The Role of 1D and 3D Radiative Heating on the Organization of Shallow Cumulus Convection and the Formation of Cloud Streets[1]

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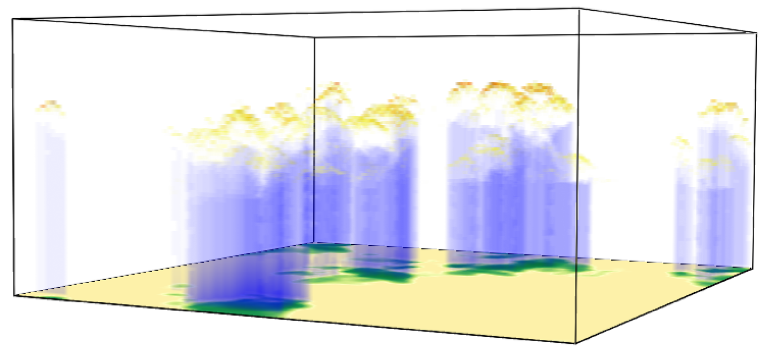
HD(CP)² High definition clouds and precipitation for advancing climate prediction

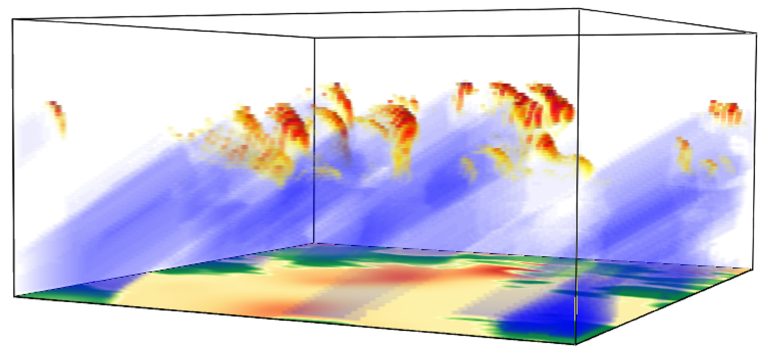
Convective Organization Depends on Radiative Transfer Solver

1D Radiative Transfer



- 1D δ-eddington two-stream solver
- each vertical column is solved independently from each other (Independent Column Approximation, ICA)
- neglects horizontal energy transfer
- shadow is therefore directly beneath cloud

