Use of satellite measurements of surface skin and air temperatures for retrieving the intensity of thermals

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Why do we want to retrieve thermals and cloud base updrafts?

- The thermal updraft speeds are precursors for the vigor of the cloud updrafts.
- Stronger updrafts imply more efficient exploitation of the instability above the boundary layer and more intense storms.
- Stronger cloud base updrafts mean more nucleated CCN into cloud drops, more suppression of warm rain, more hail and lightning, and possibly tornadoes.

Approaches to obtain thermals and cloud base updrafts

- In situ measurements by towers and aircraft.
- Remote sensing by vertically pointing radars and lidars.

All of these methods provide very little area coverage and therefore are of limited operational application.

We need a satellite base method!

Theoretical basis (1)

- Convective Velocity Scale (Deardoff, 1970):

$$W^* = [(g/T_v)z_iQ]^{1/3},$$

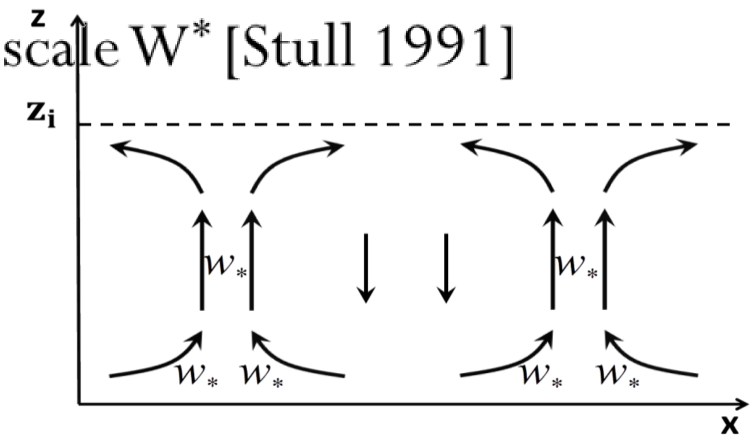
where Q stands for the surface heat flux, z_i is boundary layer depth and T_v is virtual potential temperature.

- Assumption:

(1) Surface sensible heat flux $Q = C_H V(T_s - T_a)$ [Tylor 1960]

(2) Convective circulation is formed and the induced horizontal wind is at the scale W^* [Stull 1991]

(3) In the extreme of free convection: $V = W^*$



Theoretical basis (2)

- Based on the aforementioned equations and assumptions, we have:

$$W^* = CH[\frac{g}{T_v} z_i(Ts - Ta)]^{1/2}$$

$$\Downarrow$$

$$W^* \propto [z_i(Ts - Ta)]^{1/2}$$

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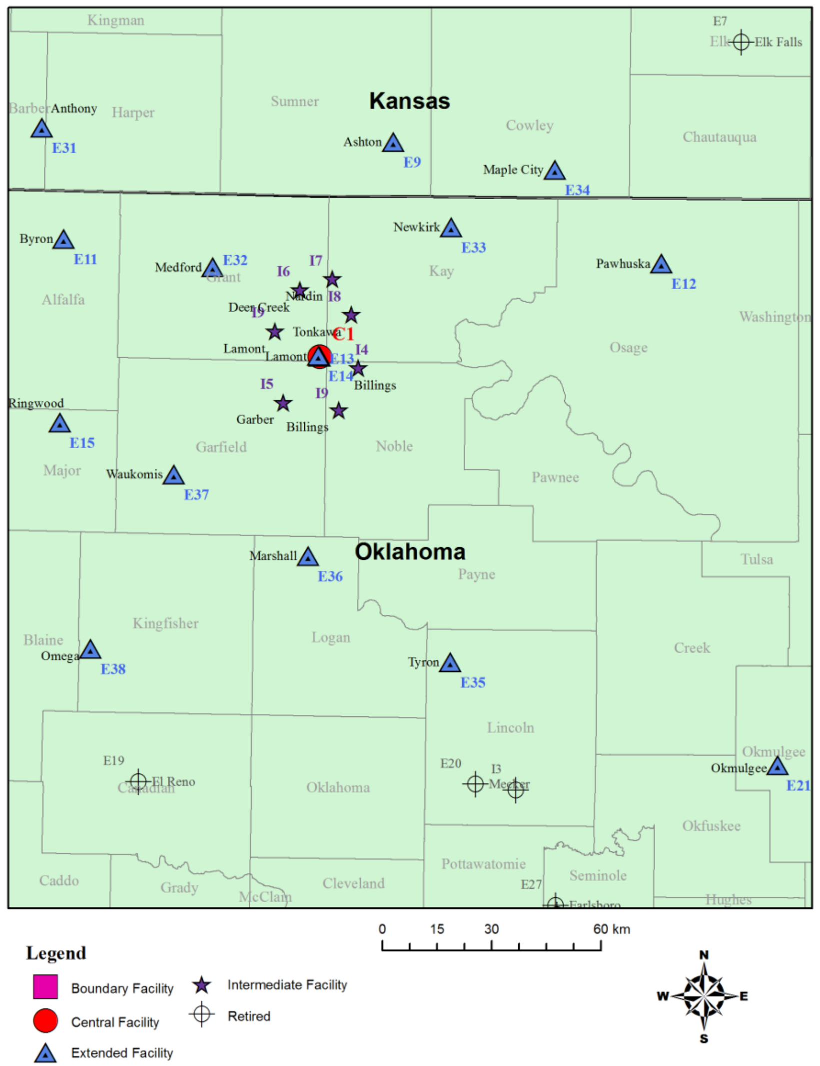
Research area of this study is the DOA/ASR site in Oklahoma



Source: ACRF GIS, December 2012

Area: SGP C1 and E13 site (36.6N, 97.5W)

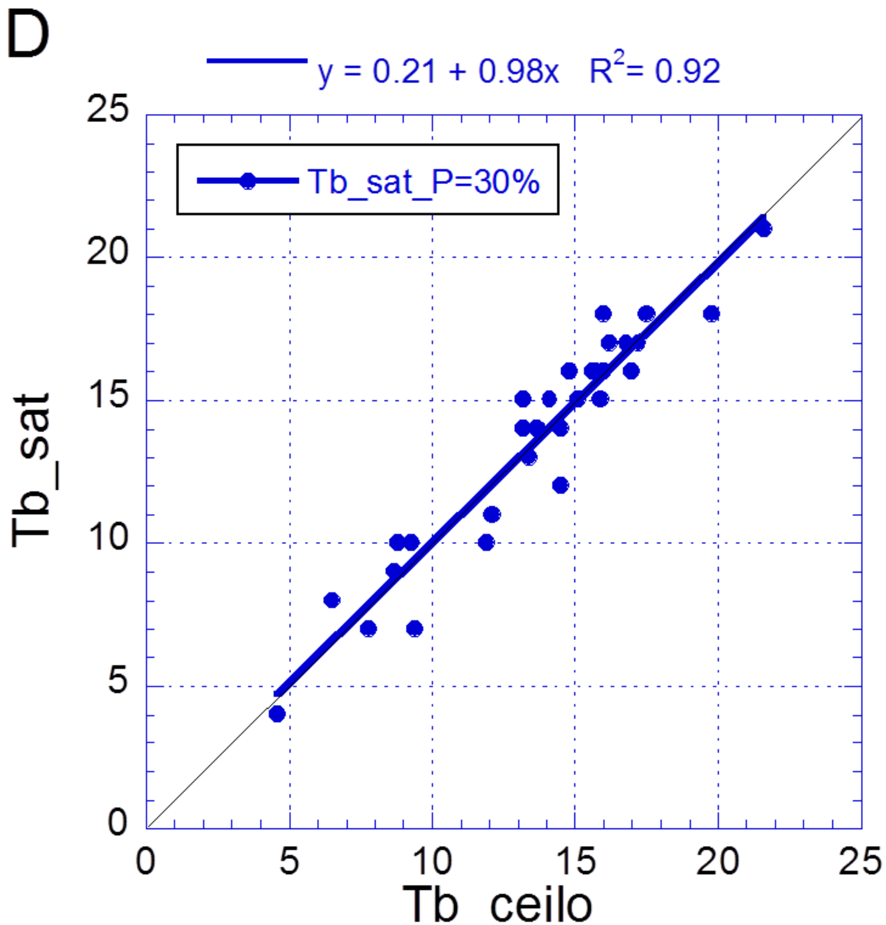
$$Q \propto V(Ts - Ta) \qquad W^* \propto z_i (Ts - Ta)]^{1/2}$$

Relevant ground-based data at the DOE/ASR/SGP site (36.6° N, 97.5° W):

1. **Surface Meteorology System (MET)** : 10-m wind speed (V), 2-m air temperature (Ta)
2. **Balloon-borne sounding system (SONDE):** vertical profiles of horizontal wind speed
3. **Vaisala Ceilometer (VCEIL):** cloud base height (H_{cb}), which defines z_i
4. **Planetary Boundary Layer Height Value Added Product:** boundary layer depth (z_i)
5. **Doppler Lidar:** vertical velocity (W)

Satellite-based data:

(1) Cloud base temperature (T_{cb}) retrieved by NPP/VIIRS

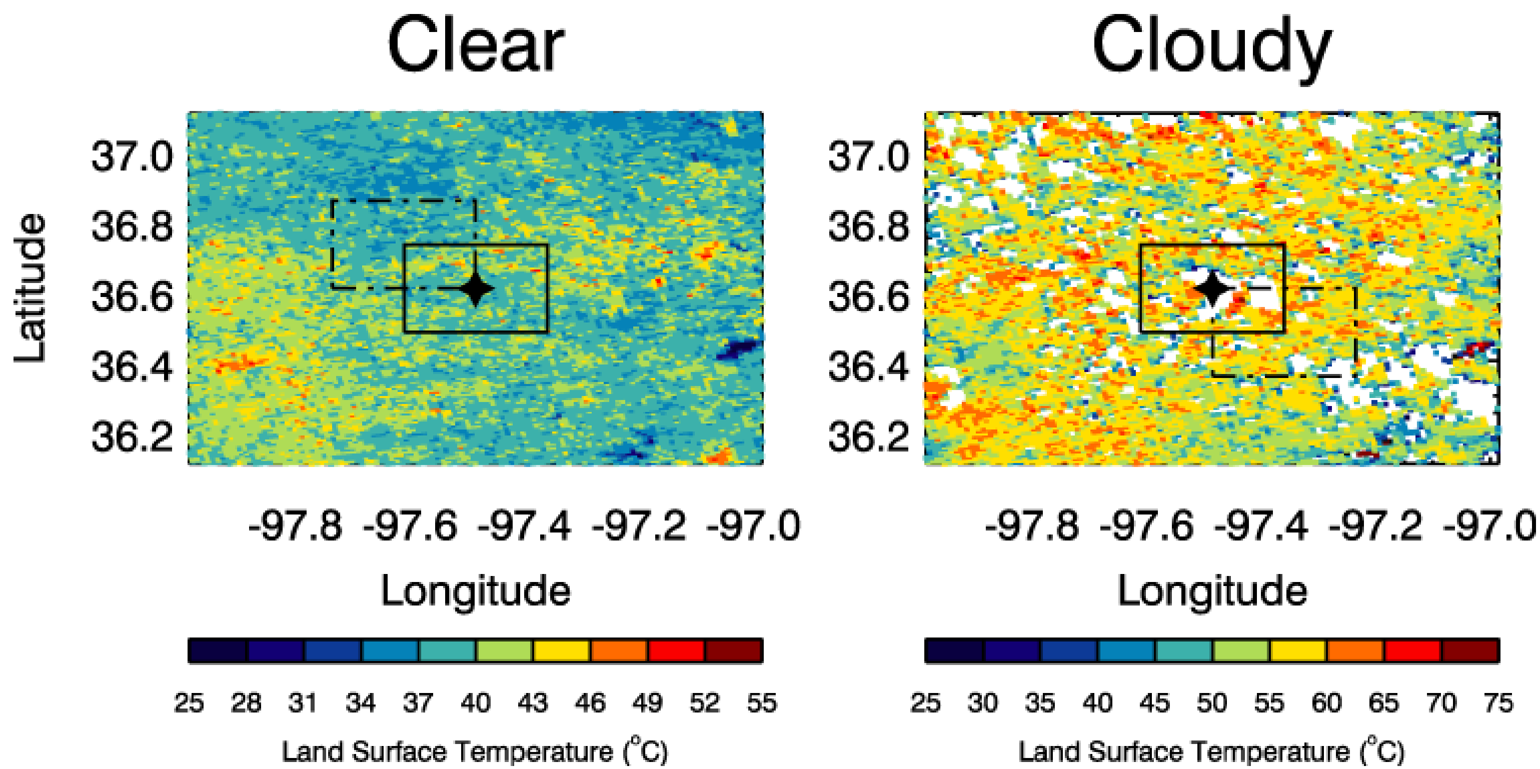


Zhu Y., D. Rosenfeld, X. Yu, G. Liu, J. Dai, X. Xu, 2014: Satellite retrieval of convective cloud base temperature based on the NPP/VIIRS Imager. GRL, 2014

RMSE = 1.1° C

Satellite-based data:

(2) Surface skin temperature (T_s) from NPP/VIIRS Land surface temperature (LST) products. T_s are averaged over 0.25 x 0.25° region in the upwind direction.



19:35 UTC, 9 Jun, 2013

19:36 UTC, 13 July, 2012

ECMWF-reanalysis data:

1. 10-m horizontal wind
2. 2-m air temperature
3. Surface geopotential
4. Wind, temperature and geopotential on each pressure levels.

Time resolution: 6 hr

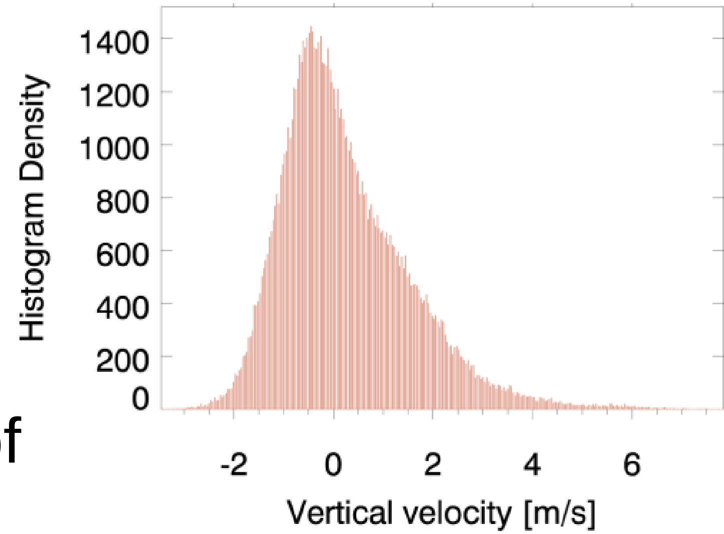
Spatial resolution: 0.125 x 0.125 degree

Vertical resolution: 25 hPa below 750 hPa level and 50 hPa from 750 hPa to 250 hPa

Methodology: calculating updraft speeds

Effective updraft speed

$$W = \sum \frac{N_i W_i^2}{N_i W_i} \Big| W_i > 0$$



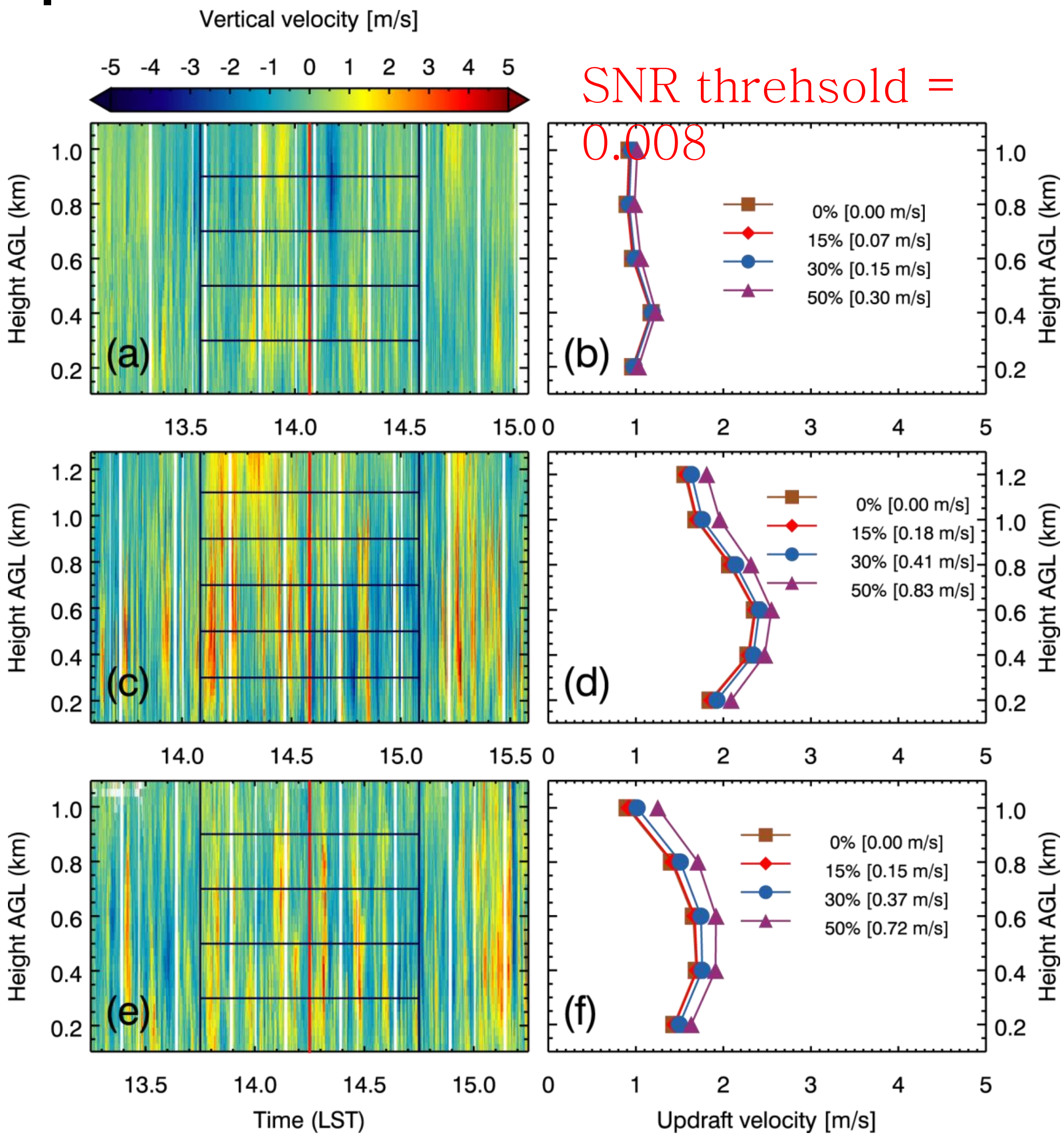
where Ni stands for the frequency of occurrence of the velocity W_i on the histogram of vertical velocity distribution retrieved by Doppler lidar.

