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 (Wmax) and updraft at cloud base (Wb) 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 a 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 Wmax with RMSE (root-mean-square error) = 0.38 m/s and MAPE (mean-absolute-percentage-error) = 19%, and Wb 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.

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:

$$W = \sum W_i^j$$

where Nj is the frequency of occurrence of velocity Wj in 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].

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):

$$W_{sl}=C_{3}[H_0(1-0.25V)(T_s-T_r)]^{1/2}+C_2$$

Where H0, V, T_s and T_r are cloud-base height, surface wind, surface skin temperature and 2-m temperature, respectively.

Figure 4. Validation of satellite-estimated Wmax (a) and Wb (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):

$$W_{st}=C_1H_s+C_4$$

Figure 5. Validation of satellite-estimated Wmax (a) and Wb (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.

Cloud base temperature (T_s) can be retrieved from VIIRS/NPP with accuracy of 1.1°C. Cloud base height (H_s) can be calculated assuming dry adiabatic atmosphere: H_s = (T_d - T_r) / g/9.8.

Figure 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.

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 Wb retrieval correspond to Nd (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