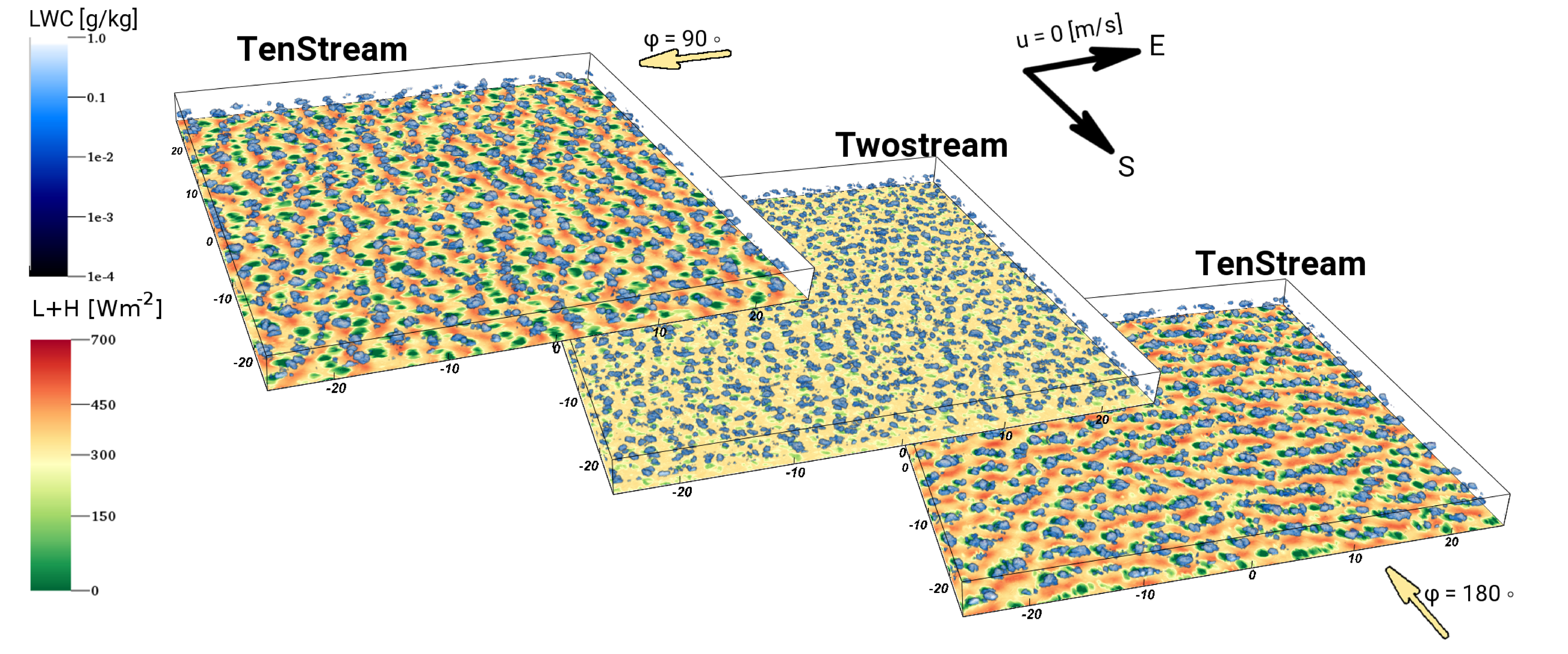
3D Radiative Transfer



- 3D TenStream solver [4, 5]
- coupling to neighboring boxes allows for horizontal energy transfer
- allows for cloud-side illumination
- slanted solar incidence leads to displaced surface shadow

Virtual photographs of UCLA-LES simulations, as seen from a cruising altitude of 15 km. The cloud simulations either use 3D or 1D Radiative-Transfer calculations and show differences with respect to cloud size distribution and the organization in cloud streets, the cloud fraction though remains the same (27 %).
Both visualizations are performed with MYSTIC (physically correct MonteCarlo renderer in libRadtran [6, 7]).

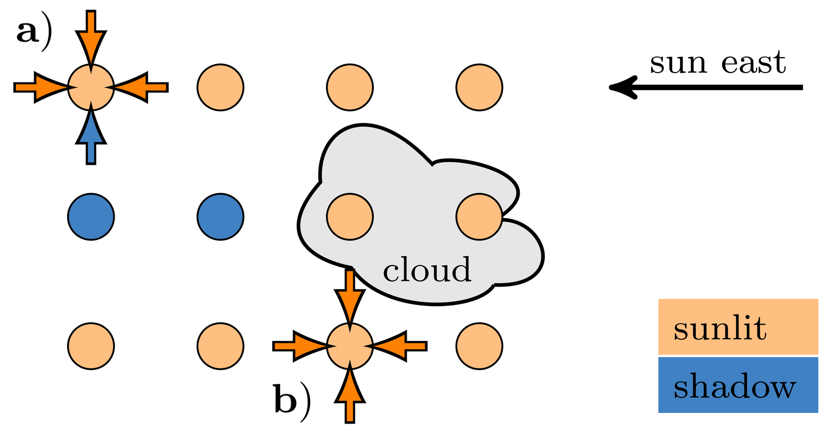
Orientation of Cloud Streets Depends on Solar Azimuth φ



Volume rendered perspective on LiquidWaterContent (LWC) and latent and sensible heat flux (L,H) for two 3D simulations with Eastern and Southern sun. Cloud-Streets form perpendicular to the sun's incident angle.