We can view $NiWi$ at cloud base as the cloud volume created by Wi, the above equation is actually:

$$W = \sum \frac{Volume_i W_i}{Volume_i} \Big| W_i > 0$$

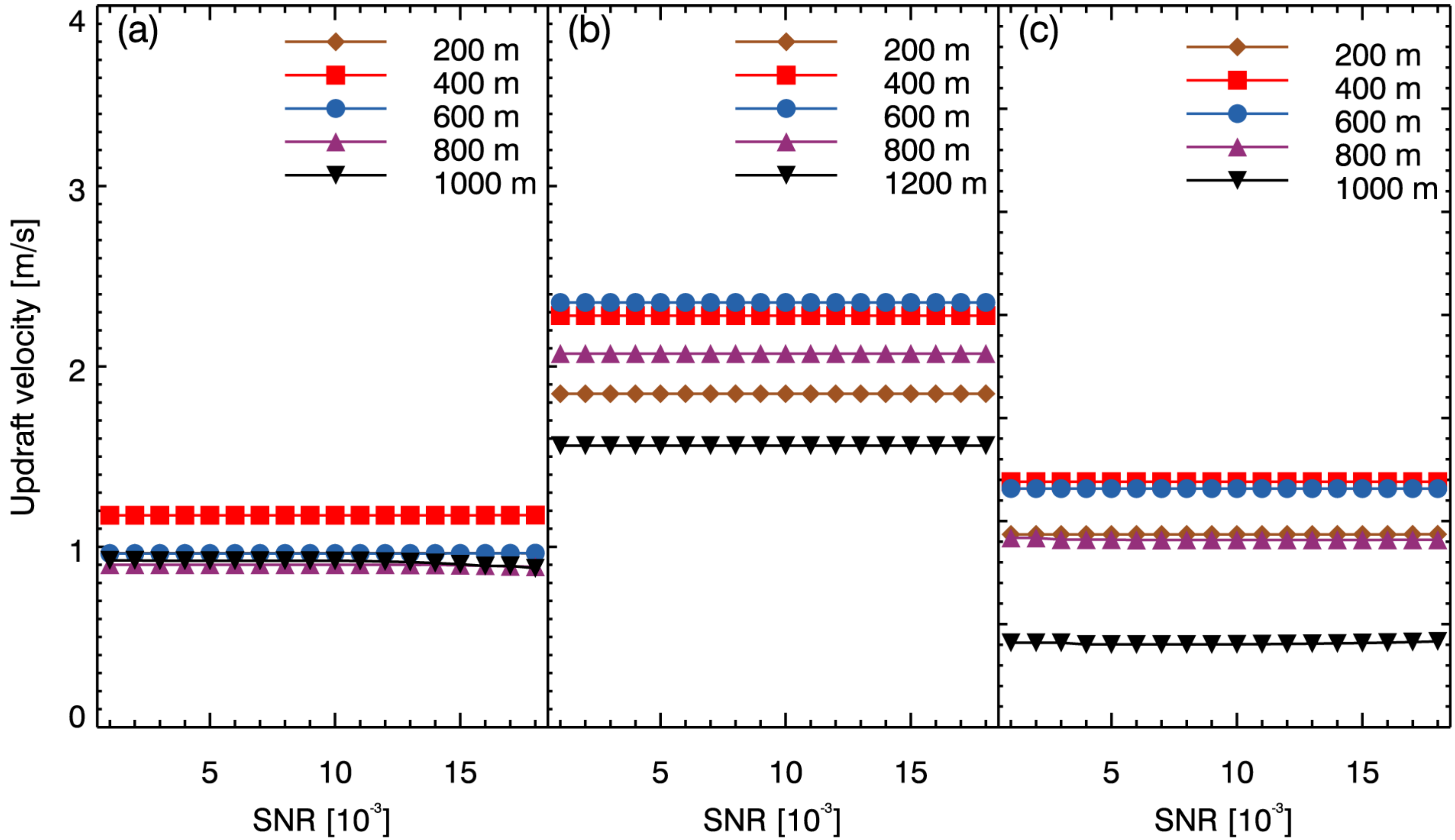
which is the volume weighted mean of vertical velocity distribution.

Methodology: vertical profile of updraft speeds



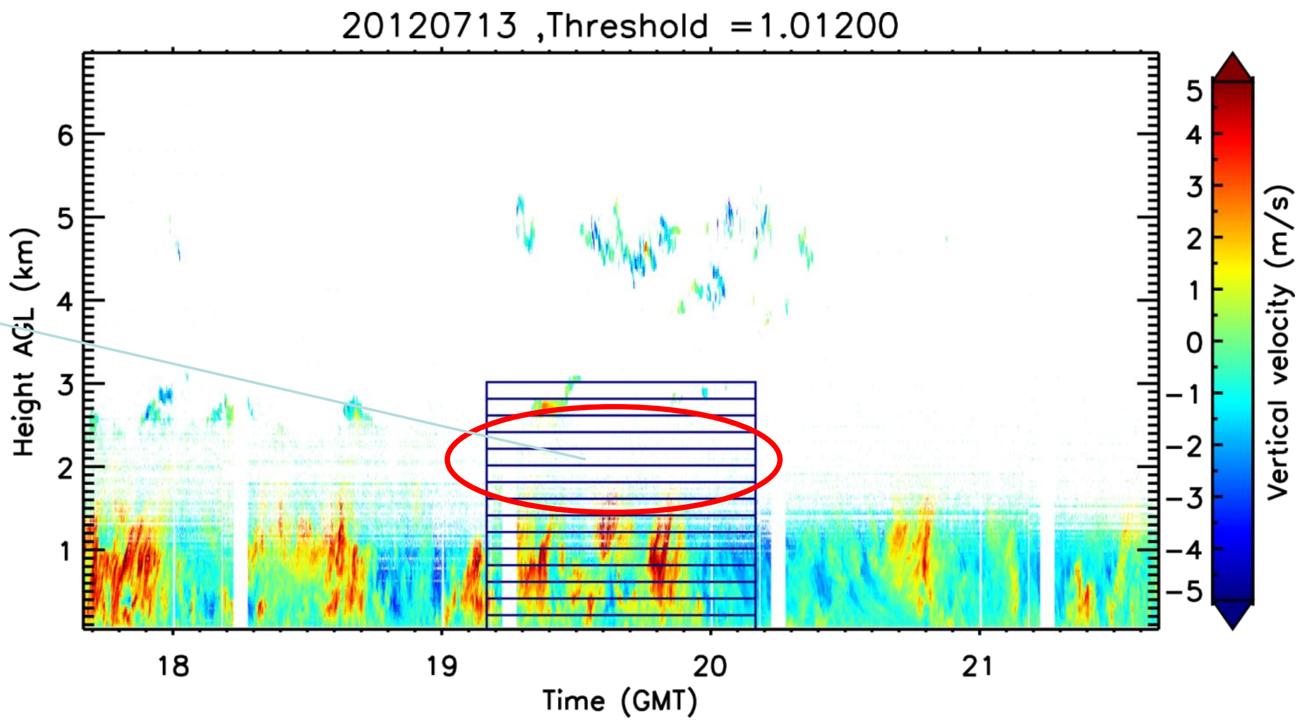
Three representative cases on (a) (b) 29 April 2013, (c) (d) 25 Jun 2013 and (e)(f) 2 February 2013. Left panels are height-time display of vertical staring data from Doppler lidar in SGP site. Red lines mark the NPP overpass time. Black rectangles denote the height-time areas within which vertical velocity pixels are selected for updraft speed calculation using equation (6). Right panels are corresponding calculated updraft speeds at each height for different

