Satellite retrieval of convective thermals and updraft speeds at cloud base

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Abstracts

Updraft speeds of thermals have always been difficult to measure, despite significant roles they play in transporting pollutants and in cloud formation and precipitation. To our knowledge, no attempt to date has been made to estimate updraft speed from satellite information in the boundary layer and at the cloud base. In this study, we introduce two methods of retrieving the maximum updraft (W_{max}) and updraft at cloud base (W_b) in the planetary boundary layer topped by convective clouds. The first method uses ground-air temperature difference to characterize the surface sensible heat flux, which is found to be correlated with updraft speeds measured by the Doppler lidar over the Southern Great Plains (SGP). Based on the relationship, we use the satellite-retrieved surface skin temperature and reanalysis surface air temperature to estimate the updrafts. The second method is based on a good linear correlation between cloud base height and updrafts, which was found over the SGP, the central Amazon, and on board a ship sailing between Honolulu and Los Angeles. We found a universal relationship for both land and ocean. The performance of these two methods of retrieving updrafts was tested against the lidar and Radar measurements with good agreements found for both methods. Compared with the first method that only works over land, the second method expands its applicability to ocean and is more accurate in retrieving the W_{max} with RMSE (root-mean-square error) = 0.38 m/s and MAPE (mean-absolute-percentage-error) = 19%, and W_b with RMSE = 0.34 m/s and MAPE = 21%.

Data

1. ARM Ground-based data:

Datasets from Atmospheric radiation Measurement (ARM) under the aegis of U.S. Department of Energy (DOE) are employed in this study.

- SGP site

The SGP CF site (36.6N, 97.5W) is located in the southeast of Lamont, Oklahoma.

- GOAmazon field campaign

The GOAmazon field campaign is conducted over the Central Amazon to the west of the city of Manaus from January 2014 through December 2015.

- MAGIC field campaign

The recent MAGIC field campaign lasted from October 2012 through September 2013. The second ARM Mobile Facility (AMF2) was deployed.

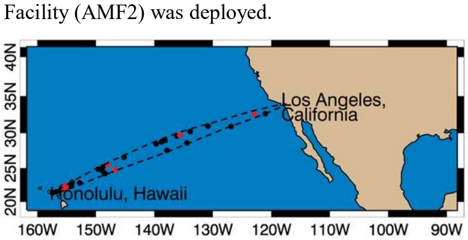

Fig 1: Approximate track of MAGIC legs (dashed line) between California and Howaii. The dots denote positions of the ship for the selected 32 MAGIC cases. Red dots correspond to the 8 cases with time window centered on satellite overpasses.

2. Satellite and reanalysis data:

- satellite: VIIRS (Visible Infrared Imaging Radiometer Suite) onboard the Suomi NPP (National Polar-orbiting Partnership)
- Reanalysis: ECMWF

Lidar retrieval of updrafts

Following *Zheng et al.* [2015], we calculate the effective updraft speed at a given volume of air that has multiple radar (or lidar) pixels using the following equation:

$$W = \left.\frac{\sum N_i W_i^2}{\sum N_i W_i}\right|_{W_i > 0} \qquad (1)$$

where N_i is the frequency of occurrence of velocity W_i on the histogram of vertical velocity distribution. The updraft speed calculated by Equation (1) is the volume weighted mean of vertical velocity distribution and is the cloud physics relevant updraft [*Zheng et al, 2015, JAS*].

