Recurrence Quantification Analysis of temperature time series from marine cumulus clouds during EUREC4A

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Data

EUREC4A [1] campaing conducted in early 2020 was an experiment focused on studying cumulus clouds and coupling between clouds and marine atmospheric boundary layer.



EUREC4A

Ultra Fast Thermometer [2], developed at the University of Warsaw, was mounted on the Twin-Otter aircraft, and gathered data during 7 flights.

Ultra Fast Thermometer

The element of thermometer responsible for sensing is a platinum-coated tungsten wire 2.5 μm in diameter. During the measurements, oversampling was applied in order to achieve 20 kHz frequency. The data was averaged to 2 kHz, which translates to centimeter-scale resolution. It was callibrated using 1 Hz MASIN data.

Ultra Fast Thermometer

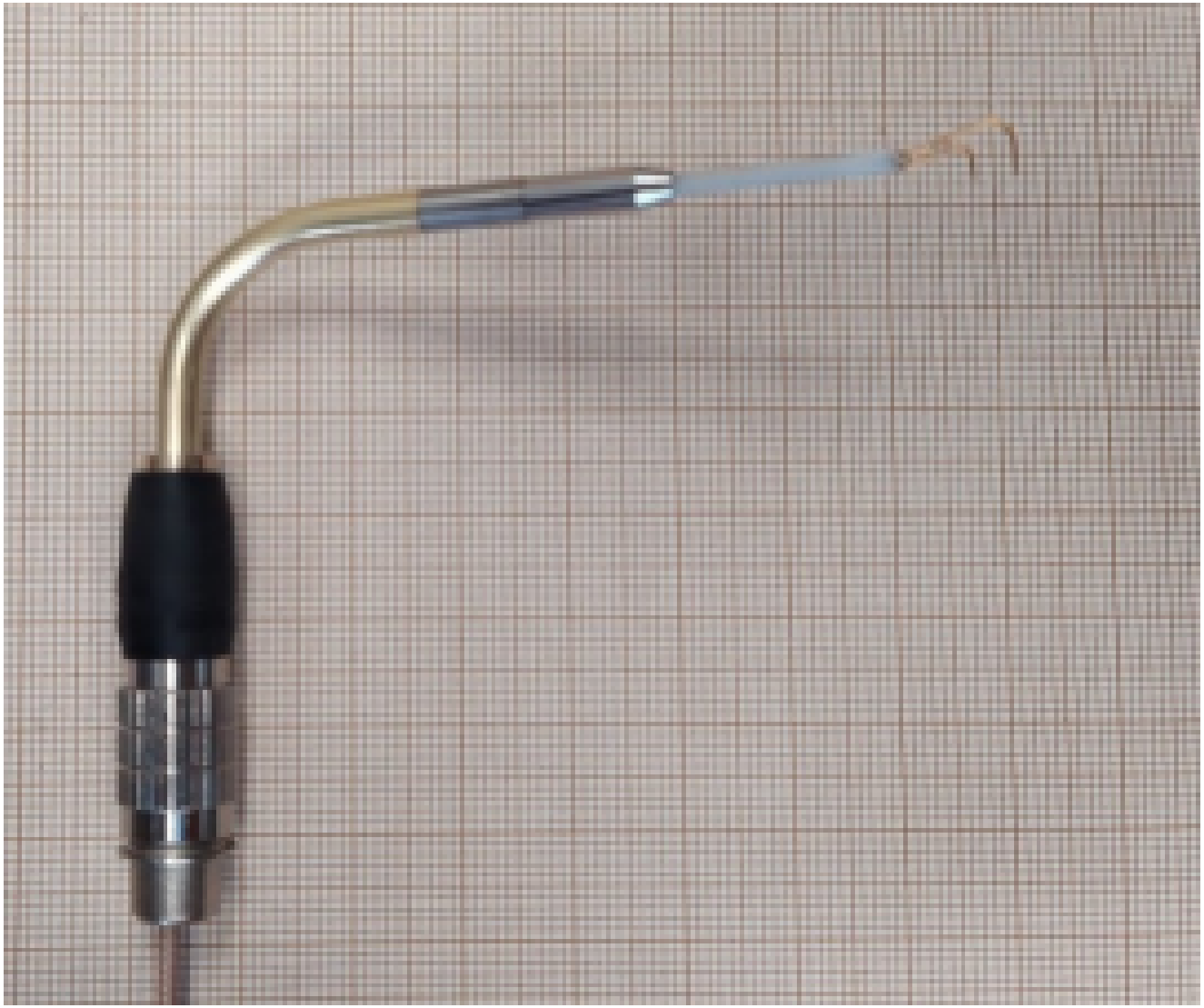


Figure: A photo of UFT2b

Data

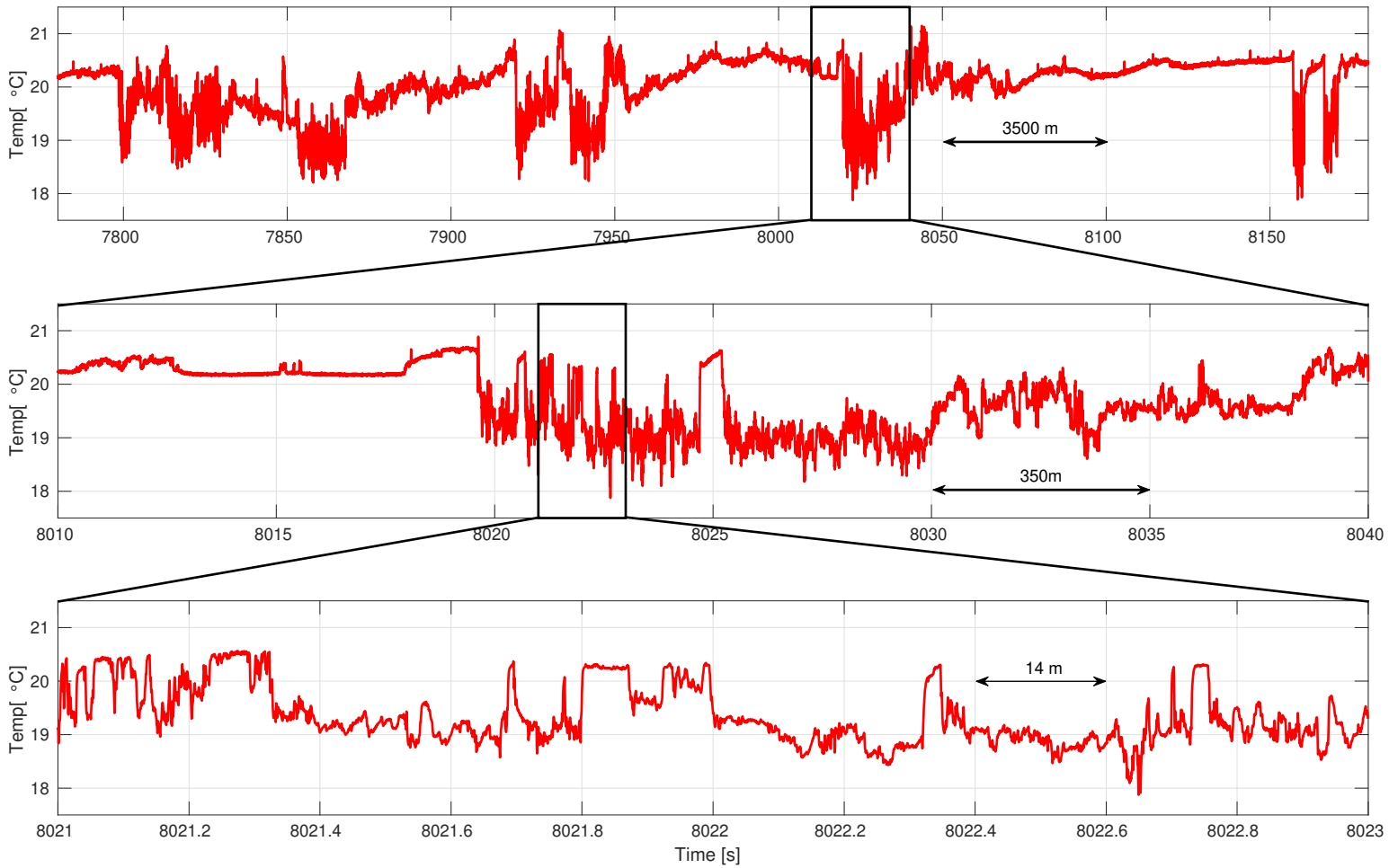


Figure: Sample readings

Data

Using microphysical data as an indicator of cloud presence, segments containing cloud data were extracted. The variables of interest include temperature, wind velocity and plane GPS data.

