Cloud Height Estimation

Through Combination of Cloud Motion Vectors from Cloud Camera and Radiation Measurements

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Content

- Motivation
- Method
- Results
- Questions and complementary observations

MOTIVATION

- CLOUDS ARE THE **DOMINANT SOURCE OF SMALL-SCALE VARIABILITY IN SOLAR RADIATION**
- **VARIABILITY IS CRITICAL** IN "STAND-ALONE" OR "GRID CONNECTED" PVPS (BIG INSTALLED CAPACITY)
- THE **CLOUD'S HEIGHT** IS AN IMPORTANT TOPIC TO TIME THE RADIATION VARIABILITY.
- **MODELS EXISTS**:
  - FOR LOW-COST IN SUN POSITIONING,
  - (SOME) FOR CLOUD MOTION DESCRIPTION,
    BUT FEW HAS ACCURATE **HEIGHT** ESTIMATION.

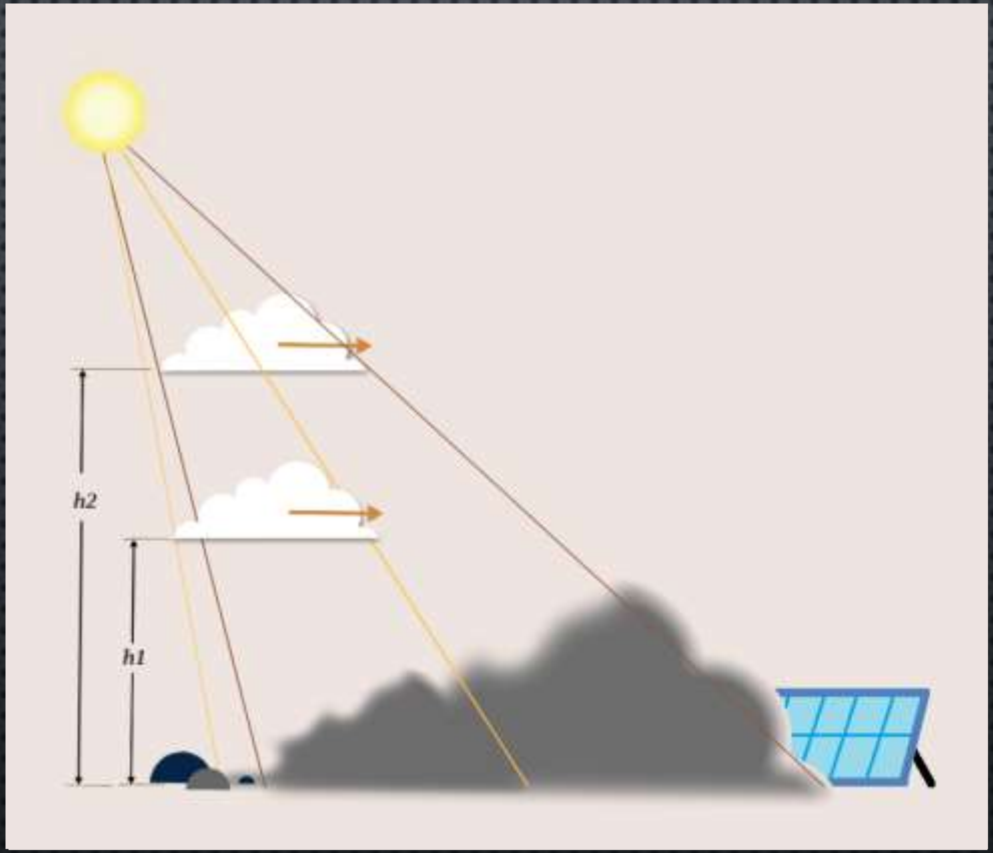
GOLD GOAL

A LOW-COST TECHNOLOGY (IMPLEMENTATION + HARDWARE)
FOR AREAL IRRADIANCE FORECAST

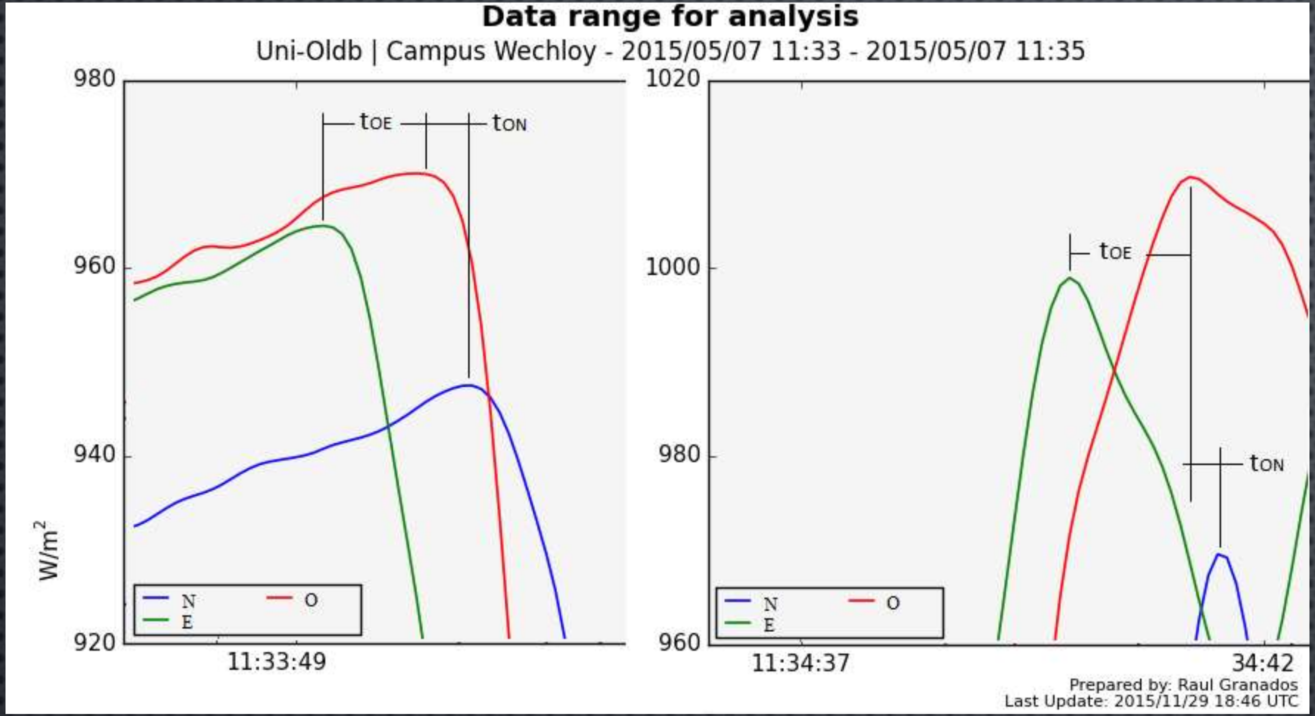
Motivation

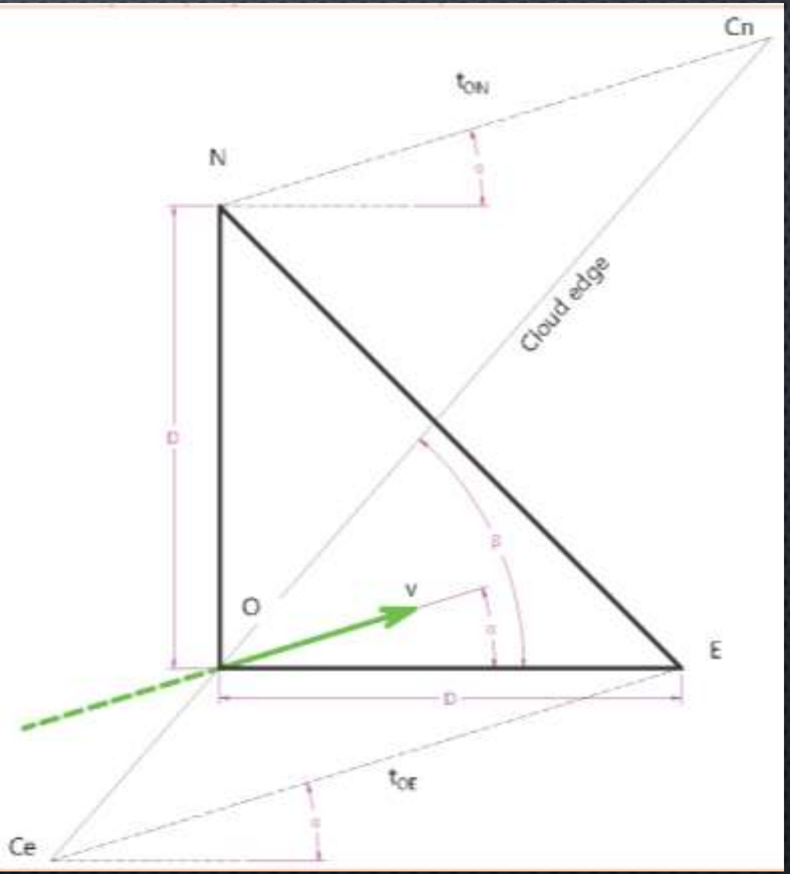
- Why is relevant to know the height?