Methodology: data quality control – sensitivity to SNR



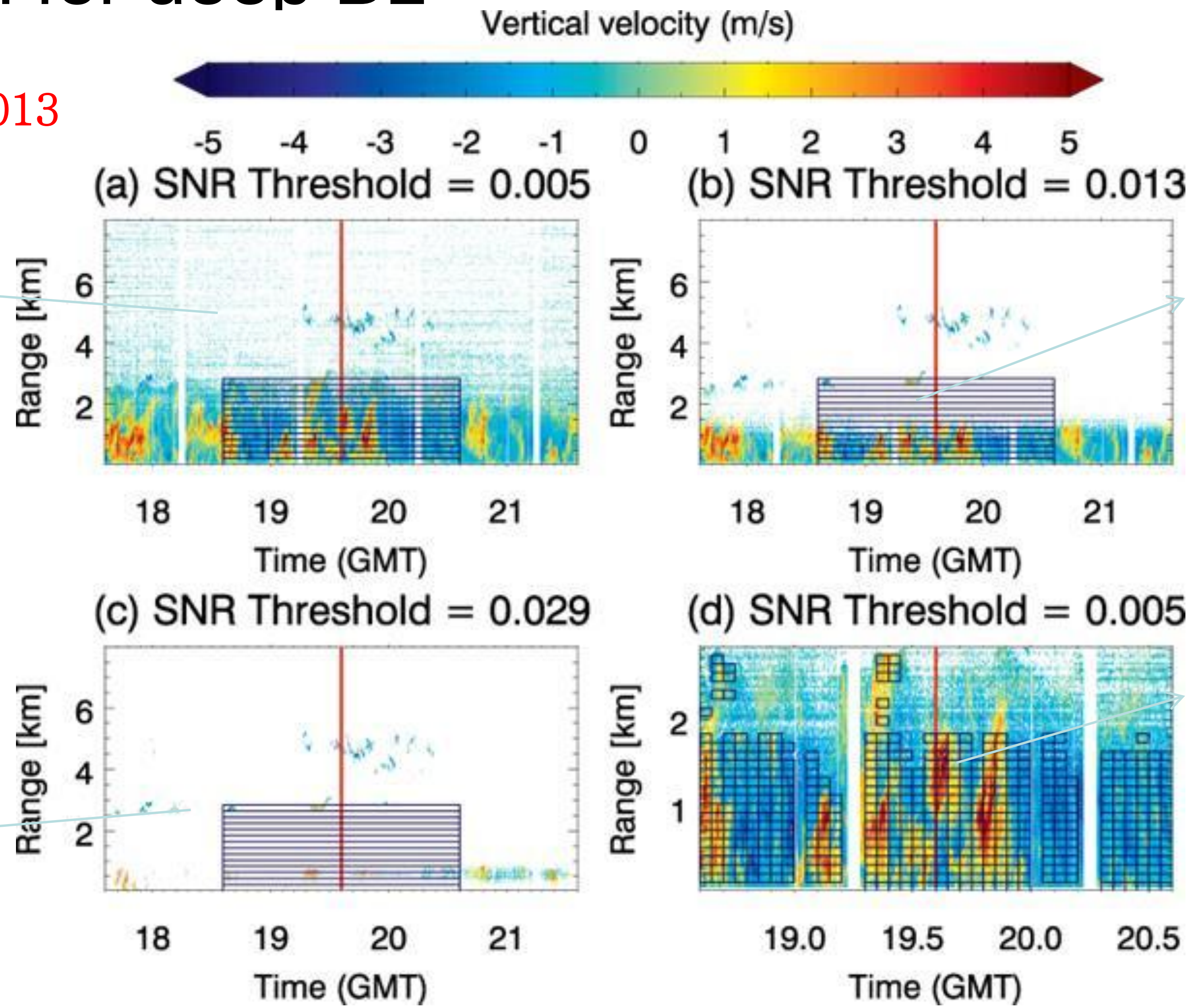
HOWEVER, for few cases with very deep boundary layer (BL), signal is lost for pixels in the upper part of the BL.

Lidar returns are pretty weak in the upper part of BL so that the calculated updraft speed is sensitive to SNR threshold



Methodology: New technique of detecting signal for deep BL

13 July, 2013



Many noises

No noise, but signals are lost

Only clouds are left

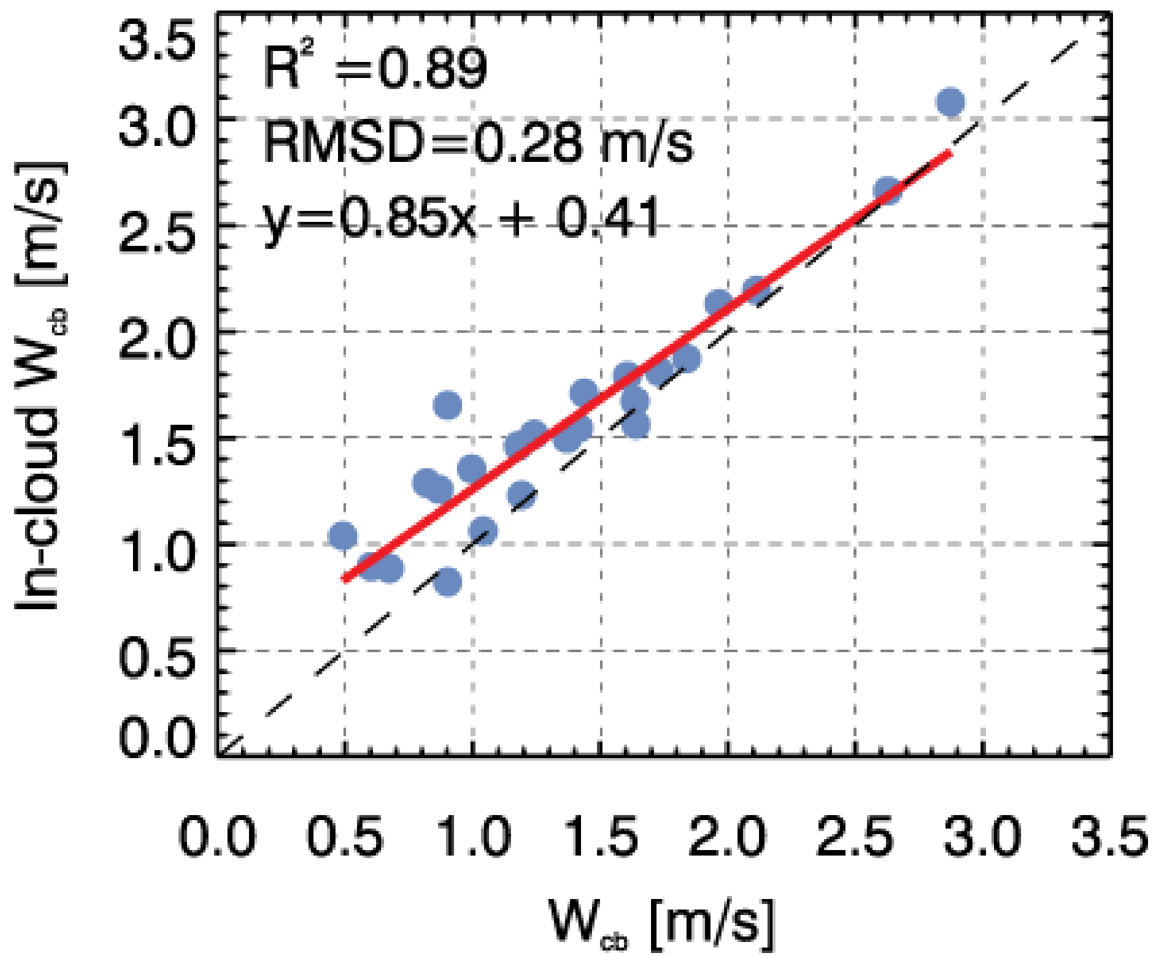
Select continuous pixels

$(\frac{N_{remain}}{N_{total}} > 90\%)$

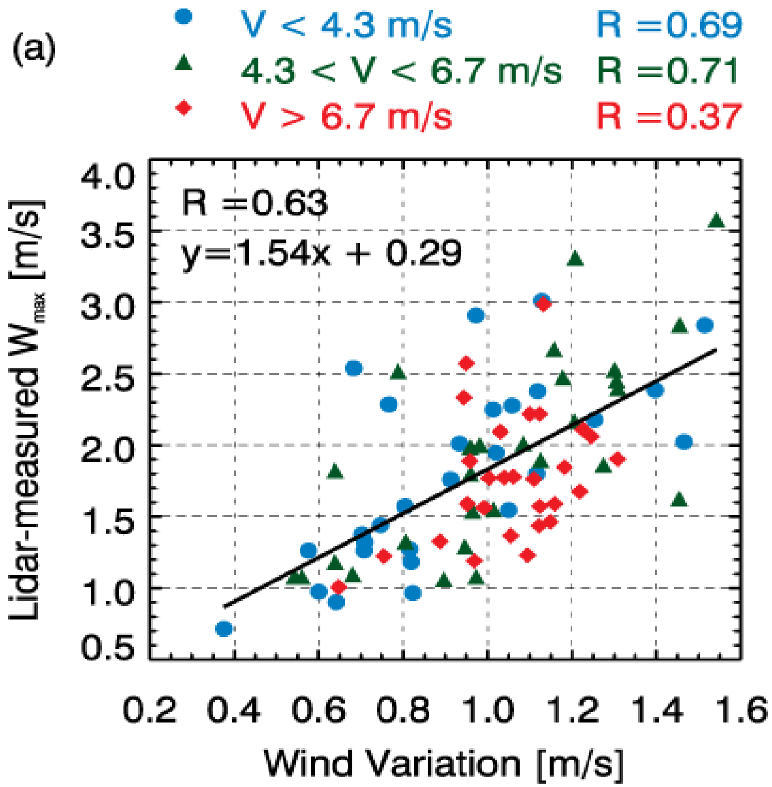
Methodology: Examining the validity of the signal detection technique

Assumption: At the cloud base, the in-cloud updraft speed should be consistent with the updraft speed just below the cloud.

