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
• **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.

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**Gold Goal**

A low-cost technology (implementation + hardware) for areal irradiance forecast
• Why is relevant to know the height?

Cloud Base Height
**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)*

\[
\alpha = \arctan \left[ \frac{t_{OE2} - t_{OE1}}{t_{ON2} - t_{ON1}} \right] \\
\nu = \frac{D}{t_{ON2} \cdot \sin \alpha + t_{OE2} \cdot \cos \alpha}
\]
Cloud Motion Vectors from Radiation Signal Measurements

**Im 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)

**Linear Cloud Edge (LCE) Method:**
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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 vector 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…**
  \[ |\vec{u}_{i_2-i_1}| = \frac{h_{ix} \cdot (\tan \theta_{i_2} \cdot \sin \varphi_{i_2} - \tan \theta_{i_1} \cdot \sin \varphi_{i_1})}{\Delta t_{i_2-i_1}} \]

- **… with the CMVs from TPS**
  \[ \vec{V}_{TPS} = \vec{V}_{i_2-i_1} \]

- **Then height can be known:**
  \[ h_{ix} = \frac{|\vec{u}| \cdot \Delta t}{\tan \theta_{i_2} \cdot \sin \varphi_{i_2} - \tan \theta_{i_1} \cdot \sin \varphi_{i_1}} \rightarrow \left[ \frac{m}{s \cdot s} \right] \]

→ 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.
- **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 maxima)
  - 29 Events with congruent and accepted accuracy
    - \( V \leq 50 \text{ m/s} \)
    - \( \text{AZ} \pm 30^\circ \text{ daily average} \)
  - 2 Events have AZ at 180° difference
    - (65° and 82°)
  - 6 Events with unreal speed
    - (from 68.9 m/s until 703 m/s)
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)
Comparison with Radiosonde from 10113 Station in Norderney
Uni-Oldb | Campus Wechloy | 20150507

CBH, CMV, Total Shadow and Pyranometer’s signal
Uni-Oldb | Campus Wechloy | 2015/05/07 07:00-19:00

Prepared with information from weather.uwyo.edu
Prepared by Paul Granato
Last Update: 2016/05/05 13:59 UTC

Prepared by Paul Granato
Last Update: 2016/04/30 20:01 UTC
CBH, CMV (Cloud Motion Vector) and Pyranometer's signal
Uni-Oldb | Campus Wechloy | 2015/05/07 11:00-12:00

Comparison with Radiosonde from 10113 Station in Norderney
Uni-Oldb | Campus Wechloy | 2015/05/07

Prepared by: Paul Granade
Last Update: 2014/03/19 19:32 UTC

Prepared with information from weather.unyko.edu
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)


• V. Fung, J. L. Bosch, S. W. Roberts and J. Kleissl, Cloud shadow speed sensor, La Joya, California: Copernicus Publications on behalf of the European Geosciences Union in cooperation with University of California, San Diego, 2014.

• N. Killius, C. Prahl, N. Hanrieder, S. Wilbert and M. Schroedter-Homscheidt, "On the use of NWP for Cloud Base Height Estimation in Cloud Camera-Based Solar Irradiance Nowcasting," DLR German Remote Sensing Data Center (Germany) and DLR Institute of Solar Research (Spain), Oberpfaffenhofen, Germany, 2015.


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