Cloud **B**ase **H**eight



Cloud Motion Vectors from Radiation signal measurements



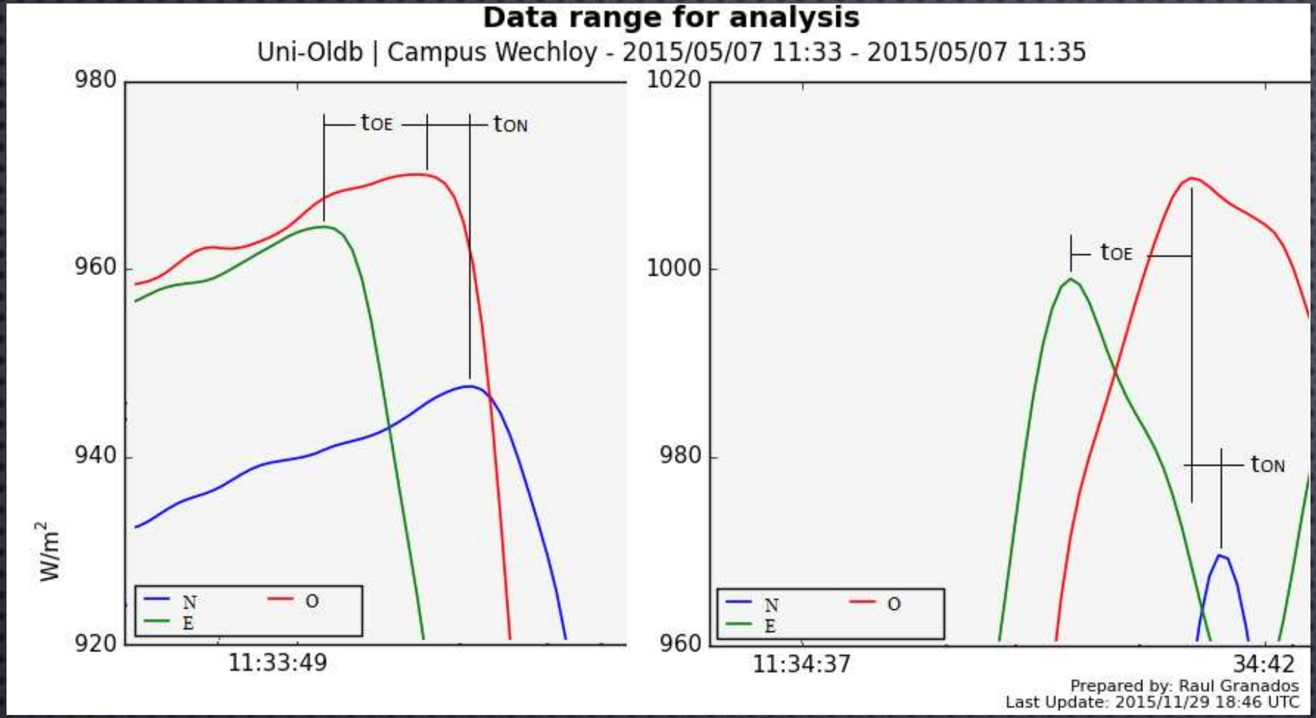


Linear Cloud Edge (LCE) Method:

- Introduced by Bosch, et al., [1]
  aside with the sibling method: "Most correlated pair"
- Arrange of three pyranometers in an right-angled triangle
- Kinematic characteristics of the cloud
  (from geometry and time shift of the Irradiation signal ramp)

$$\alpha = \arctan\left[-\frac{t_{OE2} - t_{OE1}}{t_{ON2} - t_{ON1}}\right] \qquad v = \frac{D}{t_{ON2} \cdot \sin\alpha + t_{OE2} \cdot \cos\alpha}$$

Cloud Motion Vectors from Radiation signal measurements



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Improvement:

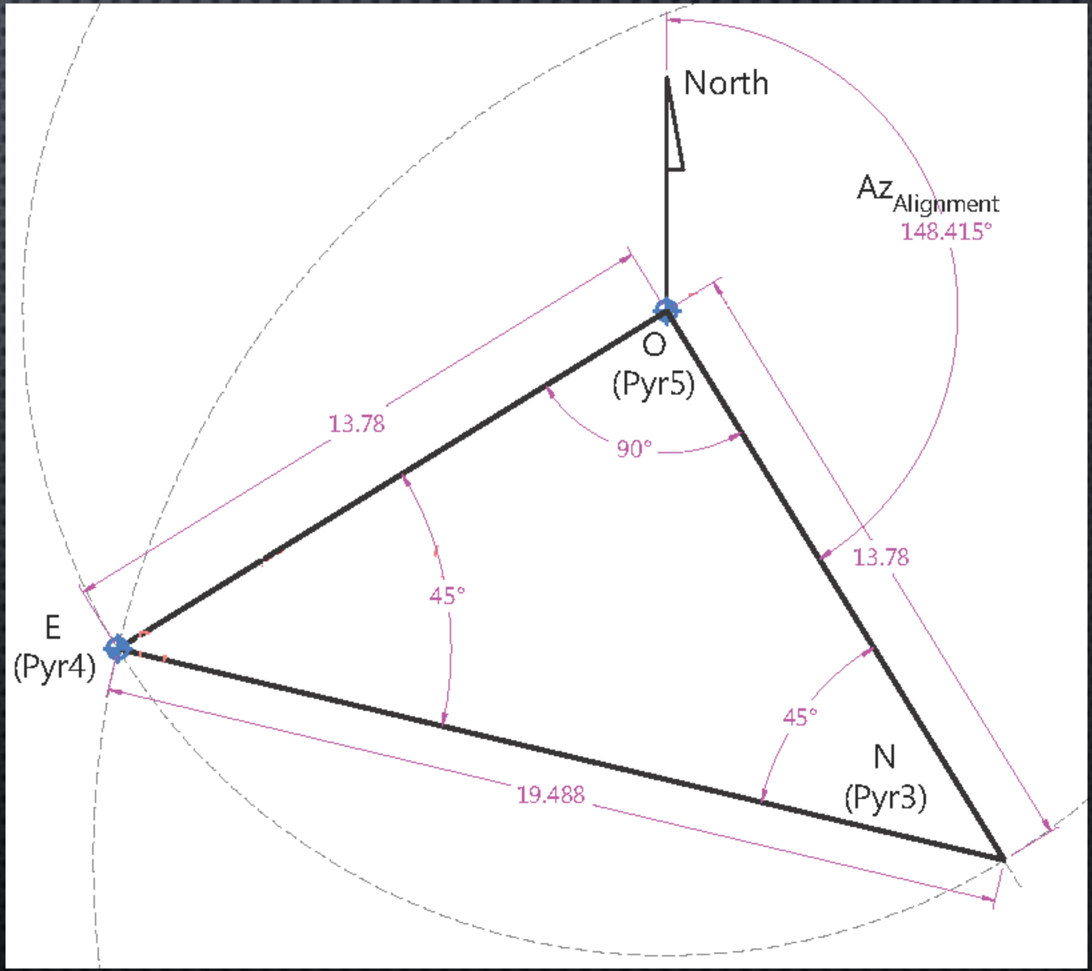
- Focusing on cloud events and time shifts robustness.
- New Approach:
  - Cloud Event Detection (CED) Algorithm
    +
  - Maxima pairing
    (Maxima entrance – Maxima retreat)
    +
  - Cross-correlation
    (Pyr5 with Pyr3) and (Pyr5 with Pyr4)