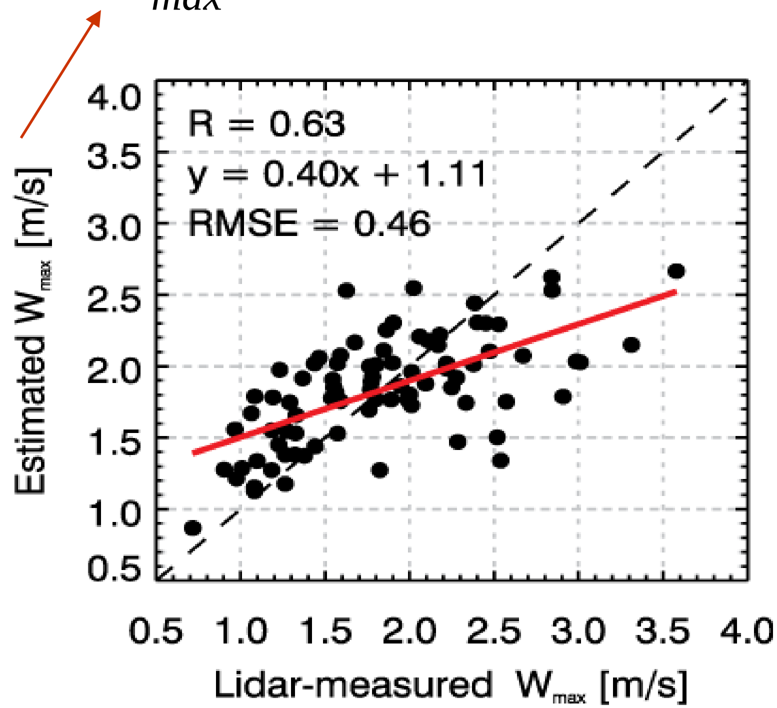
If our new technique is reliable, we should expect a good agreement between in-cloud updraft speed and the cloud base updraft speed based on our new technique of selecting signal pixels



Updrafts vs. wind variations for clear BL

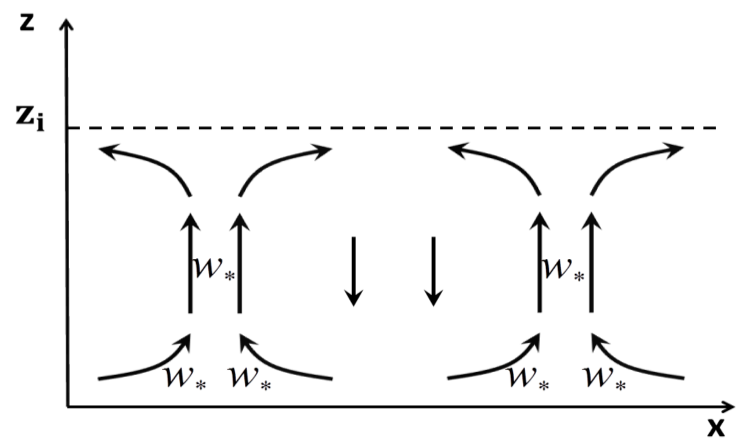


(b) $W_{max} = 1.54WV + 0.29$



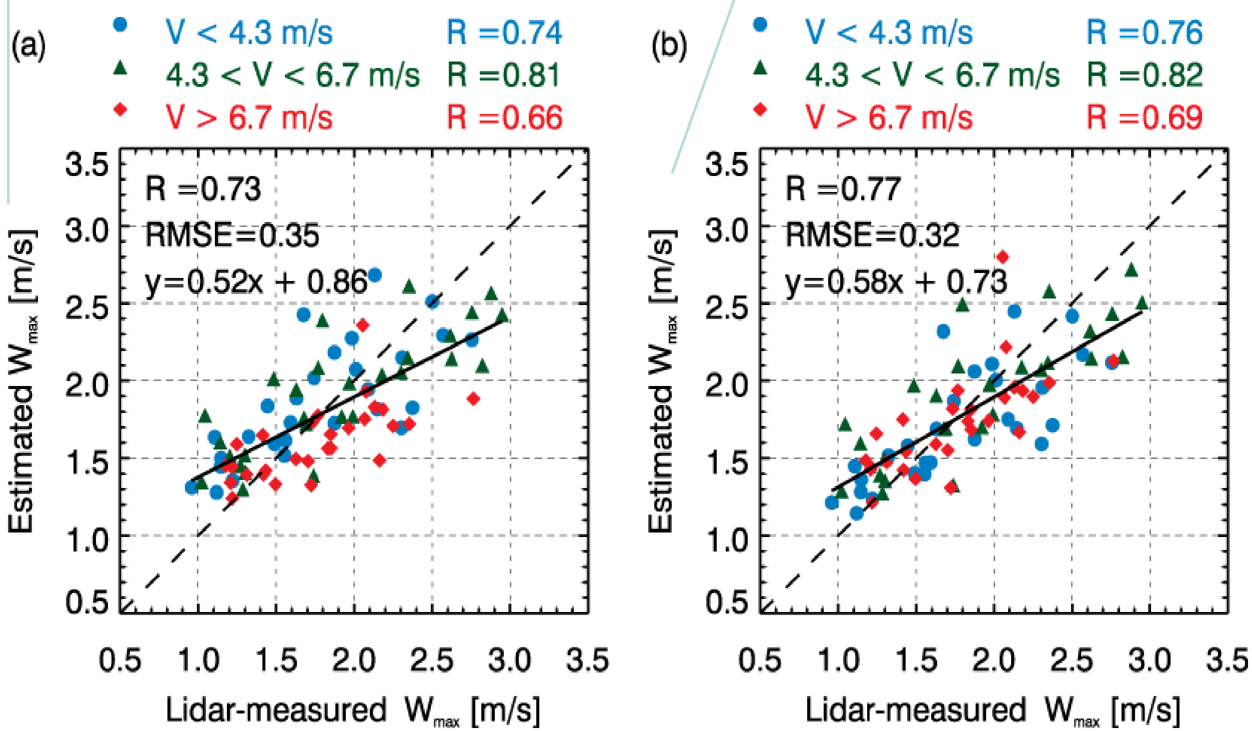
W_{max}: Maximum updraft speed in the vertical

Wind variation (WV): 30-min standard deviation of wind speeds



Updrafts vs. V, z_i, T_s, T_a for clear BL

$$W_{\max\_est} = 0.24(z_i(T_s - T_a))^{1/2} + 0.9 \quad W_{\max\_est} = 0.17(z_i(1 + 0.25V)(T_s - T_a))^{1/2} + 0.81$$