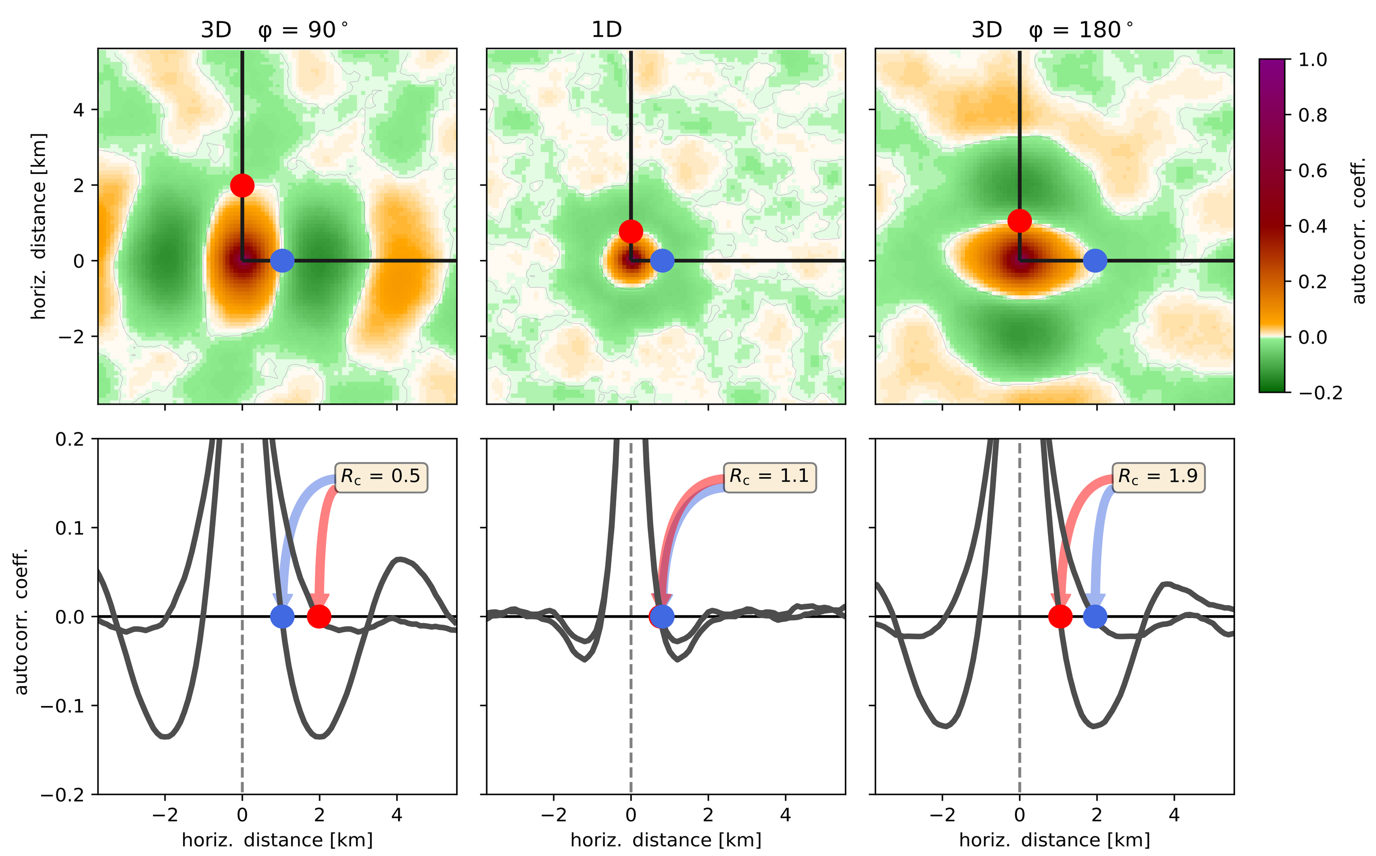
- solar zenith $\theta = 60°$
- solar azimuth $\varphi = 90°$ (East); 180° (South)
- horizontal wind $u = 0\,\mathrm{m\,s^{-1}}$
- surface: $C_{\mathrm{skin}} = 1$ cm water column