Three Pyranometers' Signal

Experimental setup… Methods

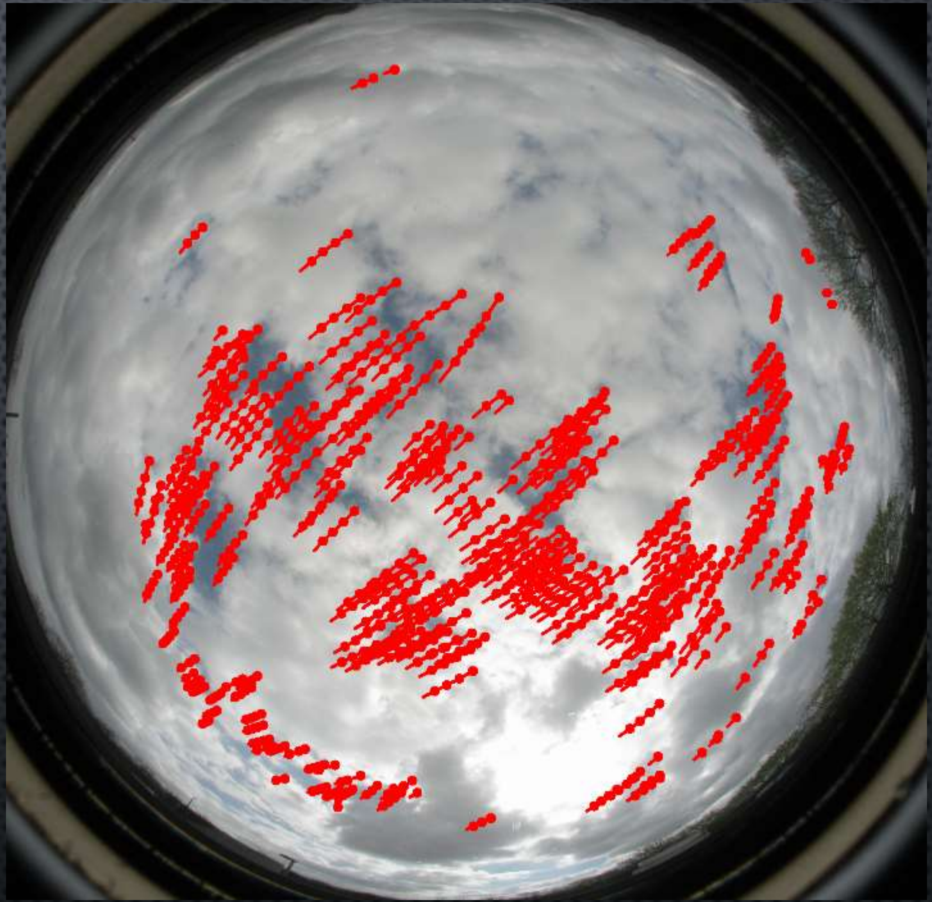
Radiation signals:

- Irradiance signal measurements
- Pyranometer used are EKO ML-01
- 10Hz (sample resolution)
- D = 13.78m (distance between pyranometers)
- "O-N" side = 148.42°



Cloud Motion Vectors From Sky Imager

- Usage of Optical Flow
- Image interval 10s
- Zenithal and azimuthal position of each vectors
  Initial and terminate point in the non-rectified image
- Filter only vectors for clouds heading the sun



CLOUD BASE HEIGHT:

- MATCH CMVS FROM SKY IMAGER…

$$|\overrightarrow{u_{i_2-i_1}}| = \frac{h_{ix} \cdot (\tan\theta_{i_2} \cdot \sin\varphi_{i_2} - \tan\theta_{i_1} \cdot \sin\varphi_{i_1})}{\Delta t_{i_2-i_1}}$$

+

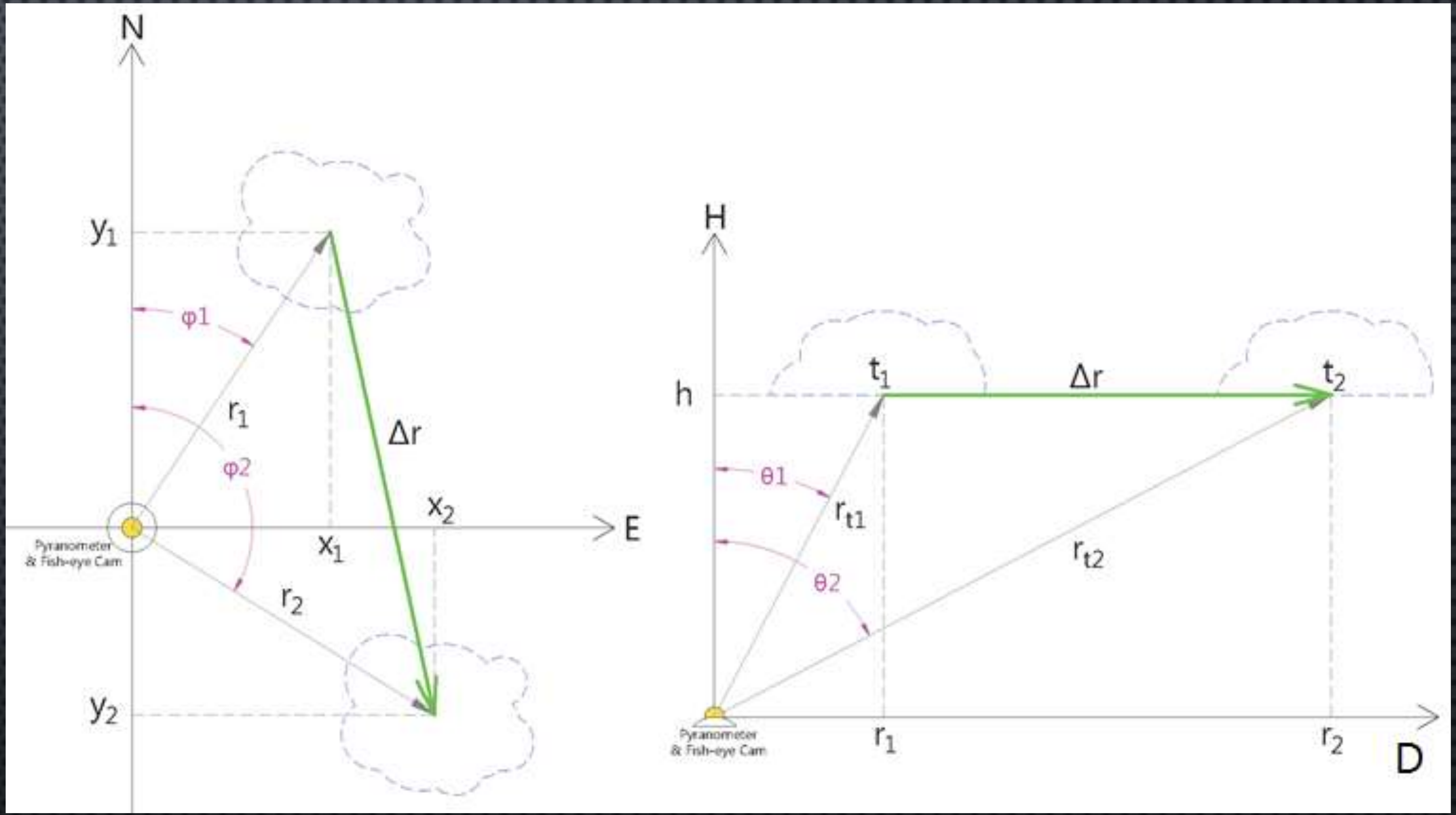
- … WITH THE CMVS FROM TPS

$$\overrightarrow{V_{TPS}} = \overrightarrow{V_{i_2-i_1}}$$

=

- THEN HEIGHT CAN BE KNOWN:

$$h_{ix} = \frac{|\overrightarrow{u_i}| \cdot \Delta t}{\tan\theta_{i_2} \cdot \sin\varphi_{i_2} - \tan\theta_{i_1} \cdot \sin\varphi_{i_1}} \rightarrow \left[\frac{\frac{m}{s} \cdot s}{1}\right]$$



2 PAIRS OF AZIMUTHAL (φ) AND ZENITHAL (θ) ANGLES.

Data & Methods

Sky imager:

- CMV database (2 Az & 2 Ze) with 10s sample resolution

Meteorological station (EnMet):

- Wind speed and wind direction ($1s_{average}$)

Radiosonde Measurements:

- Daily Wind speed and wind direction at different heights (12 UTC)

Ceilometer:

- WMO Station 10210. Friesoythe/Altenoythe, 40km from ARRANGE.

Numerical Weather Prediction:

- Cloud base height as provided by the ECMWF, grid point Oldenburg (0.125°x 0.125°) with 3h temporal resolution.