W_{max}: Maximum updraft speed

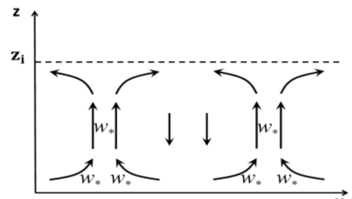
Ts: Surface skin temperature

Ta: 2-m air temperature

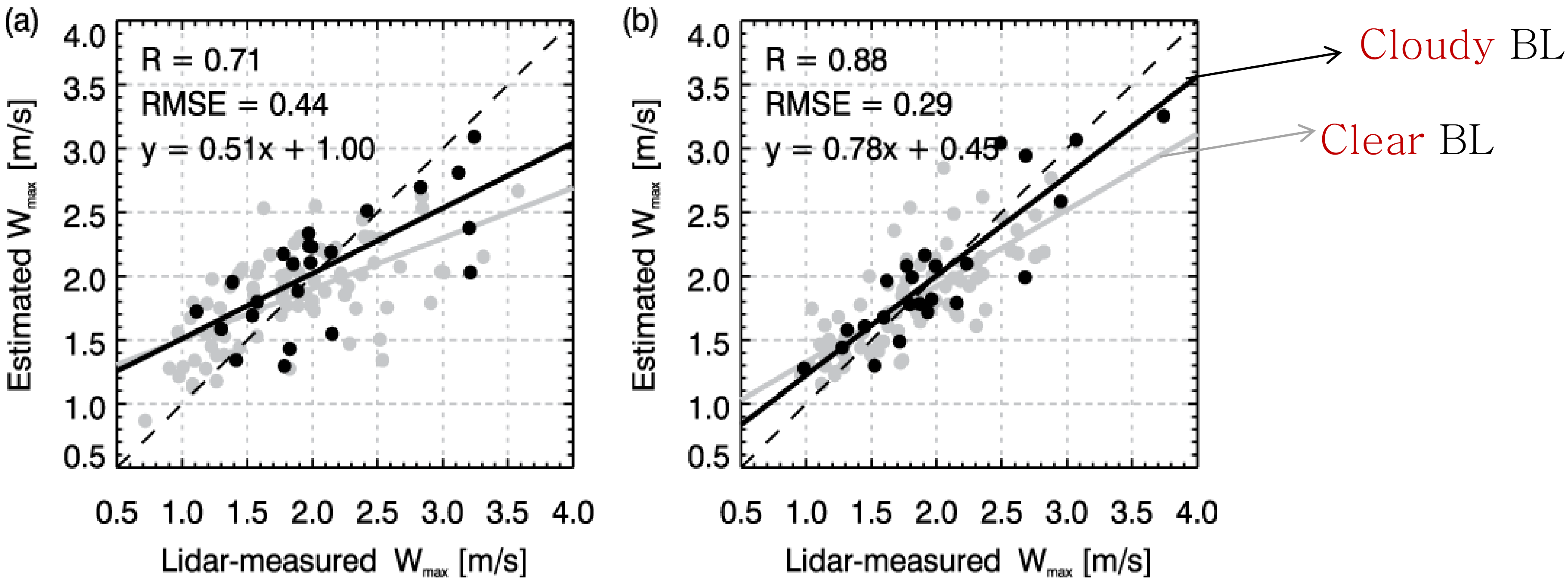
V: 10-m surface wind speed

z_i: Boundary layer depth

Results for cloudy boundary layer

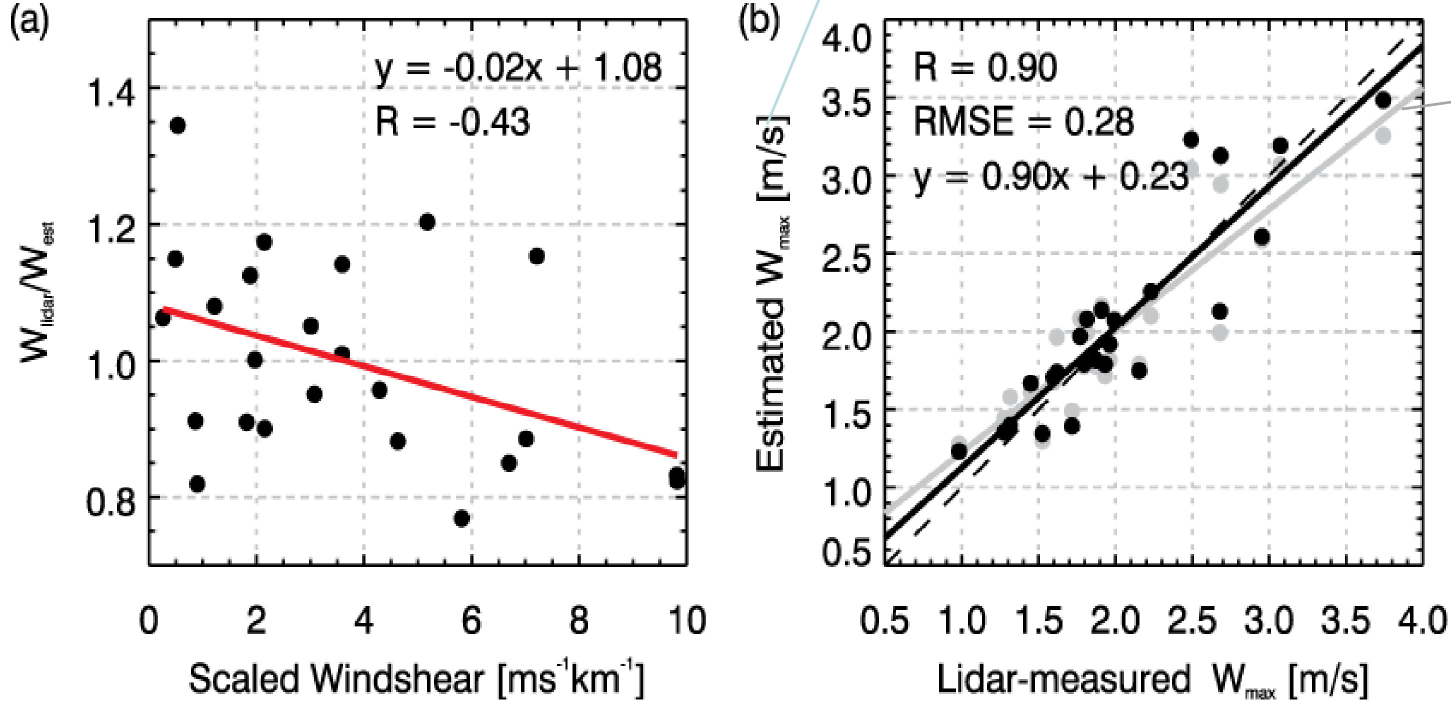


$$W_{\max\_est} = 2.12WV - 0.18 \qquad W_{\max\_est} = 0.27(z_i(1 + 0.25V)(T_s - T_a))^{1/2} + 0.54$$



Adding wind shear (**WS**) into consideration

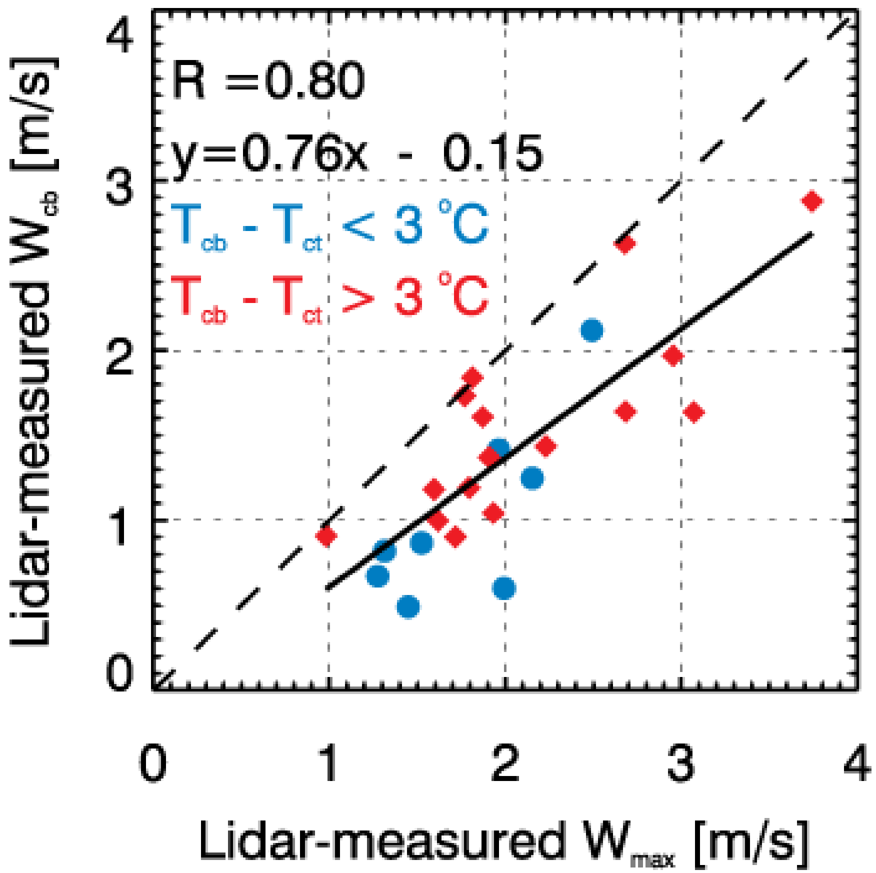
$$W_{\max\_est} = (0.02WS + 1.08)[0.27(z_i(1 + 0.25V)(T_s - T_a))^{\frac{1}{2}} + 0.54]$$



Not considering WS

Variation of cloud base updraft speed (W_{cb}) with **measured** maximum updraft speed (W_{max})

Cloud base W



Max W

T_{cb}: Cloud base temp.

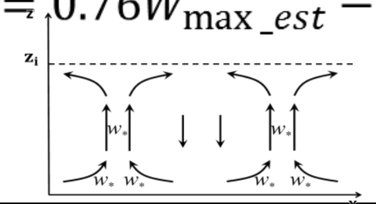
T_{ct}: Cloud top tem.

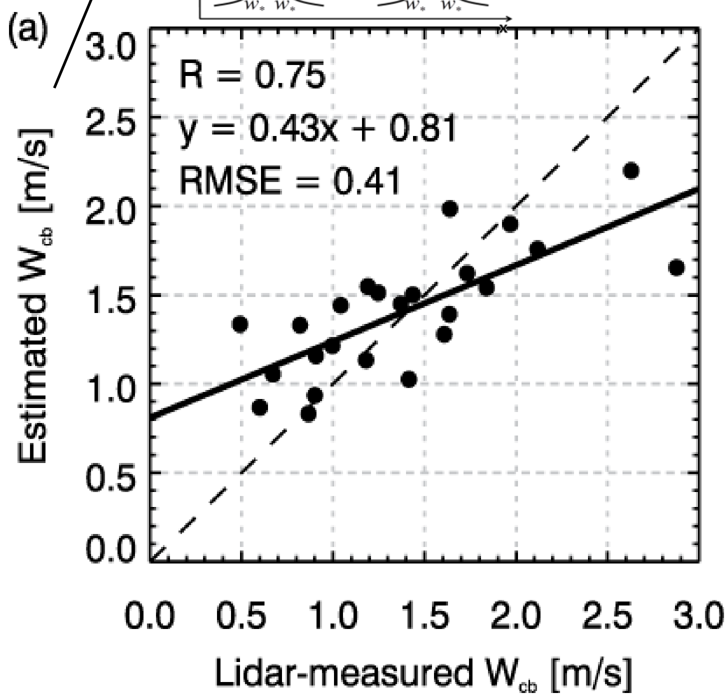
$$W_{cb} = 0.76W_{max} - 0.18$$

Variation of cloud base updraft speed (W_{cb}) with **retrieved** maximum updraft speed (W_{max})