Hypothesis for Mechanism



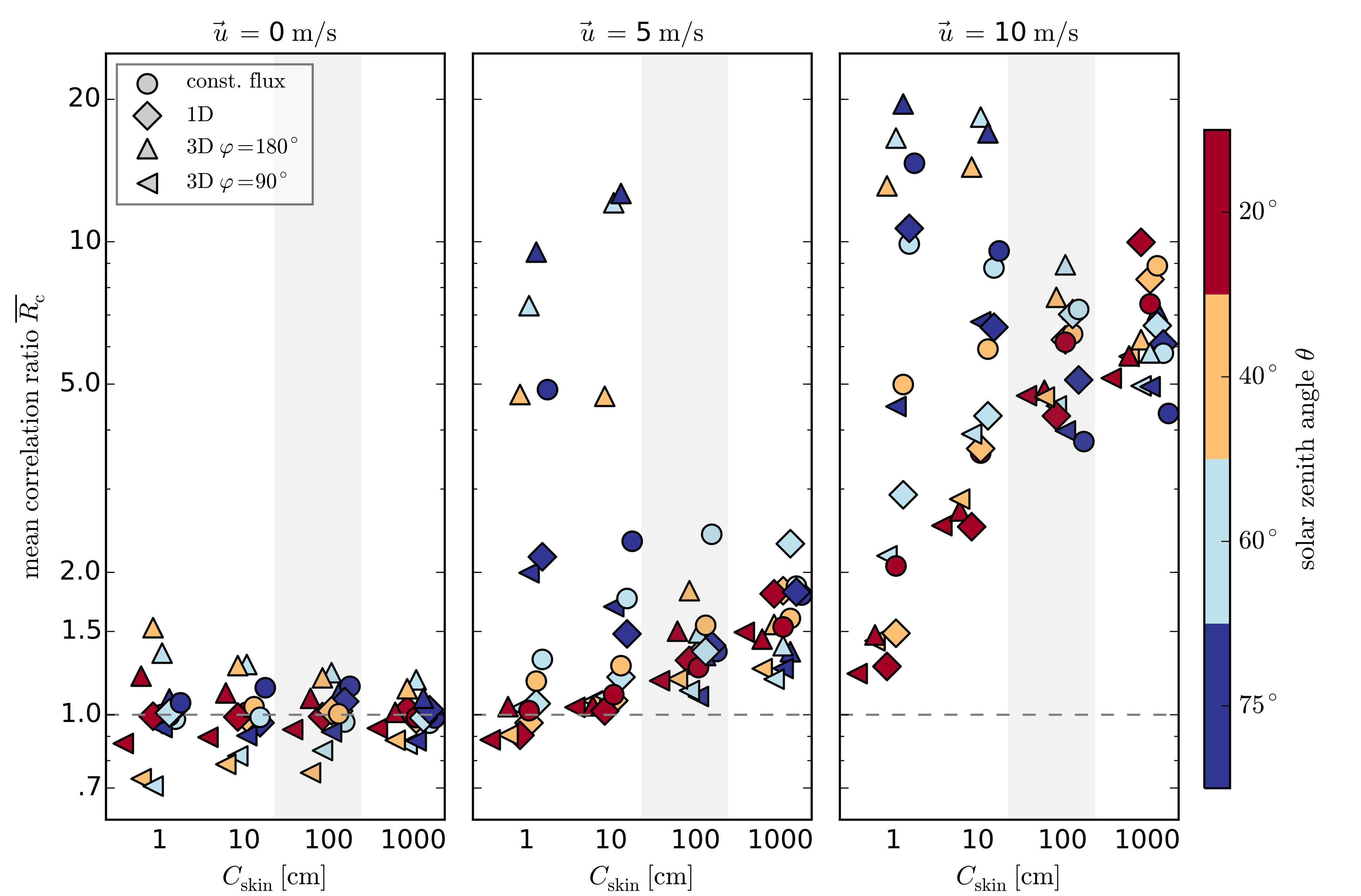
A convective plume is fueled by moist and warm air from adjacent pixels and is thus more likely to rise near sun-lit areas (b) compared to areas in the vicinity of shadows (a). This favors the organization of new clouds perpendicular to the solar incidence angle.

