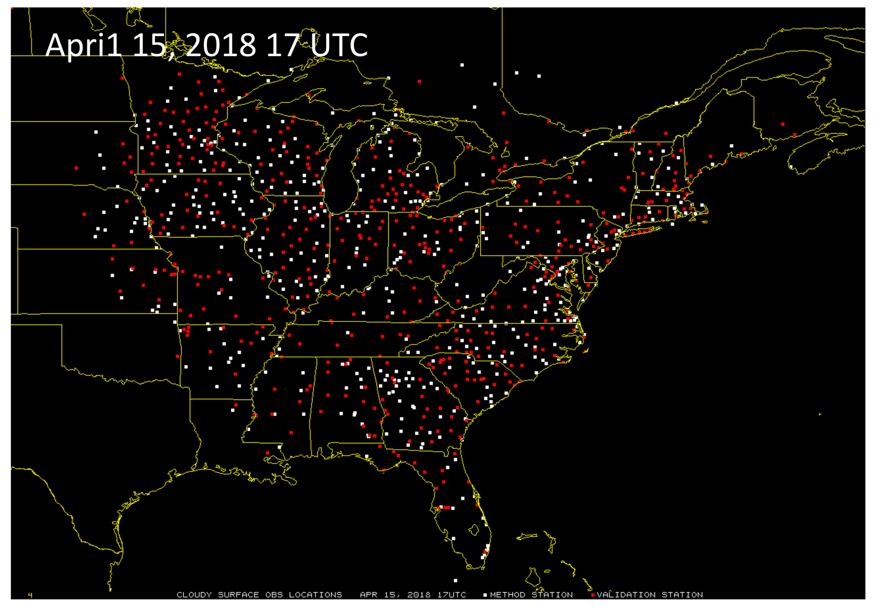
* Surface Obs Interpolation:

- 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 (M1).
- Advantages are efficiency and stability, without need for tuning; good for automating.
- Clustering approach (M2) 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|

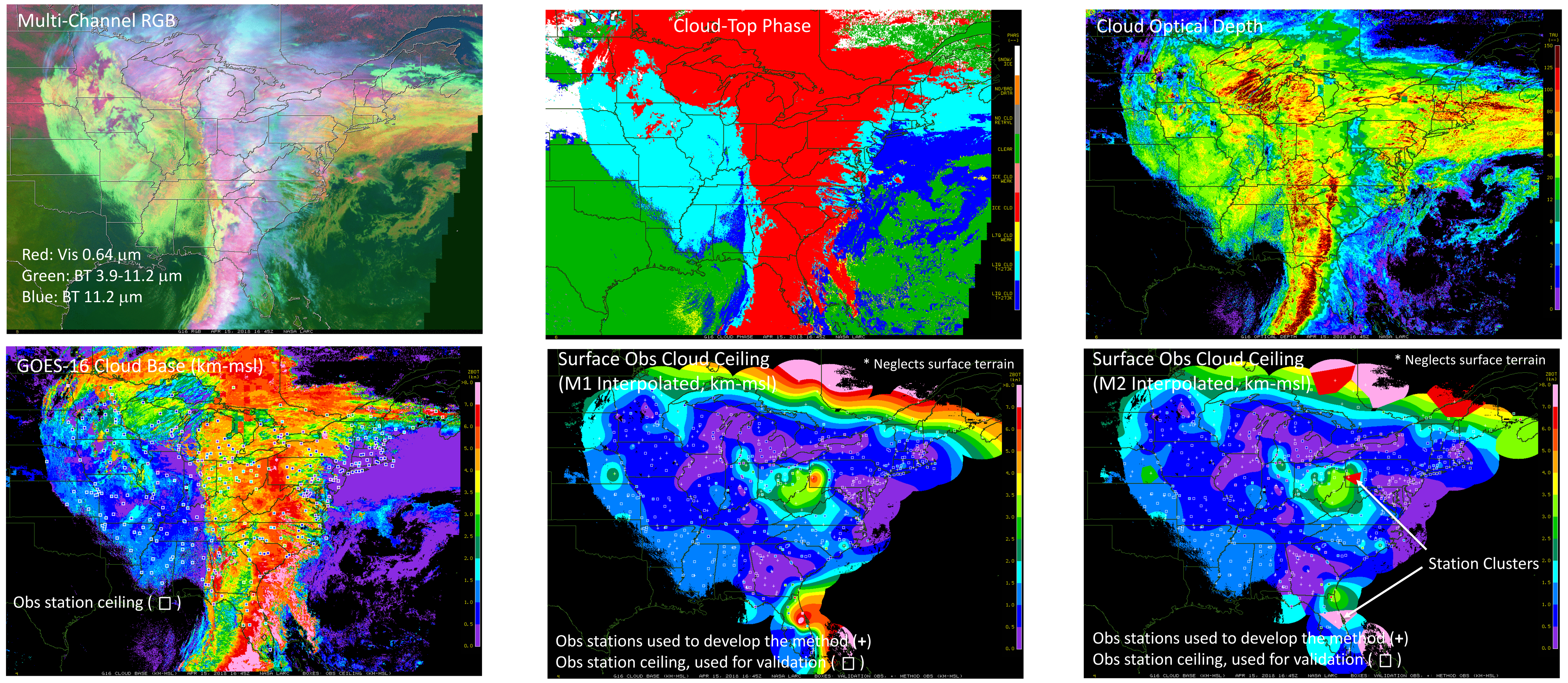
  D=effective distance between any 2 nearest stations
  - r=actual distance between 2 stations
  - ceil=station ceiling
  - phase=satellite cloud phase reported at the stations
  - w=weights for each term
- For M2, polyharmonic thin plate spline interpolation is done independently for each cluster.