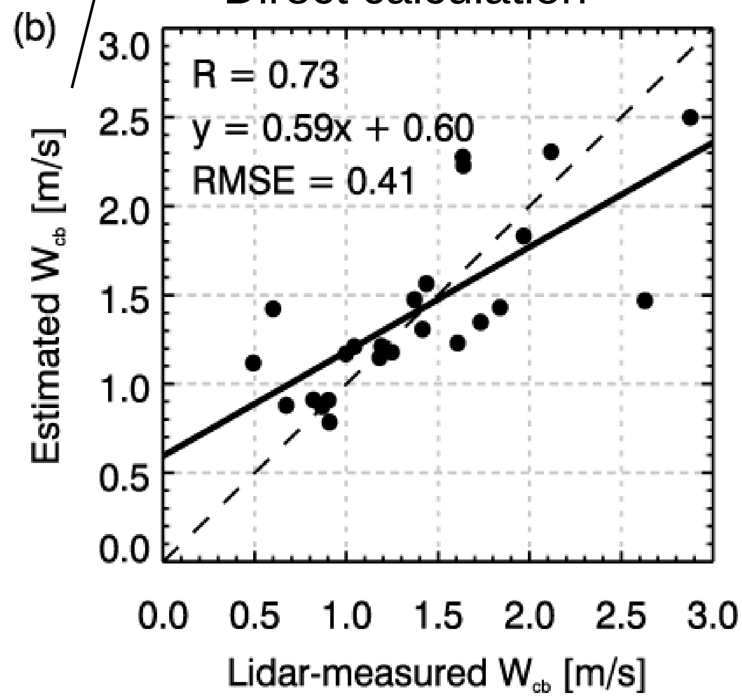
$$W_{\max\_est} = 2.12WV - 0.18 \qquad W_{\max\_est} = 0.27(z_i(1+0.25V)(T_s - T_a))^{1/2} + 0.54$$

$$W_{cb\_est} = 0.76W_{\max\_est} - 0.18 \qquad W_{cb\_est} = 0.76W_{\max\_est} - 0.18$$

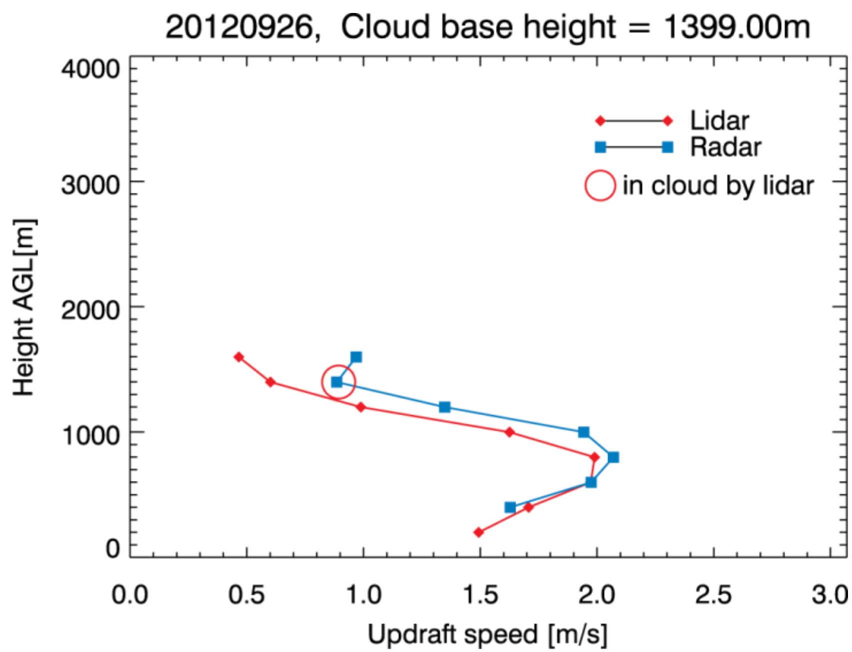


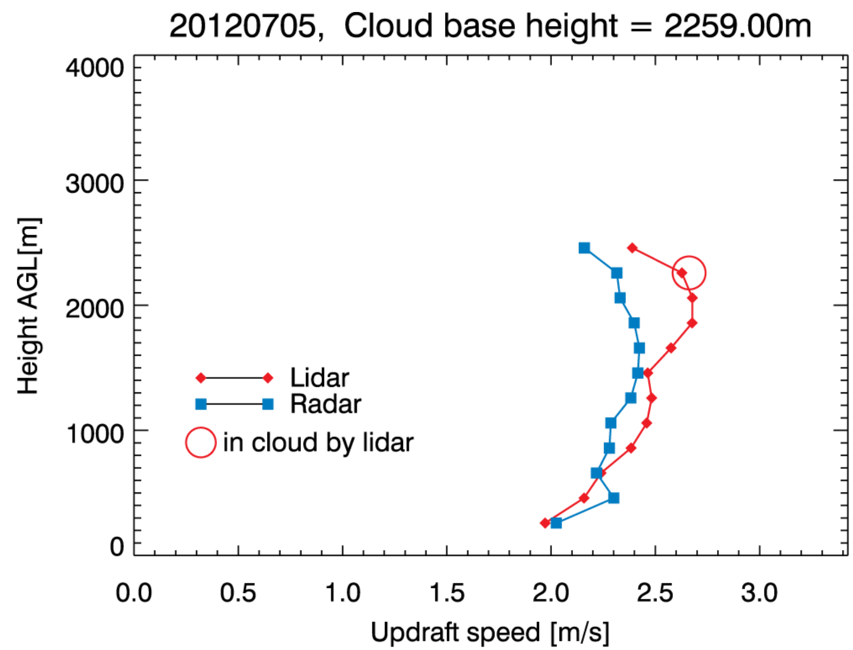


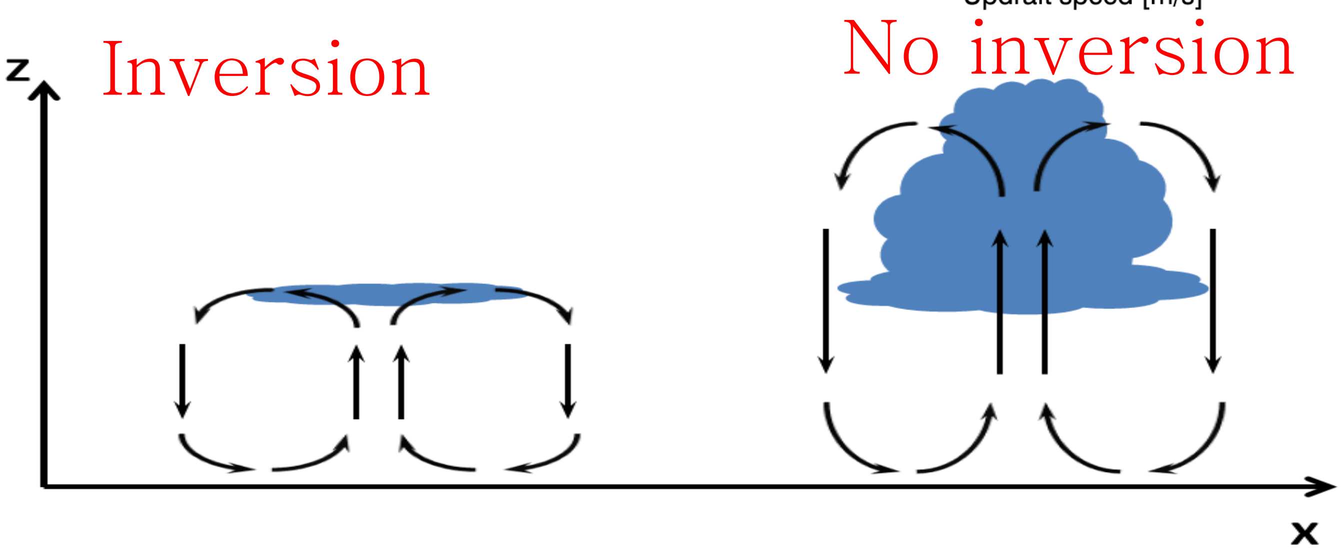
Direct calculation



Variation of cloud base updraft speed (W_{cb}) with **cloud depth** relative to max updraft speed (W_{max})