A Quantitative Measure for Streakiness



- Use 2D autocorrelation field of cloud-mask
- Search for zeroes along North-South and East-West transects
- Ratio of distances measures the degree of organization:
  - $R_c < 1$: North-South
  - $R_c \approx 1$: random
  - $R_c > 1$: East-West

Parameter Study to Determine Interactions



- Purely radiatively forced simulations (no wind) shows convective organization of clouds perpendicular to the solar incident
- Clouds don't organize in simulations with the sun near zenith (quasi 1D)
- Ocean-like surfaces diminish the radiative influence ($C_{\mathrm{skin}} > 100$ cm)
- Wind induced cloud streets may be enhanced or even suppressed through radiative feedback (dynamic surface heterogeneities)

References

[1] F. Jakub and B. Mayer. "The Role of 1D and 3D Radiative Heating on the Organization of Shallow Cumulus Convection and the Formation of Cloud Streets" ACP (2017).

[2] C. Klinger et. al. "Effects of 3D Thermal Radiation on Cloud Development" ACP (2017).

[3] F. Jakub, "On the Impact of Three Dimensional Radiative Transfer on Cloud Evolution" LMU (2016).

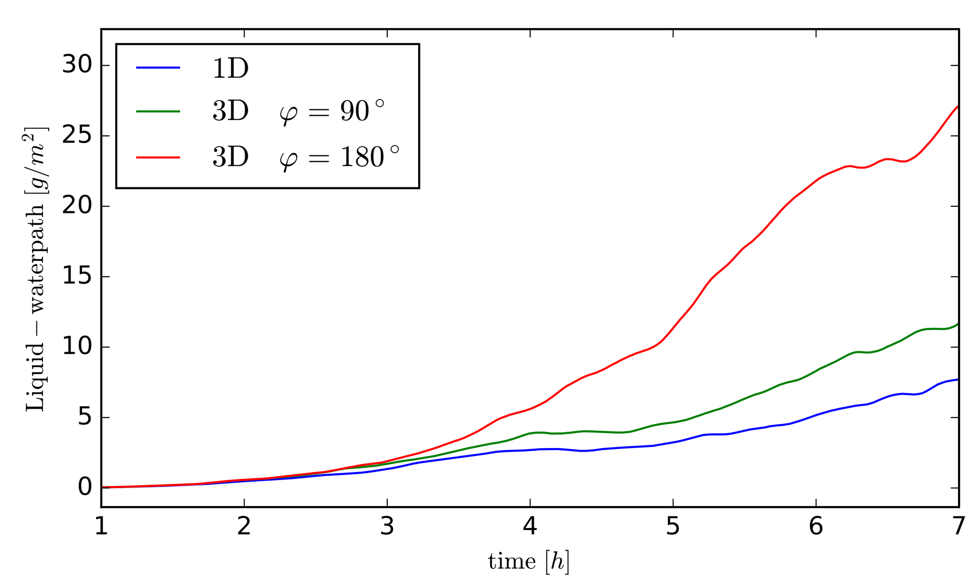
[4] F. Jakub and B. Mayer. "A Three-Dimensional Parallel Radiative Transfer Model for Atmospheric Heating Rates for use in Cloud Resolving Models–the TenStream solver." JQSRT (2015).

[5] F. Jakub and B. Mayer. "3D Radiative Transfer in Large-Eddy Simulations – Experiences coupling the TenStream solver to the UCLA–LES" GMD (2016).

[6] C. Emde et. al. "The libRadtran Software Package for Radiative Transfer Calculations" GMD (2015).

[7] B. Mayer. "Radiative transfer in the cloudy atmosphere." EPJ (2009).

Evolution of Simulations depends on Sun Azimuth



Timeseries of mean liquid water path:

- solar zenith $\theta = 60°$
- solar azimuth $\varphi = 90°$ (East), i.e. along the mean wind
- or 180° (South), i.e. perpendicular to the wind
- horizontal wind $u = 10\,\mathrm{m\,s^{-1}}$

→ Angle between solar incidence and mean wind direction may change the evolution of simulations considerably on short timescales. The generation of cloud streets happens on timescales of one hour (see [1]).