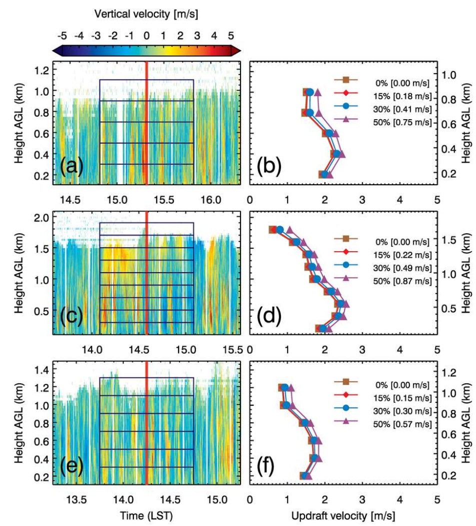

Fig 2: Three representative cases on (a) (b) 24 March 2013, (c) (d) 25 Jun 2013 and (e)(f) 2 February 2013. Left panels are height-time display of vertical staring data from Doppler lidar in SGP site. Signal-to-noise ratio (SNR) is set to 0.012 to visualize the PBL tops. Red lines mark the NPP overpass time. Black rectangles denote the height-time areas within which vertical velocity pixels are selected for updraft speed calculation using equation (6). Right panels are corresponding calculated updraft speeds at each height for different percentiles of vertical velocity (0%, 15%, 30% and 50%). The values in the brackets denote the corresponding threshold vertical velocity used to define updraft.

VIIRS retrieved cloud base temperature/height

Cloud base temperature (T_b) can be retrieved from VIIRS/NPP with accuracy of 1.1°C. Cloud base height (H_b) can be calculated assuming dry adiabatic atmosphere: $H_b = (T_a - T_b)/9.8$.

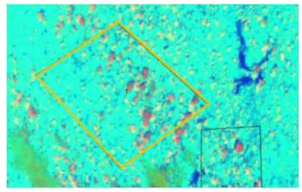

Fig 3: A VIIRS/NPP image of the convective clouds in an area over the ARM/SGP site at , at 16 July 2013, 19:37 UT . The color scheme is RGB microphysics. The imager data is at a resolution of 375 m.

VIIRS retrieval of updrafts

Method1:

We use the difference between surface and near-surface air temperature to characterize the strength of thermals that drive the updrafts. *(Zheng et al., 2015, JAS):*

$$W_{est} = C_1[H_b(1+0.25V)(T_s - T_a)]^{1/2} + C_2 \qquad (2)$$

Where H_b, V, T_s and T_a are cloud-base height, surface wind, surface skin temperature and 2-m temperature, respectively.

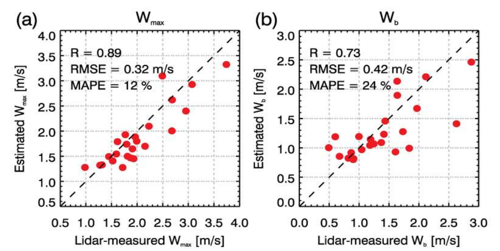

Figure 4. Validation of satellite-estimated W_{max} (a) and W_b (b) based on equation 2 against those measured by Doppler lidar at SGP site.

Method2:

We use the Linear relationship between updrafts and cloud base height to estimate the updrafts . (*Zheng and Rosenfeld, 2015, GRL*):

$$W_{est} = C_3 H_b + C_4 \qquad (3)$$

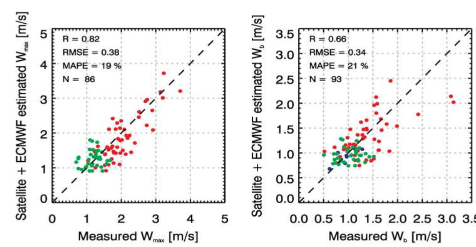

Figure 5. Validation of satellite-estimated W_{max} (a) and W_b (b) based on equation 2 against those measured by Doppler lidar and MWACR. The red, green and blue dots stand for SGP, GOAmazon and MAGIC, respectively.

Conclusion

1. It has not been possible until now to retrieve updraft speed from satellite measurements in buoyancy-driven boundary layers.
2. The methods work for both land and ocean
3. A MAPE of 27% for W_b retrieval correspond to N_d (Cloud base droplet concentration) error of only 7 to 13%, in pristine and polluted conditions, respectively. This is very useful for aerosol-cloud interaction research.

Reference

Zheng, Y. and D. Rosenfeld (2015), Linear relation between convective cloud base height and updrafts and application to satellite retrievals, *Geophys. Res. Lett.*, 42, doi 10.1002/2015GL064809.

Zheng, Y., D. Rosenfeld, and Z. Li (2015), Satellite inference of thermals and cloud base updraft speeds based on retrieved surface and cloud base temperatures, *J. Atmos. Sci.*, 72(6), 2411–2428.