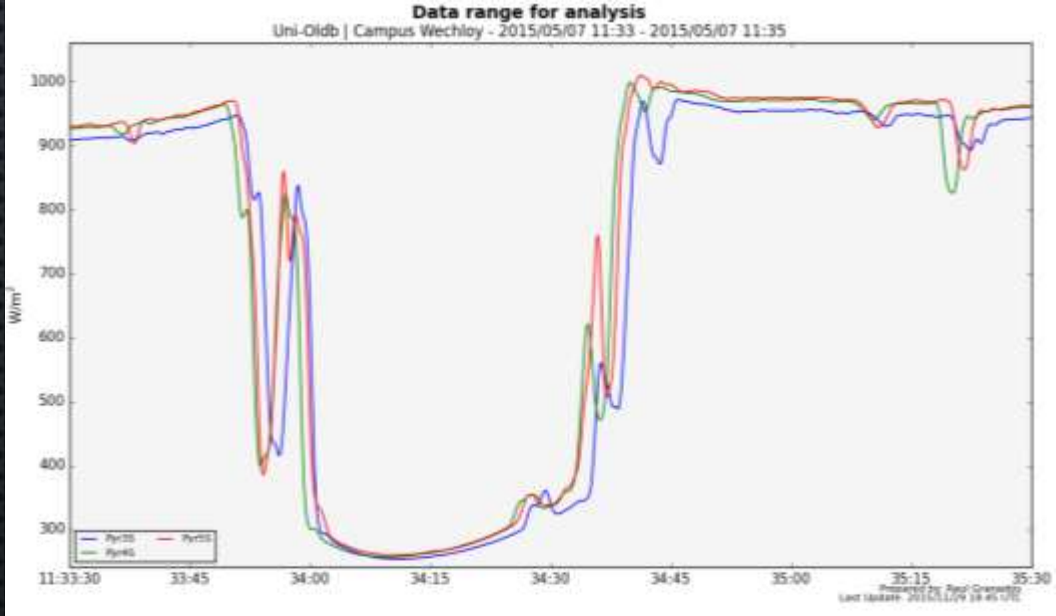
Satellite Imagery:

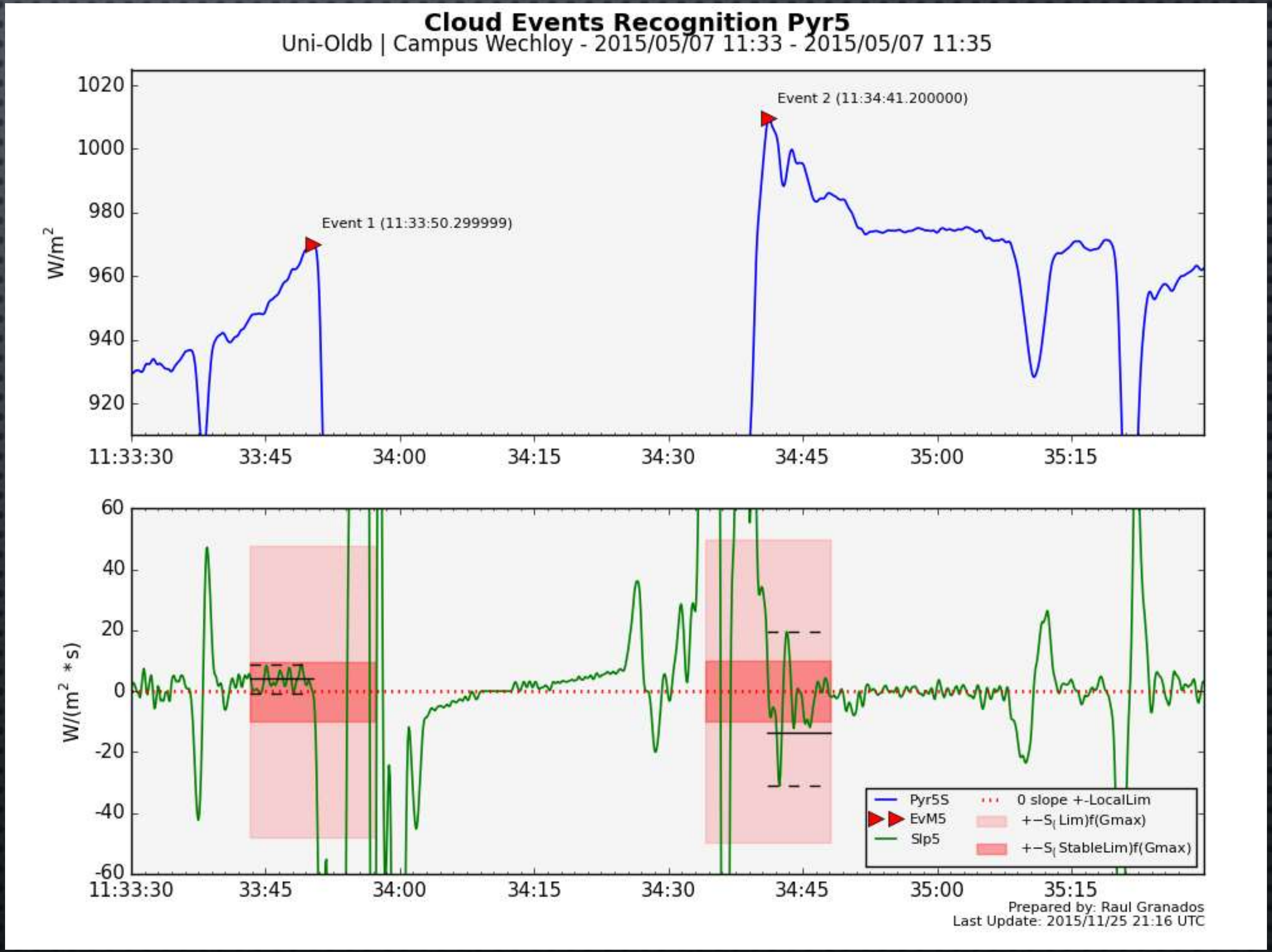
- Cloud Top Height. Downloaded from EUMETSAT, grid point Oldenburg with 15min sample resolution.

Results

Cloud Motion Vectors from TPS method

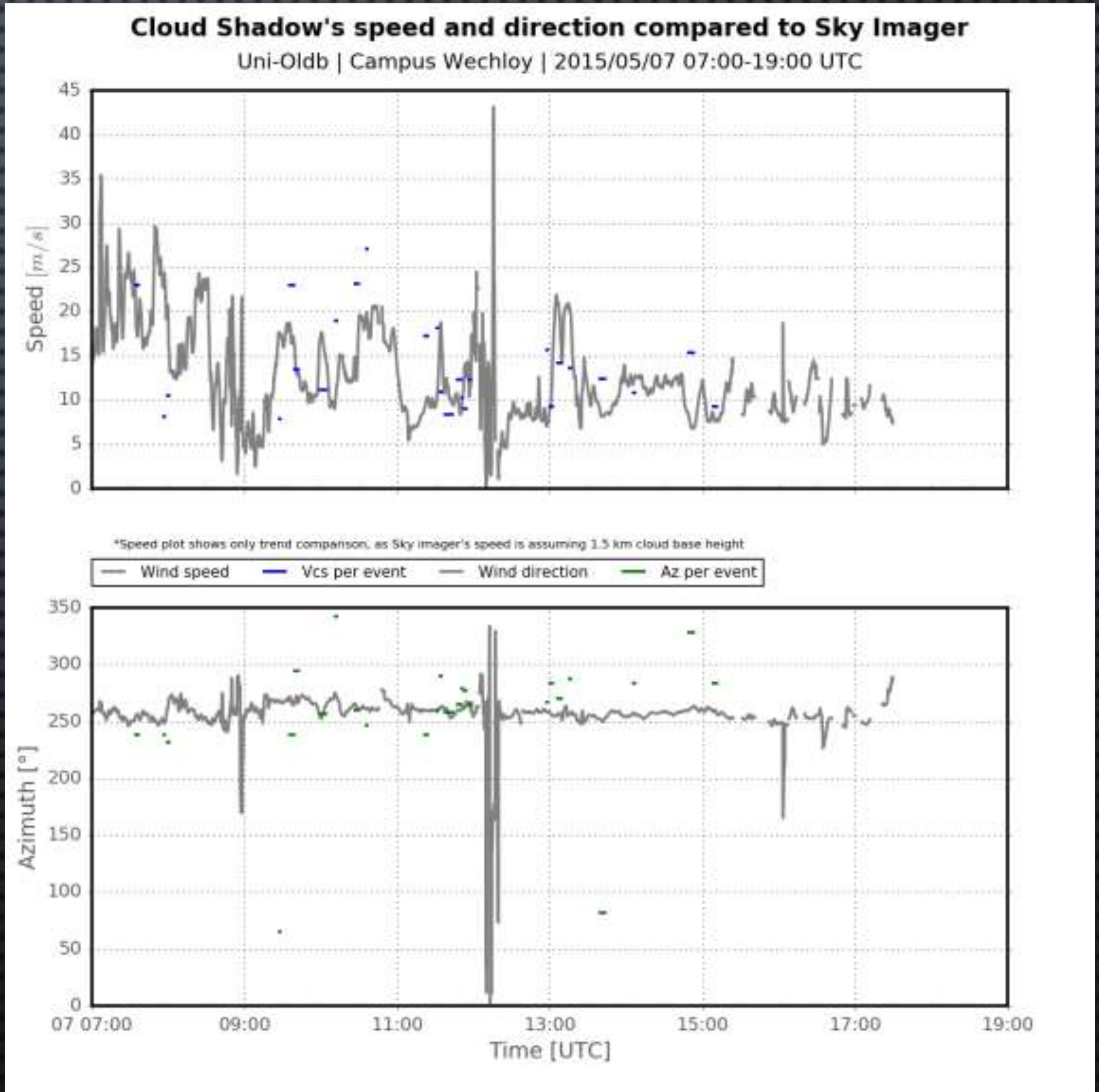
- Manual Event Selection:
  - **2015/05/07 from 11:33h to 11:35h UTC**
- Automate selection of the selected event:





Cloud Motion Vectors from TPS method

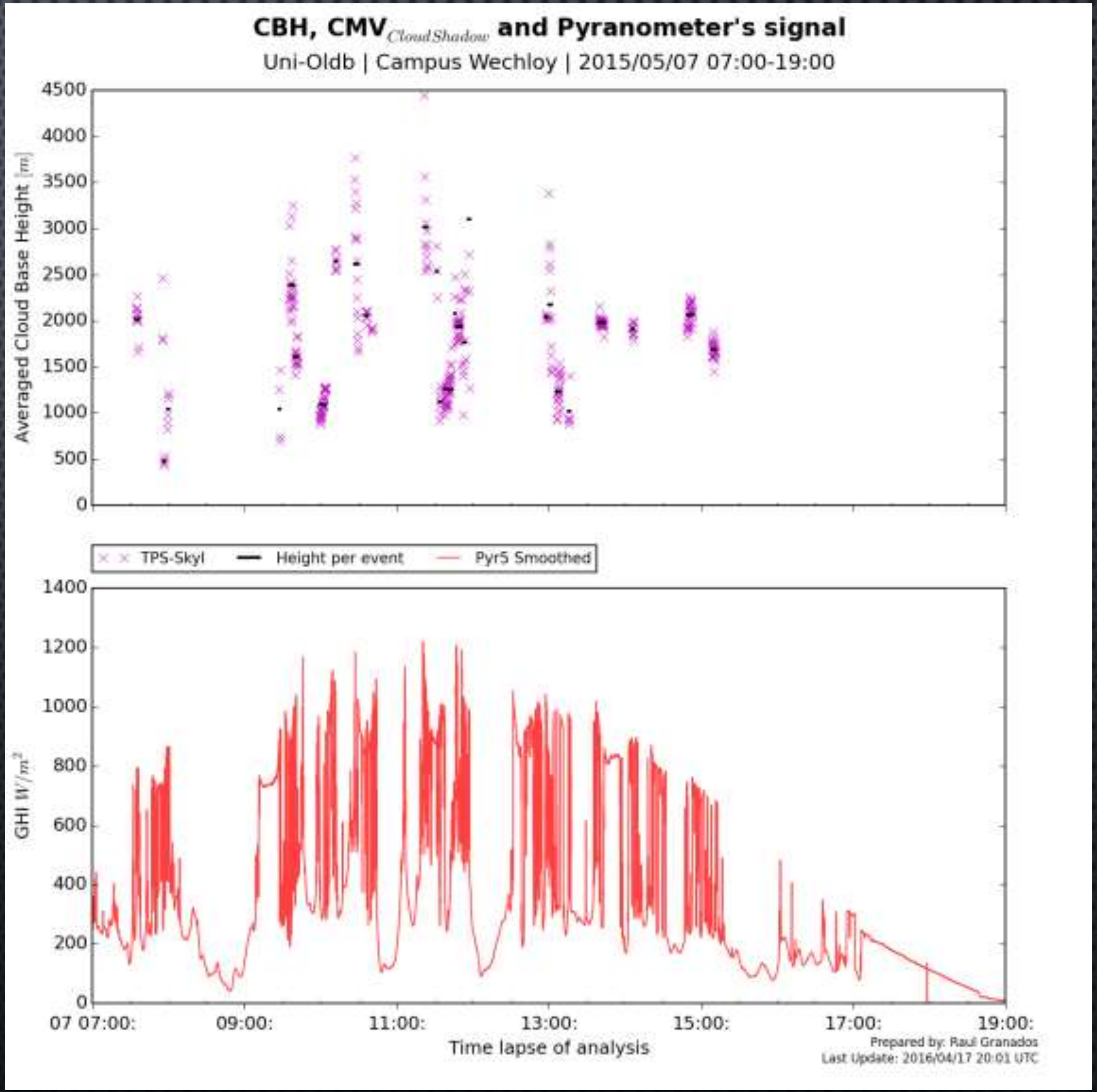
- Manual Event Selection:
    - **2015/05/07 from 11:33h to 11:35h UTS**
- Automate selection of the selected event:
- Automate TPS over 1 day analysis:
    - 35 events (from 166 maximas)
    - 29 events with congruent and accepted accuracy
      (V ≤ 50 m/s)
      (Az ±30° daily average)
    - 2 events have Az at 180° difference
      (65° and 82°)
    - 6 events with unreal speed
      (from 68.9 m/s until 703 m/s)