Hypothesis

We believe that this data contains useful information about turbulent mixing of cloud air. We treat the cloud air as a non-linear dynamical system. We want to connect the notions of chaos and turbulence.

The proposed method of data analysis is Recurrence Plot (RP) method, and Recurrence Quantification Analysis (RQA) [3].

Method

Recurrence is a crucial characteristic of dynamical systems. In the recurrence plot method, we study the recurrencies of vector $\vec{x}$ in a phase space, and construct a matrix R_{ij}:

$$R_{i,j} = \Theta(\epsilon - ||\vec{x}_i - \vec{x}_j||).$$

Where $\Theta(...)$ is the Heavyside function, and indices i and j denote points in time series. Then we draw the plot of the matrix, colouring cells containing 1 - black, and cells containing 0 - white.

Method

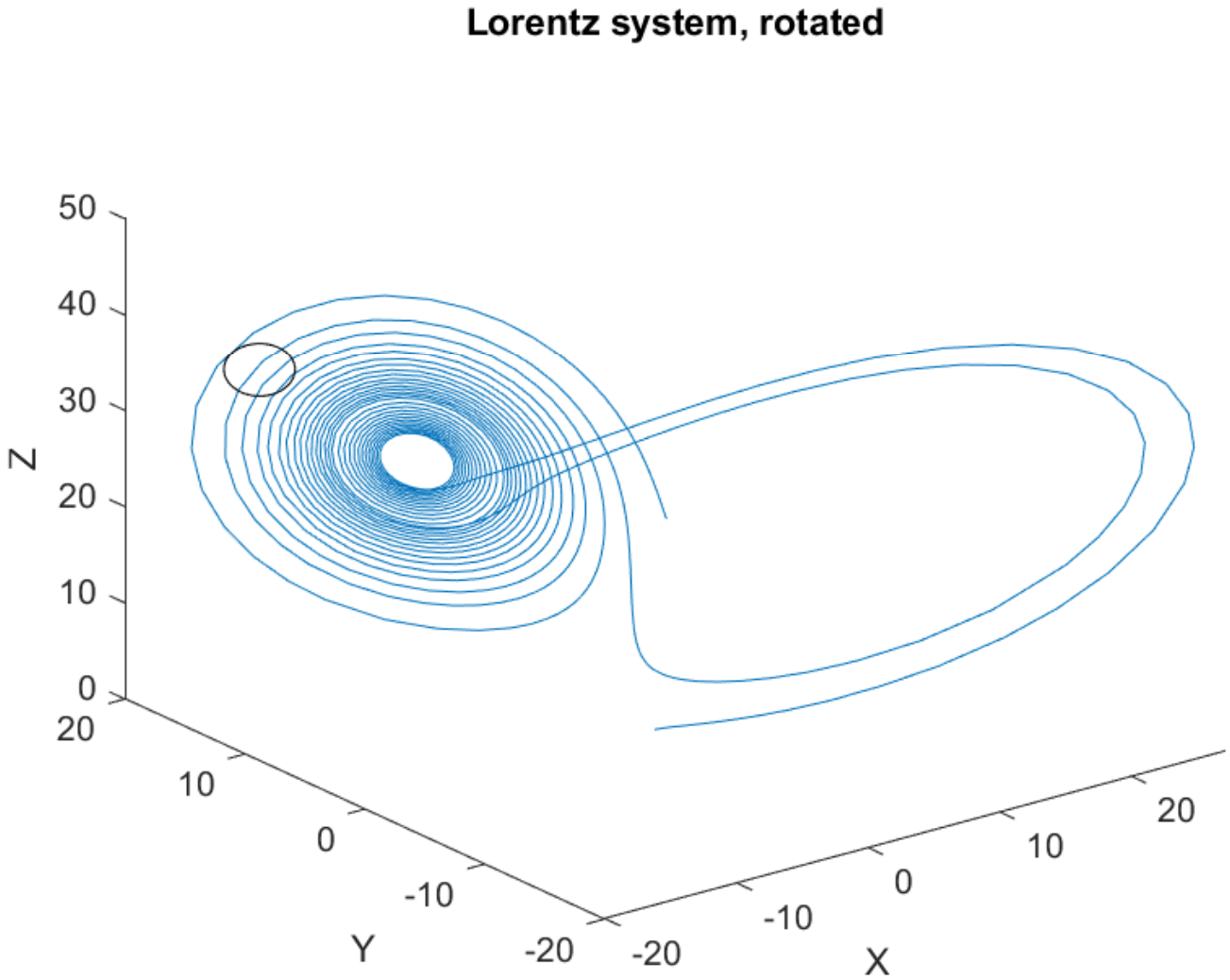


Figure: Lorenz system

Method

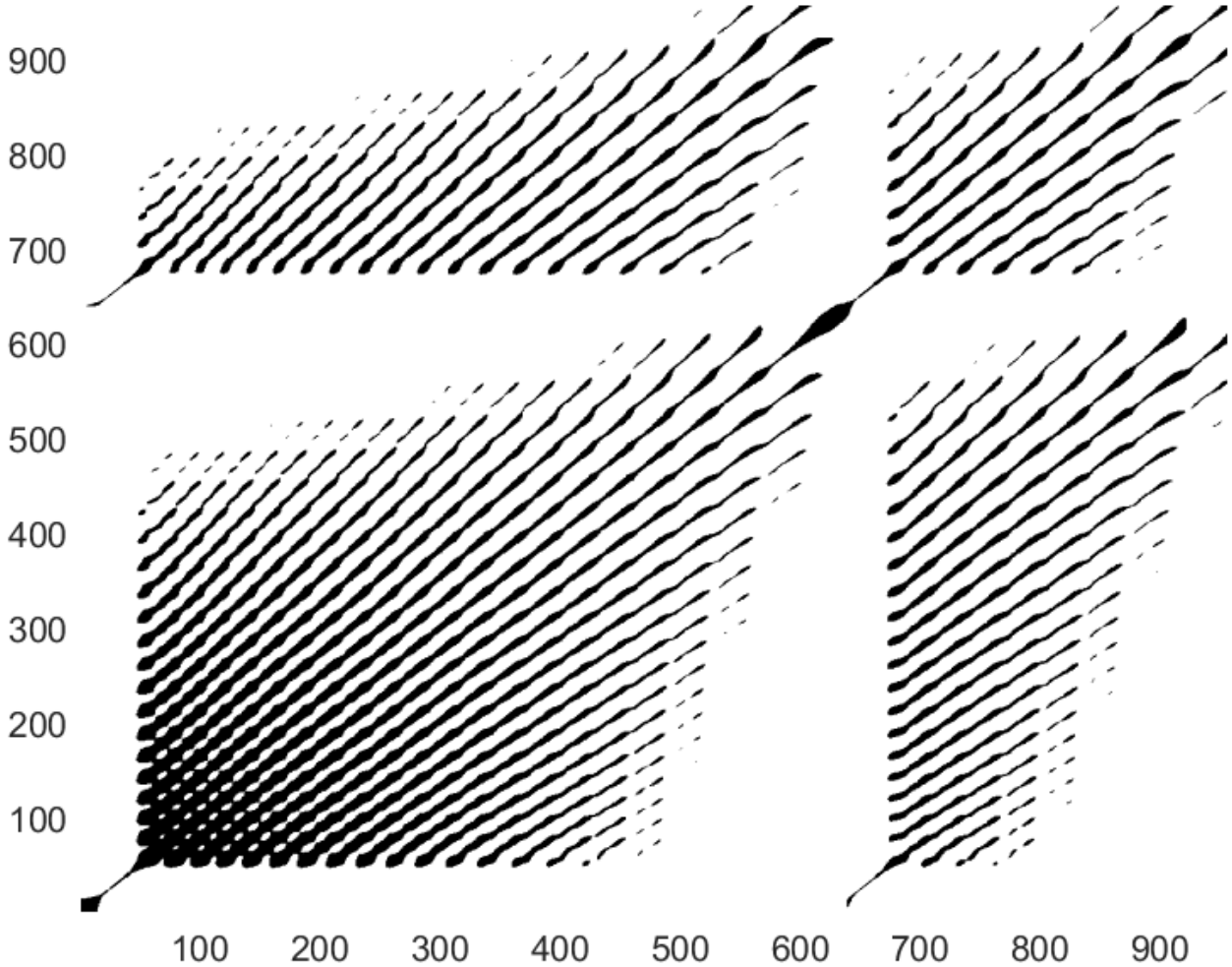


Figure: RP of Lorenz system

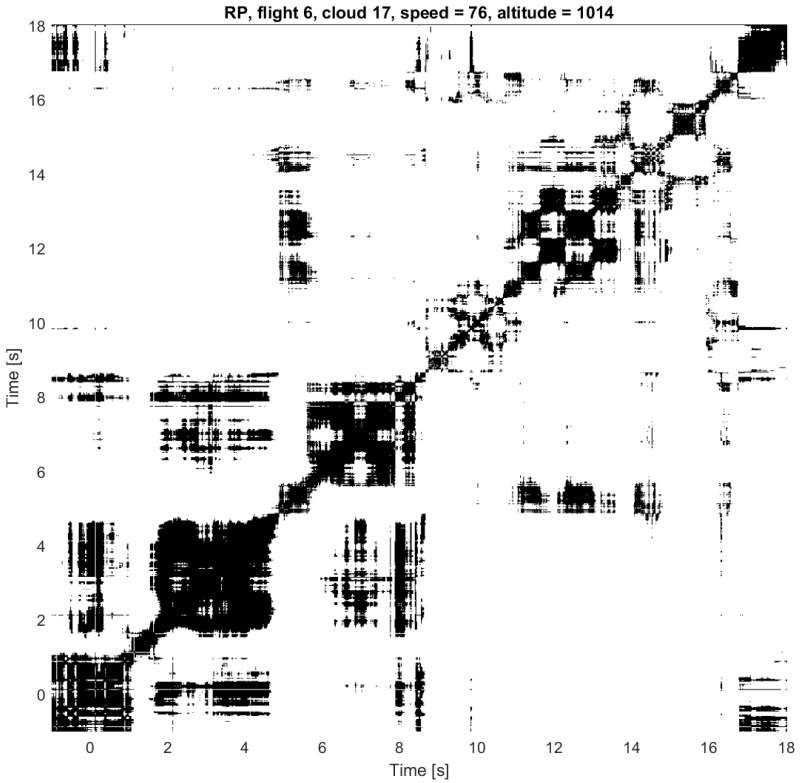
Methodology

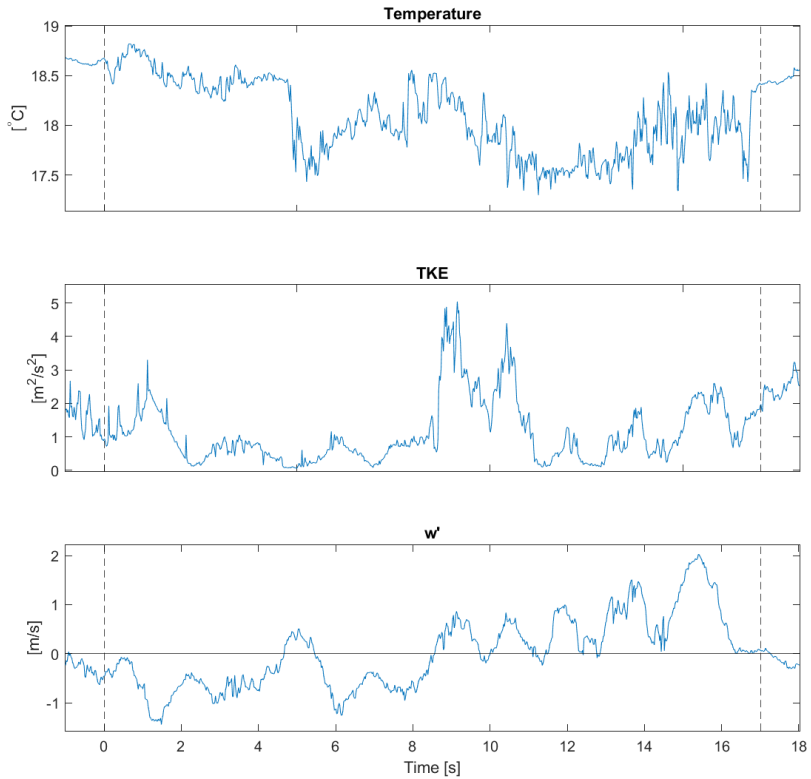
In our case:

$$\vec{x} = [T, k, w'].$$

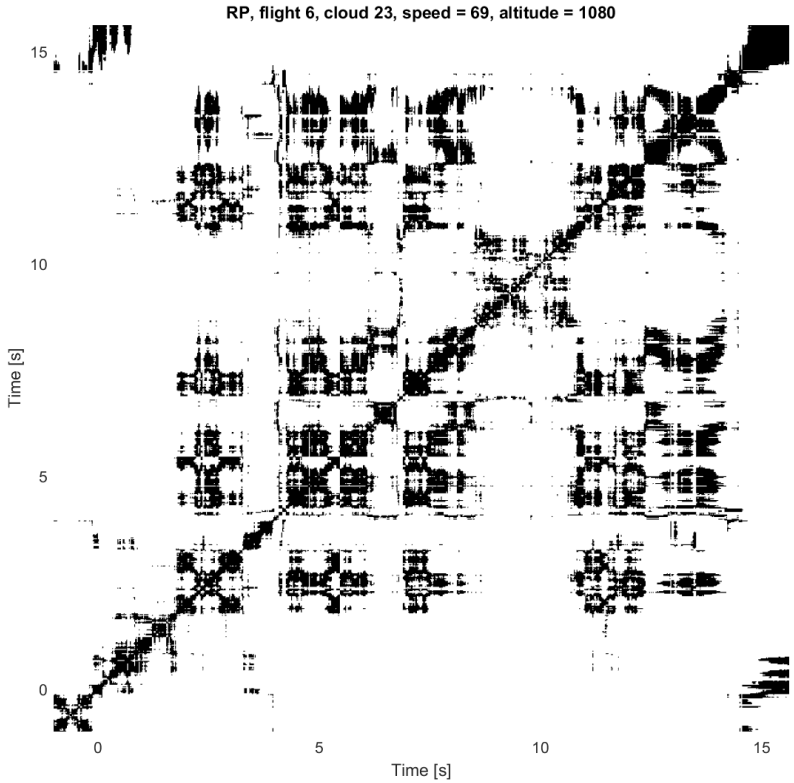
Over 200 cloud events were observed. The cases need to be filtered because of noise, changing altitude and malfunctioning equipment, reducing the number of cases to around 100.

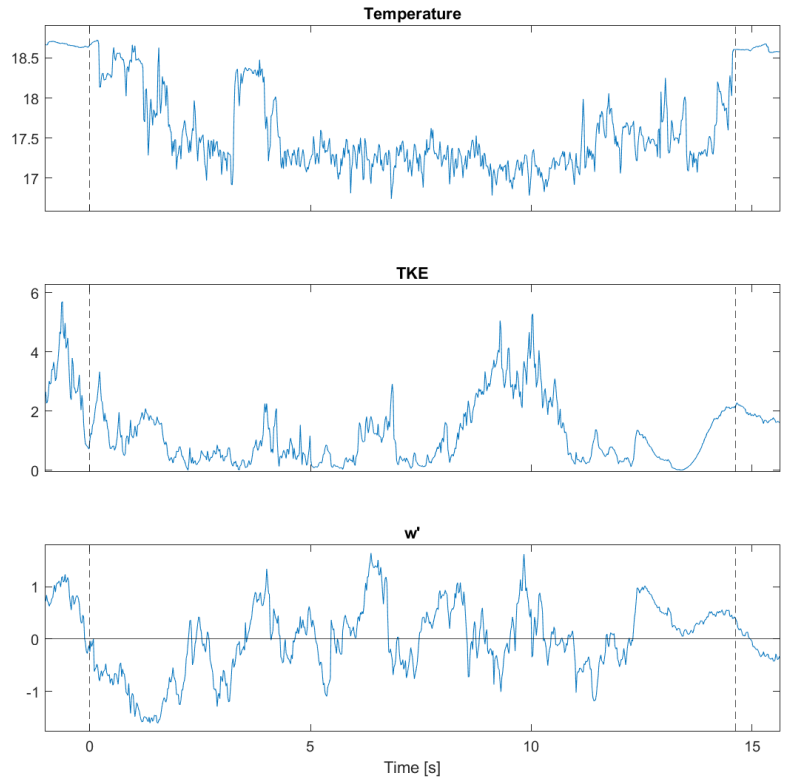
Example results





Example results





Results

First case:

- Leeward
- Less erratic to more erratic
- Two distinct regions of w'
- Disctinct region of increased TKE
- Distinct regions in RP

Second case:

- Side
- Constant erratic behaviour
- Oscilating w'
- Disctinct region of increased TKE
- Fractal-like structure of RP

Results

We want to quantify the structures found in the matrix. We can do this by conducting Recurrence Quantification Analysis (RQA).