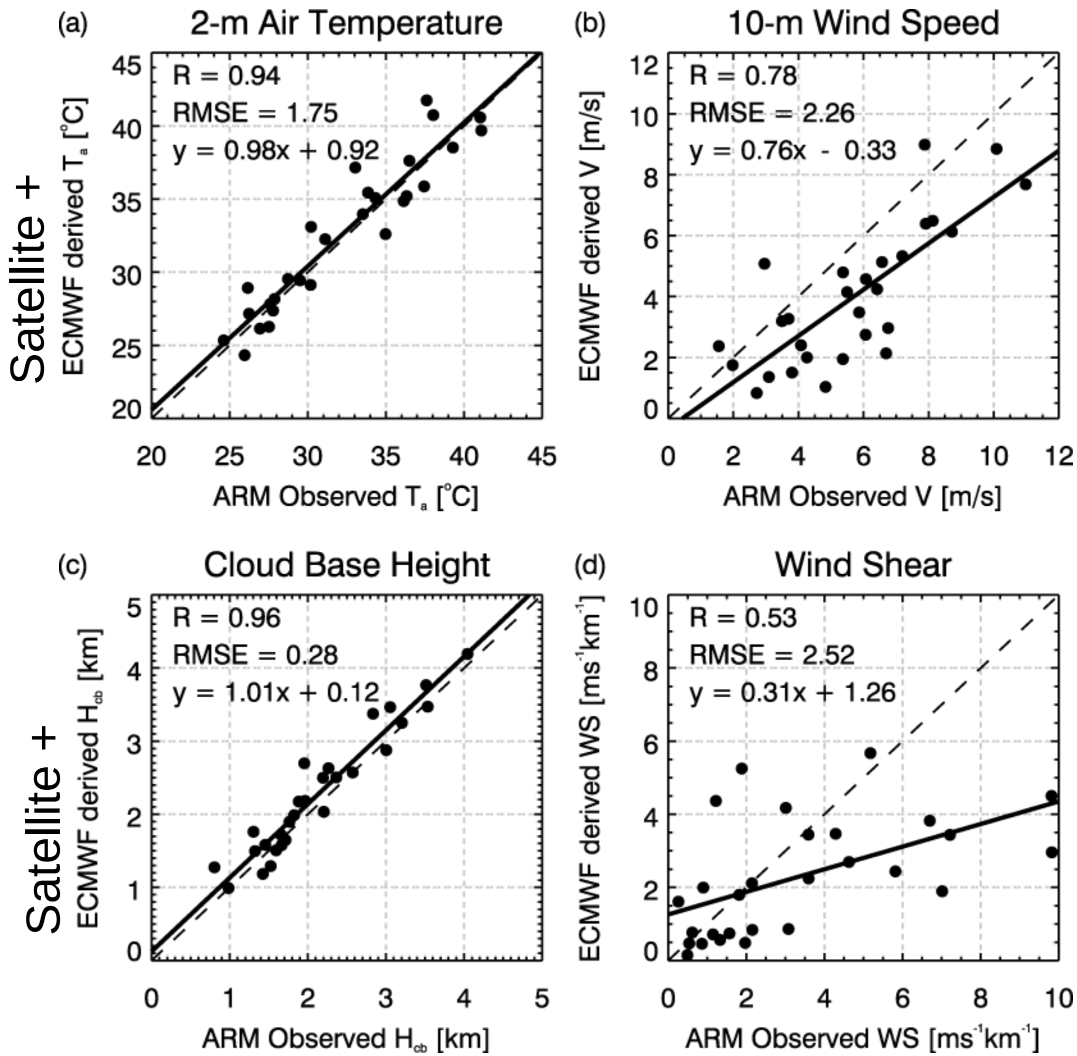




Intermediate summary: the use satellite and reanalysis to estimate the input parameters

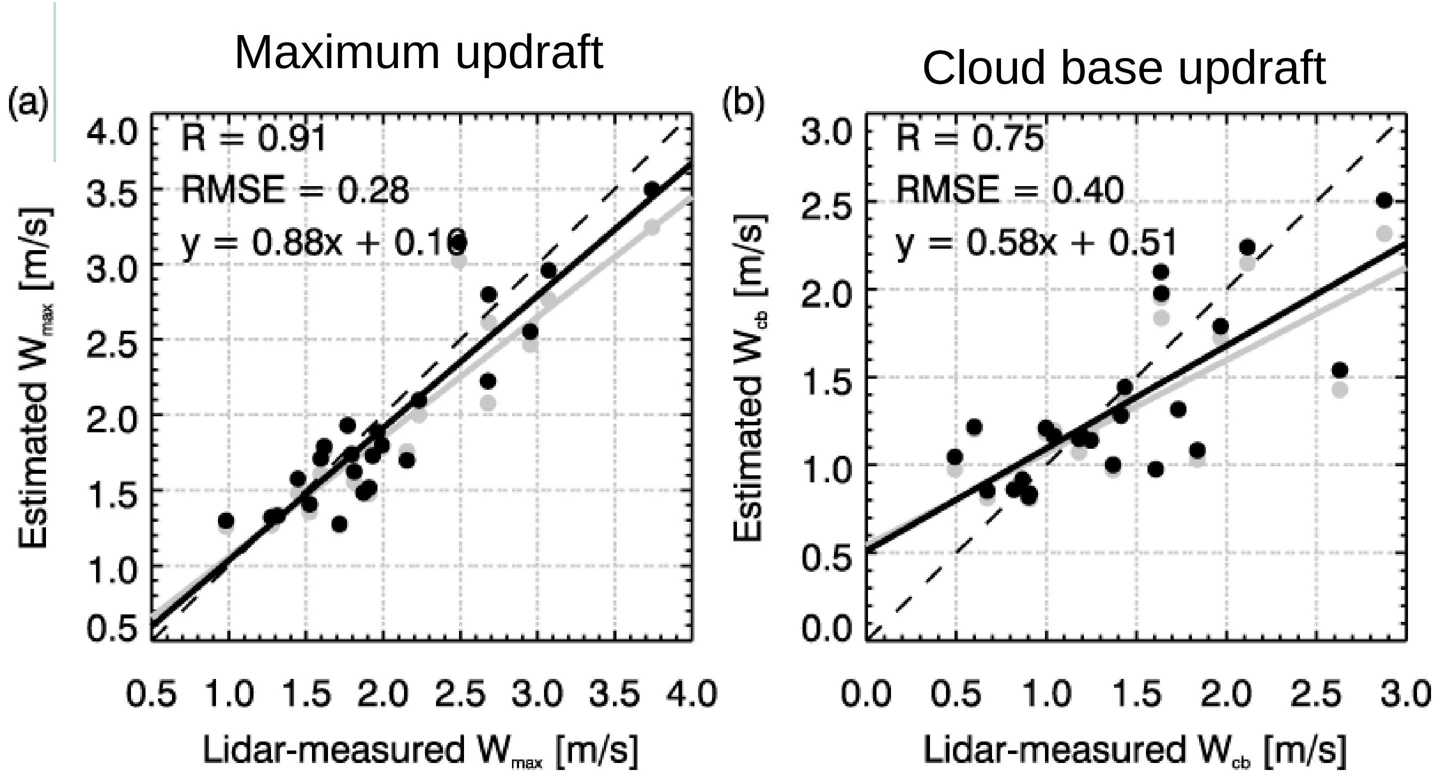
- Surface skin temperature (T_s) can be retrieved by VIIRS/NPP in the same way mentioned in 3.1.2.
- 10-m wind speed (V) can be obtained from ECMWF reanalysis 10-m wind product.
- Cloud base height (H_{cb}) and 2-m air temperature (T_a) are retrieved based on VIIRS-retrieved cloud base temperature (T_{cb}). H_{cb} is estimated by finding the height where the T_{cb} occurs according to the vertical profile of temperature from ECMWF reanalysis data. With H_{cb} and T_{cb}, we calculate the T_a by assuming a dry adiabatic lapse rate below H_{cb}. This methodology of estimating H_{cb} and T_a works for ~ 70% of the cases according to comparing them with observed ones (errors are mostly less than 2.0 ° C for T_a and 200 m for H_{cb}). For some cases, however, large error of estimated H_{cb} and T_a exists. This is primarily attributed to large deviation from dry adiabatic lapse rate below the H_{cb} in ECMWF reanalysis. In this situation, we directly use the 2-m air temperature product from ECMWF reanalysis as the retrieved T_a and calculate the H_{cb} with T_a, T_{cb} and dry adiabatic lapse rate.
- Scaled wind shear (WS) can be obtained with retrieved H_{cb} and vertical profile of wind speed from ECMWF reanalysis.

Validation of satellite- and reanalysis-retrieved parameters



Satellite + Reanalysis- only retrieval of updraft speeds

- $W_{max\_est} = 0.27(z_i(1 + 0.25V)(T_s - T_a))^{1/2} + 0.54$
- With additional wind shear correction: *Wmax = 0.02WS+1.08* *Wmax_est*

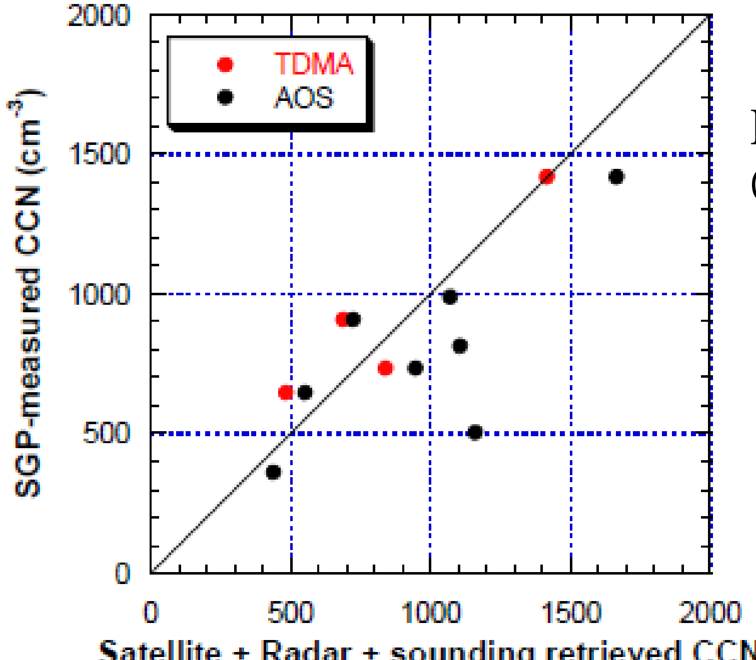


Conclusions

- We show two new methods for estimating updraft speeds:
  1. Based on surface wind variation (*WV*).
  2. Based on retrieved surface (V, Ta, Ts) and BL (z_i, WS) parameters.
- This is valid for both clear and cloudy BL.
- Satellite + reanalysis analyses retrievals perform equally well.
- Cloud base updrafts are reliable if clouds are at least 500 m deep.
- Satellite retrievals of W_{max} (RMSE = 0.28 m/s) and $W_{\mathbf{cb}}$ (RMES = 0.40 m/s) are feasible.

Next steps

Using the satellite-retrieved cloud base updraft speeds to fill the last missing part of CHASER satellite mission, retrieving the activated CCN at cloud base on a global scale.



D. Rosenfeld et al, 2014, GRL, submitted