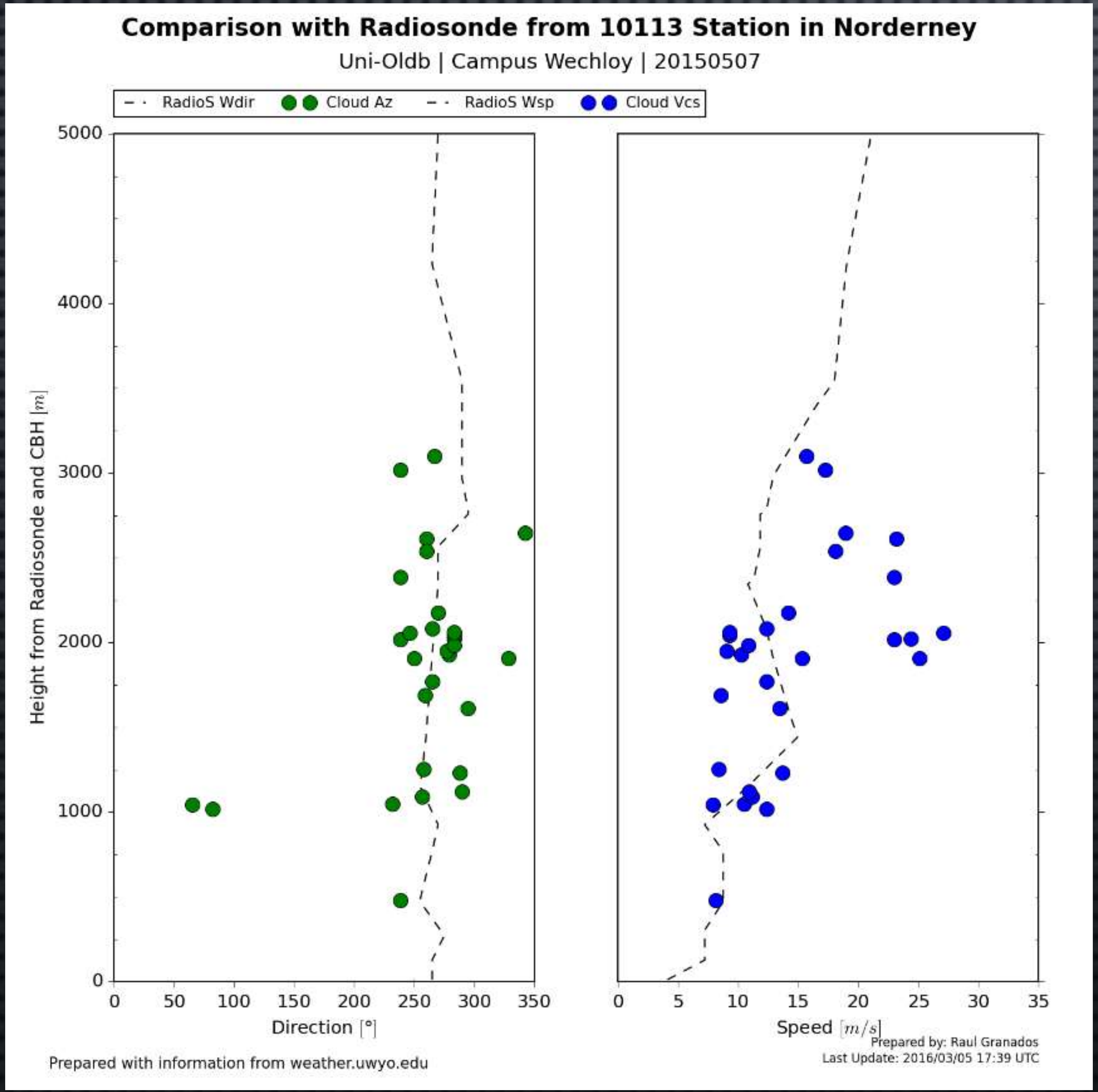
Cloud Base Height with TPS-Sky method

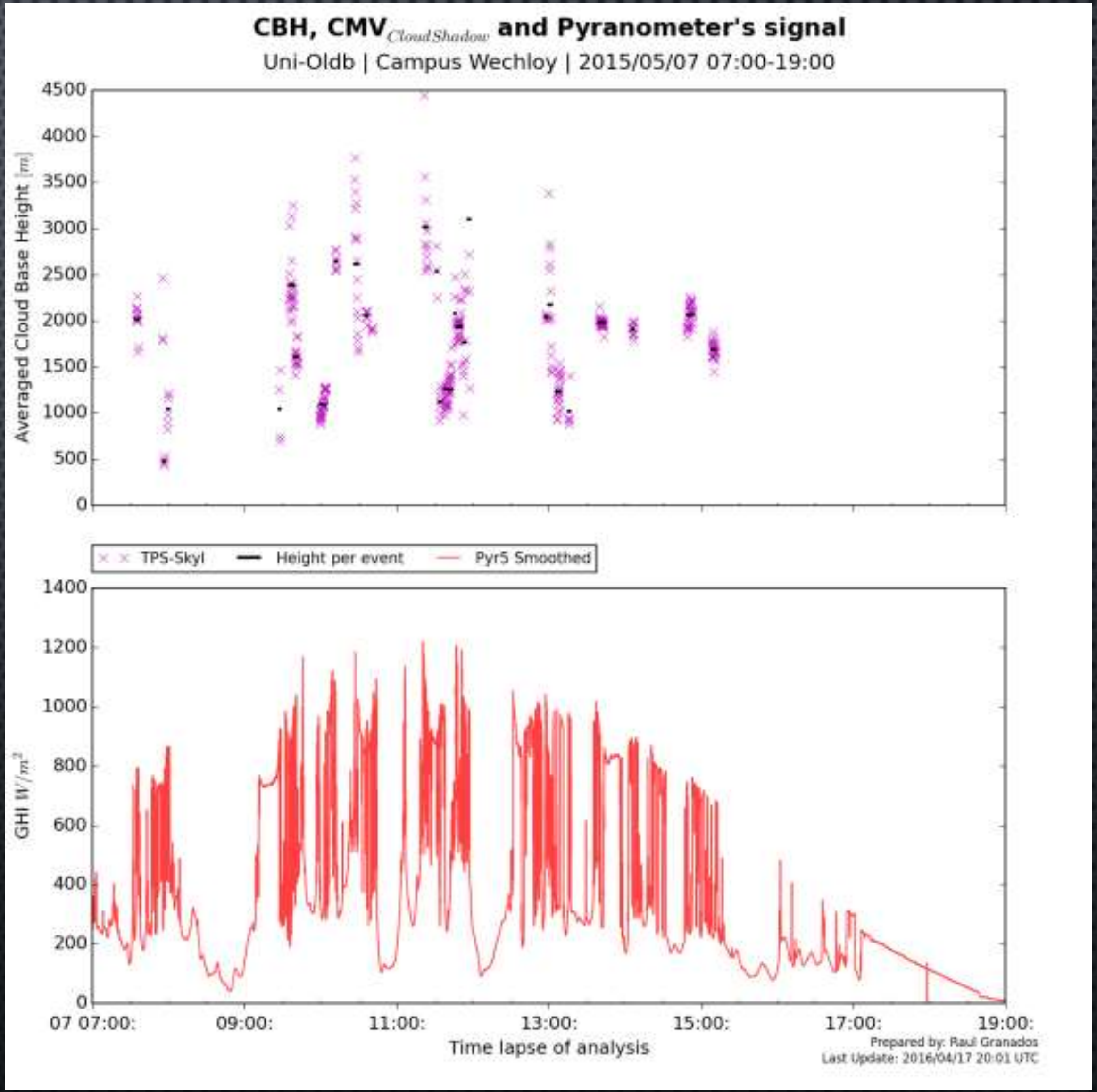
Run with the same 35 CMV events:

- Sky imager's CMVs (476 imgs.) with sector filter
- Neglected events:
  - unreal speeds (are the 6 CMVs from TPS)
  - "Out of Limit" heights
    - Unreal heights for clouds (>10 km)



