Benchmarking cloud height and cloud motion measurements

Pascal Kuhn, Pascal.Kuhn@dlr.de


European Conference for Applied Meteorology and Climatology 2017, 6-Sept-2018

OSA 2.4

Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

Knowledge for Tomorrow
Overview

1. Relevance of cloud height and cloud motion vector measurements
2. Benchmarking five cloud height measurement systems
3. Development and application of a novel cloud motion vector reference
4. Conclusion and future work
On the relevance of cloud motion vector measurements

Cloud motion vectors are important for forecasts and site evaluations

Cloud motion vectors are relevant for
- Solar forecasts
- Solar site assessments
  (expected max. ramp rates)
- Wind profiles at cloud heights
- Model inputs / reference measurements

Reference cloud motion vectors could be used to validate
- NWP products
- Satellite-derived cloud motion vectors
- All-sky imager derived cloud motion vectors
- Cloud motion vectors derived by radiometer networks

Cheap, low-maintenance, high-quality, long-term
ground-based reference cloud motion vectors were previously not available.
On the relevance of cloud height measurements

Cloud height measurements are important for various applications

Reliable cloud height measurements are relevant for
- Solar forecasting
- Non-instrument rated flight operations
- Variety of leisure activities
- Model inputs / reference measurements

Approaches to derive cloud heights:
- Ceilometer / LIDAR
- Radar
- Model-based (NWP)
- Satellite-based
- All-sky imager based
- ...

What is the best approach to measure cloud heights?

Report: Scottsdale attorney who died in plane crash not certified to fly in bad weather

[Link to report](https://goo.gl/9Hnc9e)
**Benchmarking five cloud height measurement systems**

Brief presentation of the considered approaches

1. Combination of one all-sky imager and a Cloud Shadow Speed Sensor
   - Adaptation from Wang et al., [https://doi.org/10.1016/j.solener.2016.02.027](https://doi.org/10.1016/j.solener.2016.02.027)
2. Differential approach combining one all-sky imager and a shadow camera
3. Differential two all-sky imager approach
   - These approaches also provide cloud motion vector measurements

4. NWP cloud heights: Integrated Forecast System, ECMWF (3h data)
5. Ceilometer: CHM 15k NIMBUS, G. Lufft Mess- und Regeltechnik GmbH
Ground-based cloud height measurement systems

Cloud heights are derived from cloud speeds in [rad/s] and [m/s]

Cloud height can be derived if $v_{\text{rad/s}}$ and $v_{\text{m/s}}$ are known

\[ h = v_{\text{m/s}} \cdot \frac{(t_2 - t_1)}{\cot(\beta_1) - \cot(\beta_2)} \]

\[ \sim \frac{x}{v_{\text{rad/s}}} \]
Deriving $v_{\text{rad}/s}$ without detecting clouds

Cloud detection is a difficult task and an origin of deviations

- Detecting clouds within all-sky images is surprisingly difficult

- Novel approach is independent from detecting clouds

- Difference images of the blue color channel are used

- More robust against dirt

We have the angular velocity – how do we get the absolute velocity [m/s]?
Cloud shadow speed sensor (CSS)
Detecting cloud shadow speeds by measuring signal ramps

(Simplified case)

In this example:

\[ \Delta t_r \approx \frac{r}{v} \]

Shadow camera system (SC)
Detecting cloud shadow speeds by imaging an area

Off-the-shelf surveillance camera

Shadow camera image (4 per minute)

Orthoimage (5m per pixel)
Obtaining cloud motion vectors with a shadow camera

Determination of motion vectors is independent from segmentation

\[ t = 0 \text{ s} \]

\[ t = -15 \text{ s} \]

\[ t = -30 \text{ s} \]

\[ \Delta x \]

Shadow speed \( v_{m/s} = \frac{\Delta x \times k}{\Delta t} \) meter/pixel

- Low cost sensor
- Little maintenance is needed
- Aperture problem is less relevant
Using two all-sky imagers (ASI)
Measuring cloud speeds by matching difference images

• Two all-sky imagers are used
• Difference images are calculated as shown for $v_{rad/s}$

Matching via cross-correlation: $v_m/s$ is determined by the known distance between the cameras

• No cloud detection needed - more resilient against dirt, more hardware-independent
Benchmarking five cloud height measurement systems

Results of the benchmarking campaign

- Benchmarking campaign on 59 days
- Benchmarking site:
  Plataforma Solar de Almería, Spain
- Validation period contains large variety of cloud heights
- Multilayer cloud situations are included
- All considered systems provide one cloud height
  - For the ASI-ASI-approach, individual cloud heights can be derived
  - Systematic differences between point-like ceilometer cloud base heights and cloud heights derived by developed systems

This study is published in Kuhn et al., *Benchmarking three low-cost, low-maintenance cloud height measurement systems and ECMWF cloud heights against a ceilometer*, Solar Energy, 2018, [https://doi.org/10.1016/j.solener.2018.02.050](https://doi.org/10.1016/j.solener.2018.02.050)
Benchmarking five cloud height measurement systems
Results of the benchmarking campaign

This study is published in Kuhn et al., Benchmarking three low-cost, low-maintenance cloud height measurement systems and ECMWF cloud heights against a ceilometer, Solar Energy, 2018, https://doi.org/10.1016/j.solener.2018.02.050
Development and application of the novel cloud motion vector reference on 59 days

- Validation of the Cloud Shadow Speed Sensor:
  - MAD: 1.6 m/s (21.9 %) w/o temp. avg.
  - MAD: 30.4° (16.8 %) w/o temp. avg.
  - Detection rate on 223 days: 3.7 % - 21.6 %
  - Aperture problem
- Data availability of the shadow camera reference system:
  - Years, 2015-2017
  - Currently looking for new setup, imaging a larger area
- Validation of all-sky imager derived cloud speeds conducted, publication in review

Conclusion and further work

- Three low-cost, low-maintenance systems to derive cloud motion vectors and cloud heights are developed and benchmarked to ECMWF and ceilometer data on 59 days.
- A system consisting of two all-sky imagers shows the best accuracy in comparison to a ceilometer.
- A novel method to derive reference cloud motion vectors was developed and applied to a Cloud Shadow Speed Sensor.
- Cloud motion vectors can be derived and used as a reference for ground-based sensors, satellite-based products and NWP models.
- Study on optimal distance between all-sky imagers finalized.
- Future work: Camera-derived cloud heights for aviation.

Pascal Kuhn
Pascal.Kuhn@dlr.de

Thank you! Questions?
Thank you!

Questions?

Pascal.Kuhn@dlr.de