Results

Quantities of interest:

1. Determinism (DET)

$$DET = \frac{\sum_{l=l_{min}}^{N} lP(l)}{\sum_{l=1}^{N} lP(l)}$$

2. Average diagonal line length (L)

$$L = \frac{\sum_{l=l_{min}}^{N} lP(l)}{\sum_{l=l_{min}}^{N} P(l)}$$

3. RATIO

$$RATIO = \frac{DET}{\frac{\sum_{i,j=1}^{N} R_{i,j}}{N^2}}$$

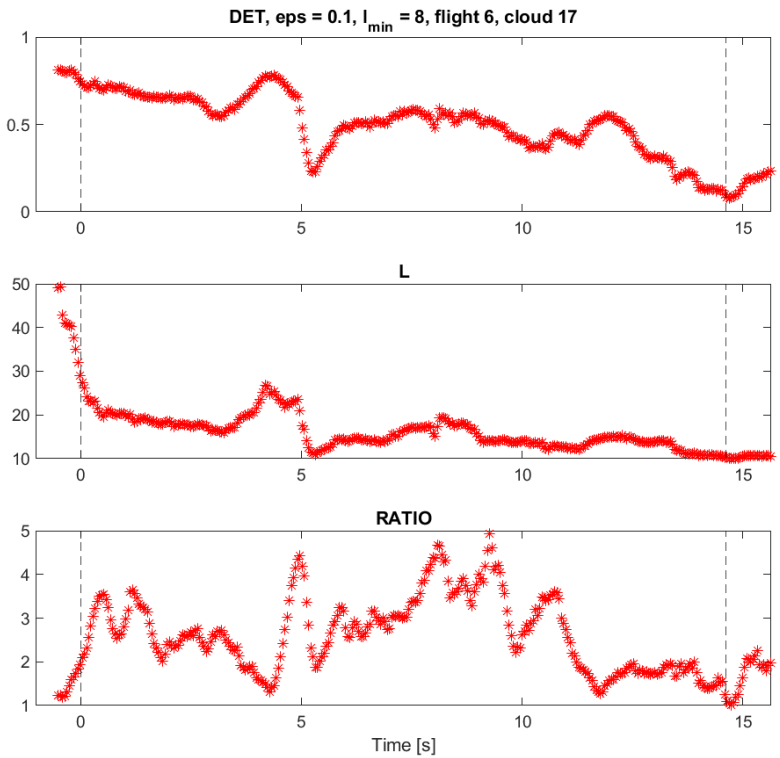
The value l_{min} is chosen using space-time separation plot [3].

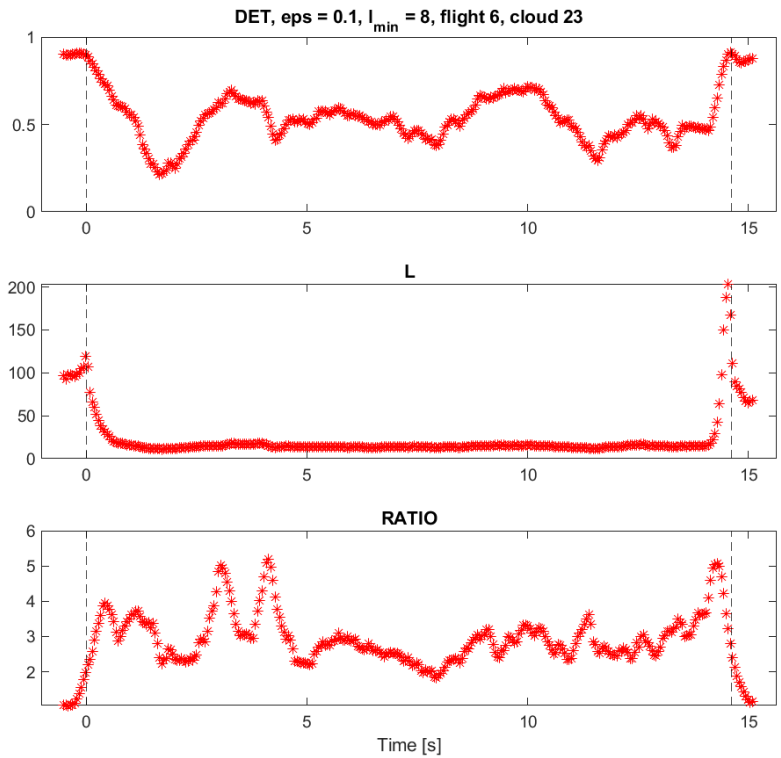
Results

For each 2000 points we create a RP and then perform RQA and then move by an jump and repeat the procedure. Therefore we obtain a time dependence of certain quantities of RQA of temperature time series.