Cloud Base Height with TPS-Sky method





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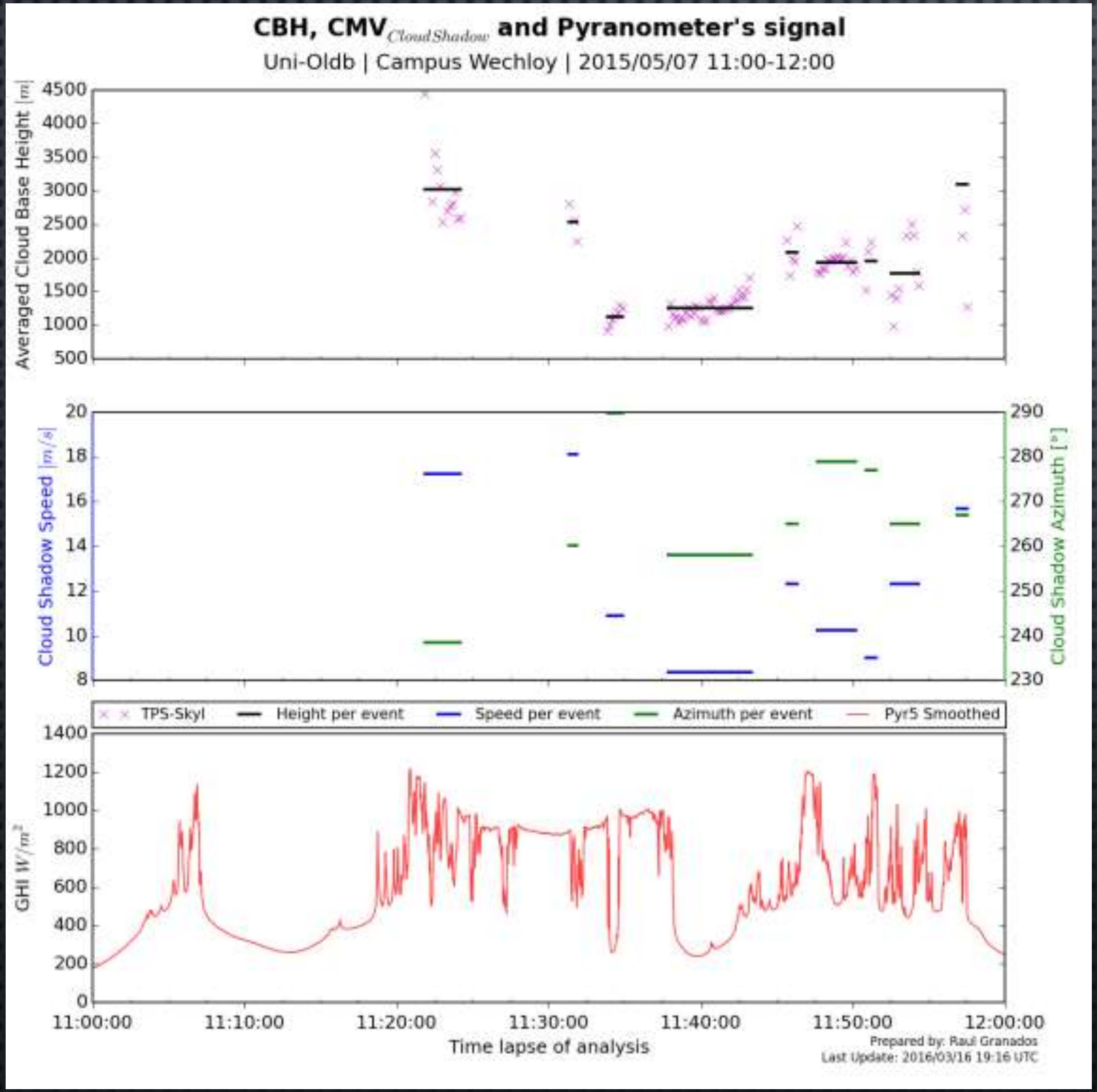
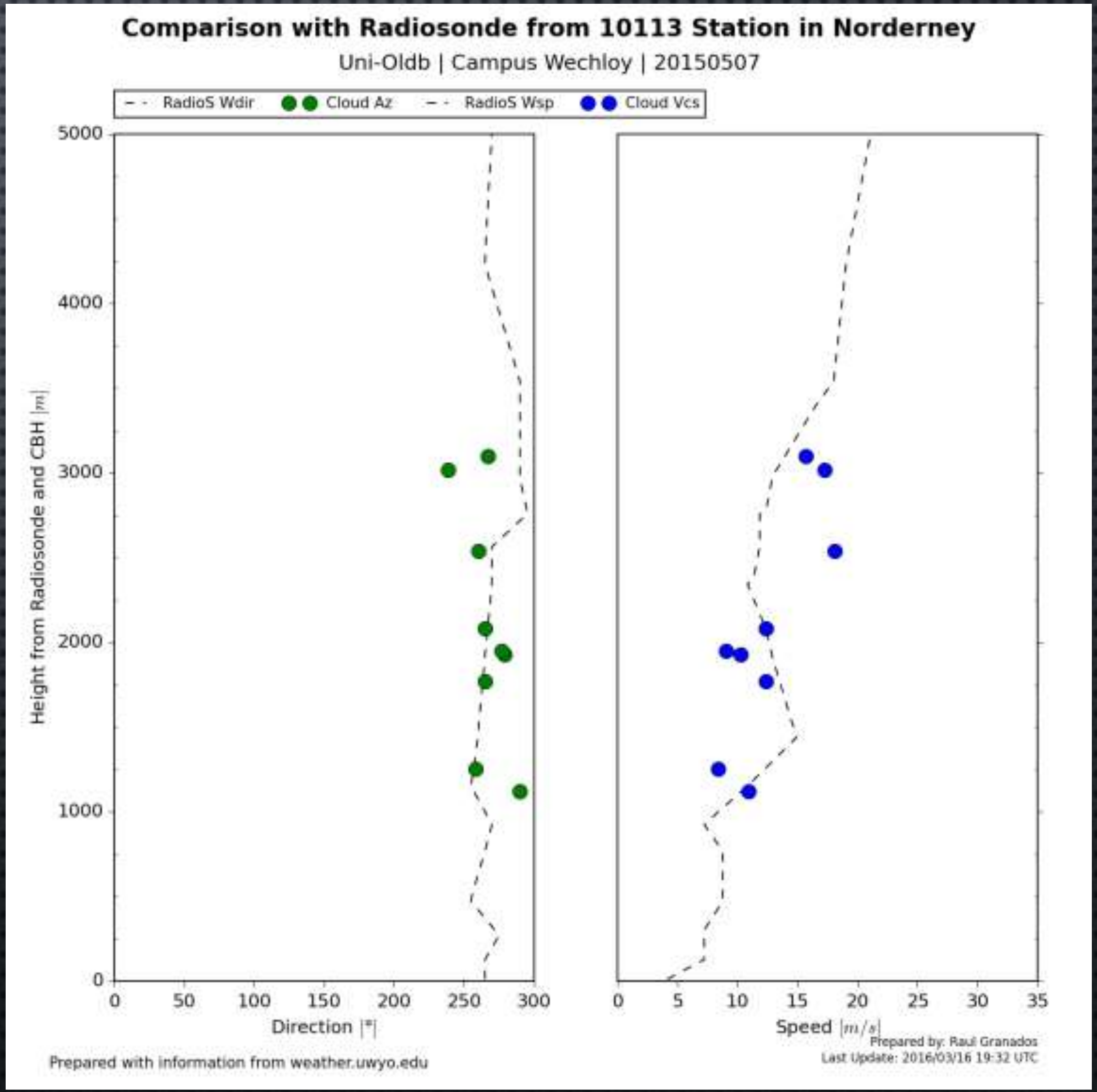
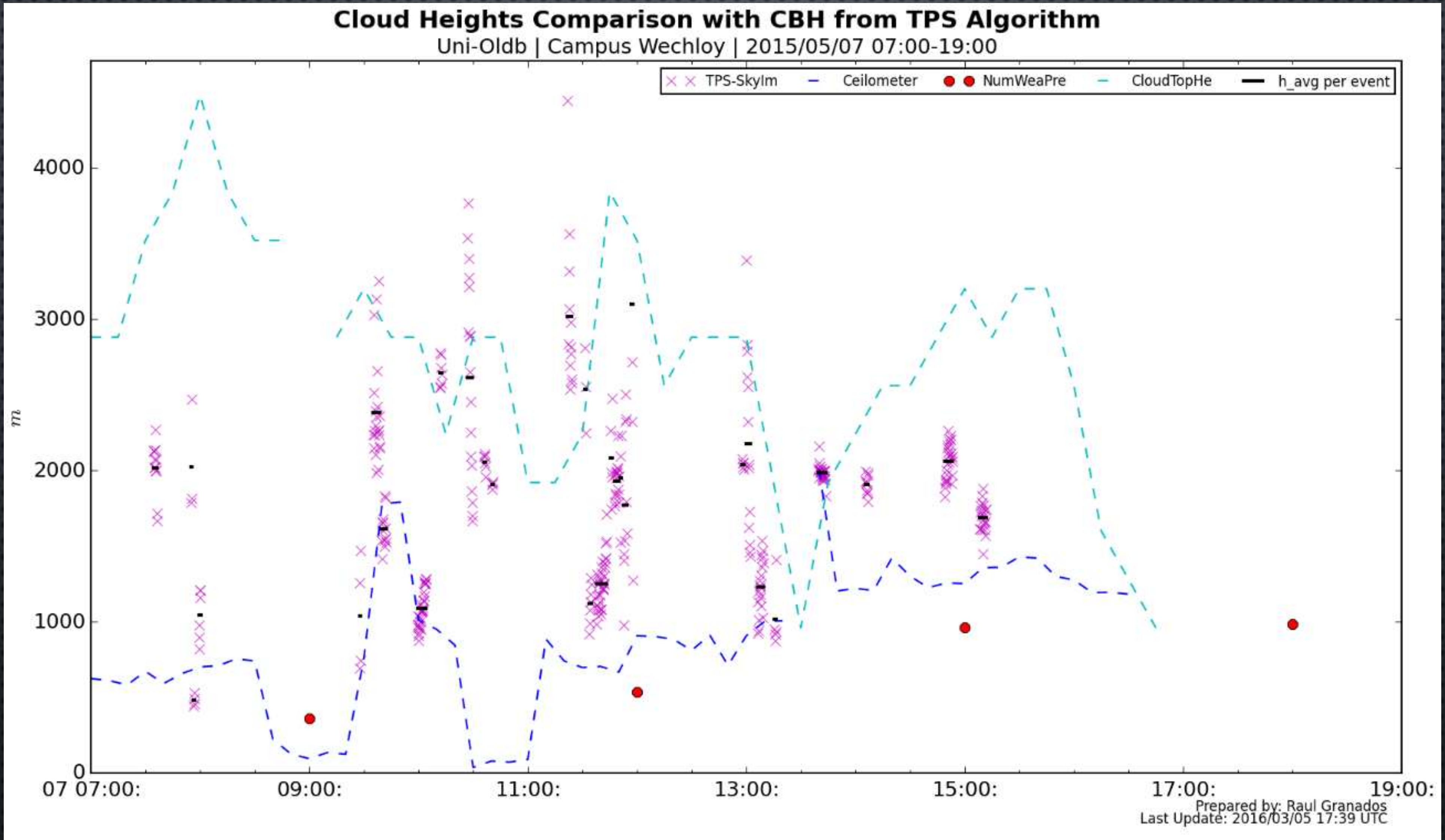
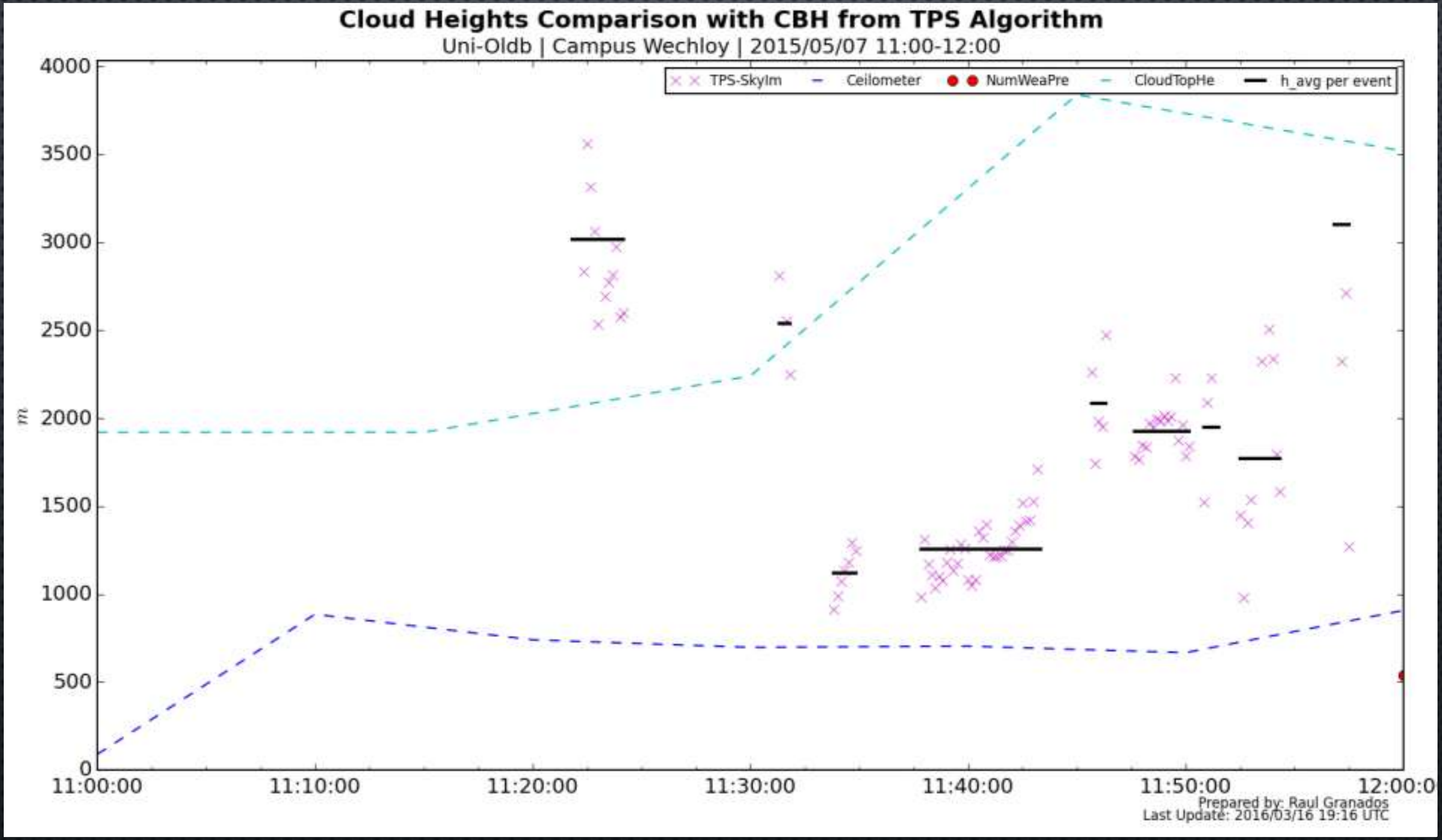