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

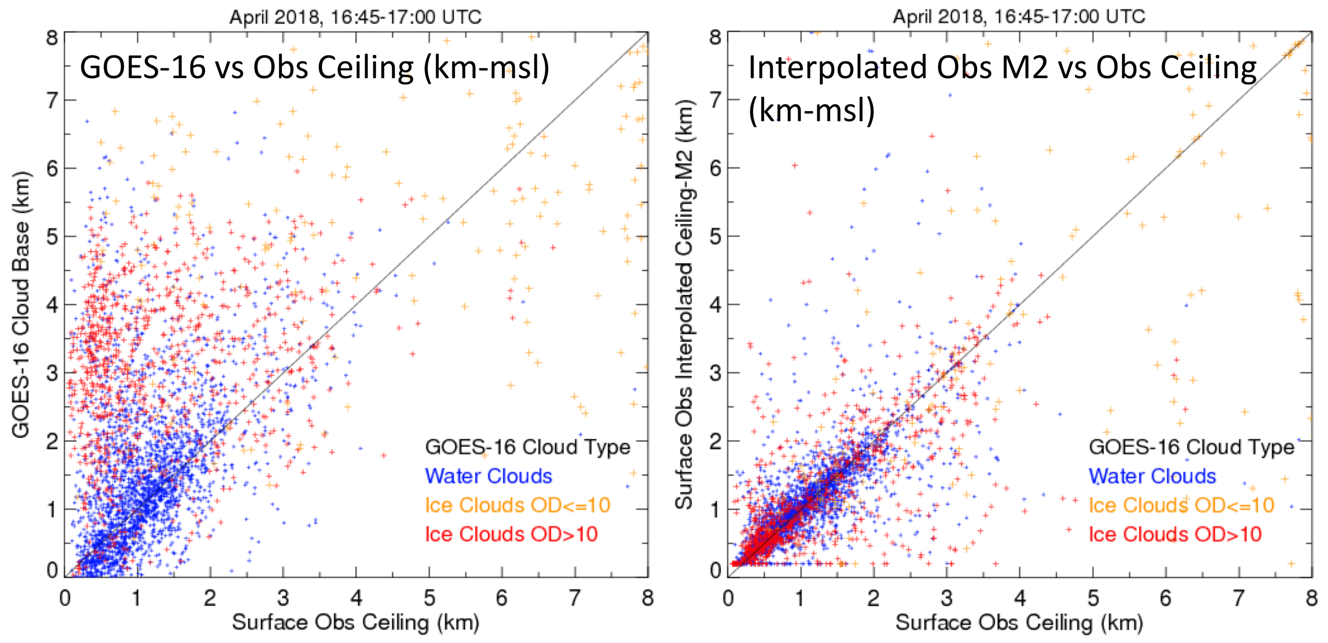


3. Results

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



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



Cloud Type	N	Surface Obs	GOES-16/ Interpolated Obs Images	Bias Image-Obs	RMSE
Liquid Water	2516 2485 2485	1.16 1.16 1.16	1.60 1.17 1.17	0.43 0.01 0.01	1.19 0.59 0.64
Ice OD<=10	186 167 167	4.78 4.56 4.56	5.24 4.00 3.94	0.47 -0.55 -0.61	2.75 2.46 2.22
Ice OD>10	842 834 834	1.34 1.33 1.33	3.05 1.30 1.28	1.71 -0.02 -0.05	2.23 0.84 0.90

Red=GOES-16 only

Blue=Surface obs ceiling interpolation only (M1)

Black=Surface obs ceiling interpolation with distance, ceiling, cloud phase clustering (M2)

4. Summary

• A method is being developed to improve cloud ceiling estimates away from surface stations using a hybrid GOES-16 and interpolated 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.

• Liquid water clouds show best agreement with surface observations; satellite overestimate of 0.4-km and 0 bias in station interpolated methods.

• For optically thin ice clouds, the satellite overestimates cloud base by ~0.5-km with an underestimate of the same magnitude for interpolated methods.

• Satellite-only algorithm overestimates cloud ceiling by 1.7-km in optically-thick ice-topped cloud systems, near 0 bias in station interpolated methods.

• RMS errors were significantly lower in the station interpolated methods compared to the satellite.

• For station cloud ceiling, using distance weighted interpolation across the entire CONUS shows nearly the same accuracy as breaking up the stations into clusters based on distance, ceiling and cloud phase with cluster-based interpolation.

• 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. Future Work

• Use station cloud ceiling to bias-correct GOES-16 first guess cloud base for different cloud types; apply in areas of the image where no station data is available.

• Use distance-weighted station interpolation for different cloud types separately, then assign GOES-16 pixel value based on the corresponding station interpolated cloud type.

• Account for surface terrain height in final station ceiling interpolated products.

• Use NWP model data to update satellite cloud ceiling well away from surface stations.

• Machine learning/neural net can be used to improve the GOES-16 first guess cloud ceiling with surface obs ceiling as the training set.

• Use more months to validate the new hybrid satellite-surface station cloud ceiling product.

6. References

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