Results

Time-dependent RQA for temperature readings:

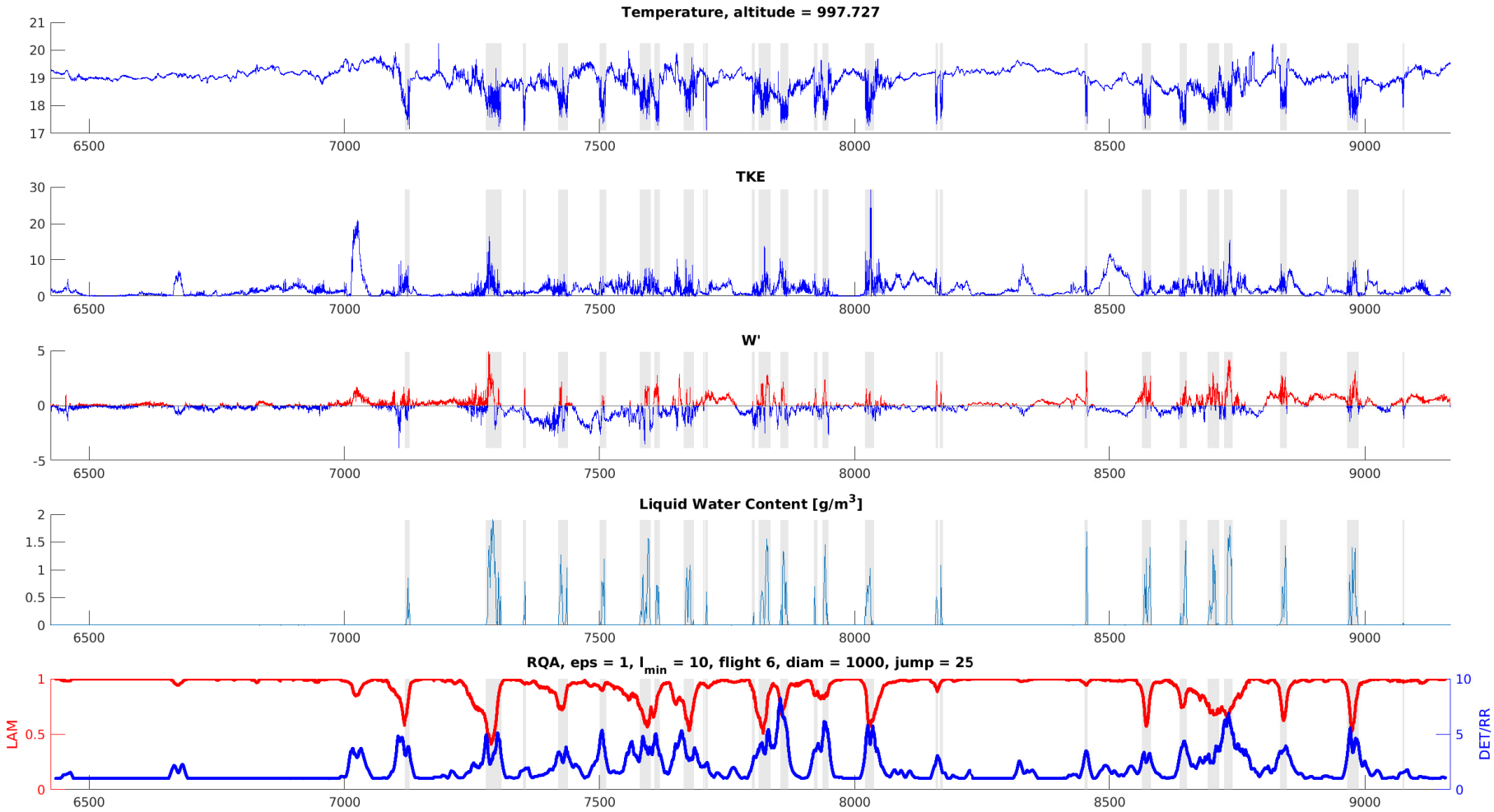




Results

The value DET which is a rough estimate of chaos in the system decreases in the first case, and in the second case remains constant with some oscilations. In the first case this means that the system goes through more ordered state to the less ordered state, and in the second case its state remains relatively constant with some transitions.

Bigger picture



Example results

By selecting a certain threshold, it is possible to distinguish between turbulent and nonturbulent air inside and outside clouds. The quantities of interest are LAM (laminarity) and RATIO (ratio between DET and RR). The latter one is sensitive to changes in the system dynamics.

Acknowledgements

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Bibliography & further reading:

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