Cloud Base Height with TPS-Sky method



Cloud Base Height with TPS-Sky method



Conclusions

- Method to derive cloud base height by combination of cloud motion vectors
- Pro: Low cost setup
- Contra: Accuracy is sensitive to uncertainties in CMV determination

Outlook

- Long-term evaluation
- Combine CMV from Camera and Satellite
- Comparison with other methods (e.g. Triangulation)

References

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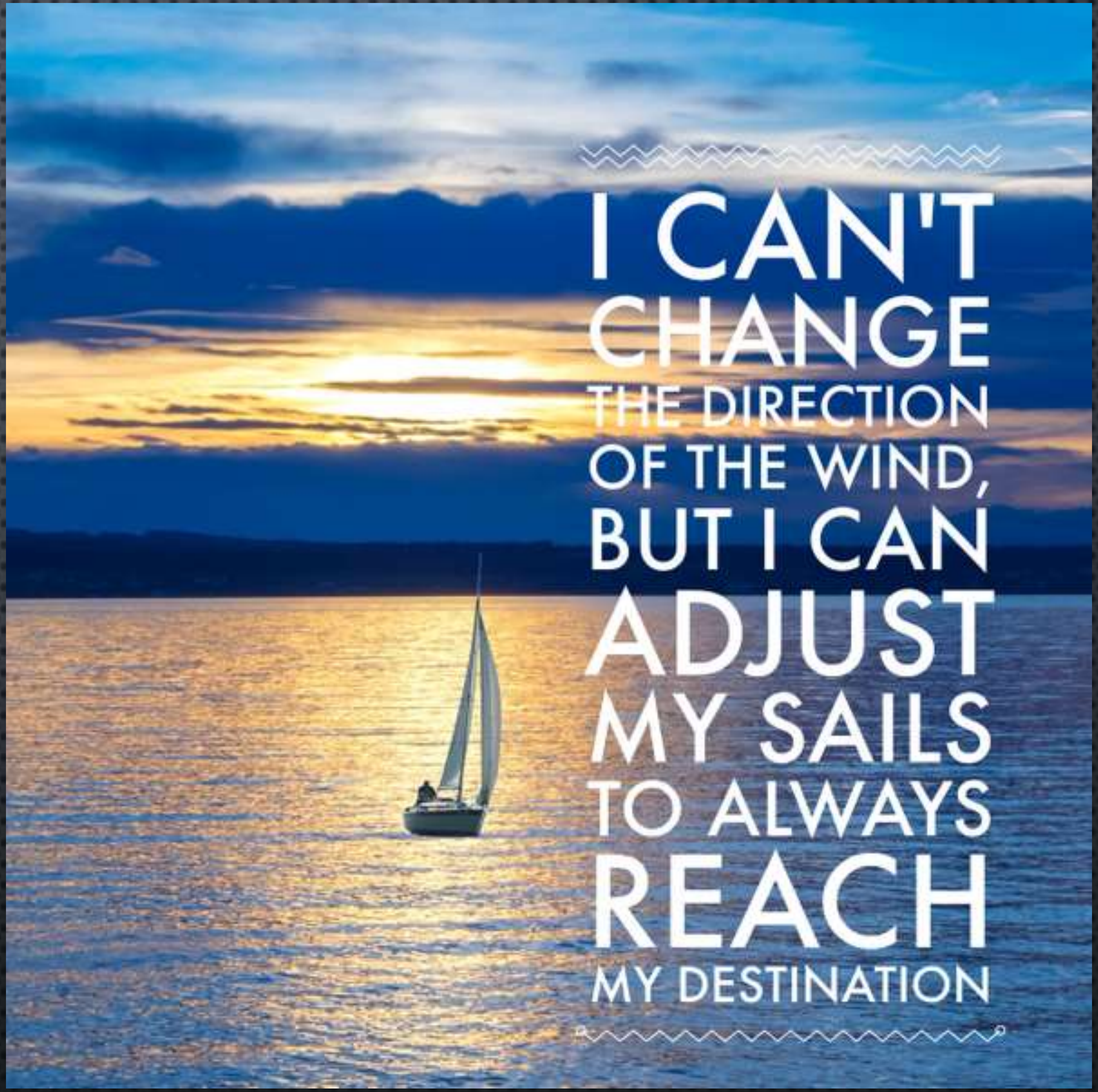
Questions?


I CAN'T
CHANGE
THE DIRECTION
OF THE WIND,
BUT I CAN
ADJUST
MY SAILS
TO ALWAYS
REACH
MY DESTINATION