# EDDY MATRIX: TESTING ASSUMPTIONS OF SURFACE-ATMOSPHERE EXCHANGE UNDER IDEAL CONDITIONS AT GOBABEB, NAMIBIA


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## Background

Globally, at the earth's surface around 17% of the net radiation $R_n$ achieved from the sun is converted into sensible heat flux H heating the first 1-2 km of air, i.e. the atmospheric boundary layer ABL (Rotty & Mitchell 1974, cited in Oke 1987). In deserts H reaches almost 100% of available energy AE ($R_n$ minus storage related fluxes, mainly soil heat flux G) due to the lack of water for evapotranspiration. In the ABL of the Namib desert the resulting temperature change gives rise to consistent circulation patterns which in turn foster advection of coastal fog supporting the Namib's unique ecosystem.

In August 2012 students of the University Basel (Switzerland) and the Technische Universität Dresden (TUD, Germany) jointly utilised the ideal conditions of large environmental signals in the Namib desert at Gobabeb. The Dresden group of master students in hydrology focussed on a fundamental assumption for the investigation of surface fluxes: the ergodic hypothesis or – in micrometeorology - Taylor's hypothesis. Here, this hypothesis is explicitly tested by comparing a standard one tower with an areal ensemble measurement.

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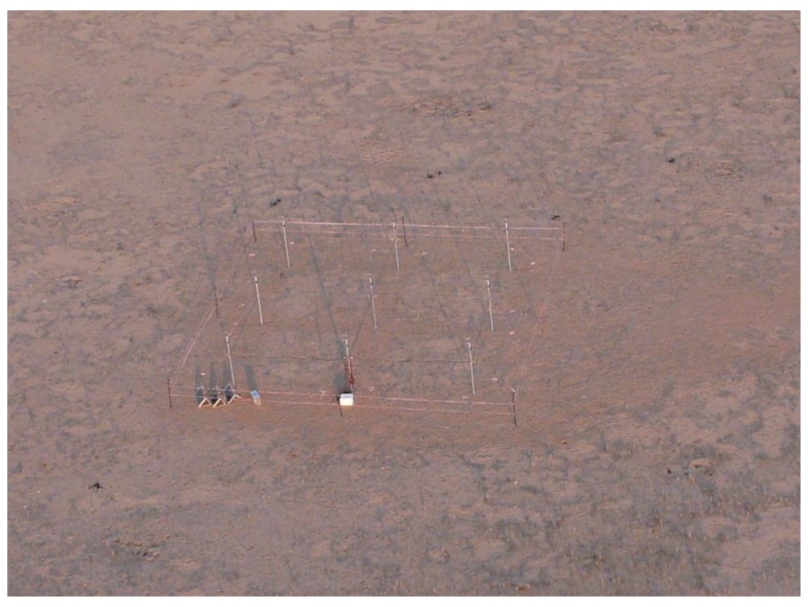
## Taylor's hypothesis and the eddy covariance method

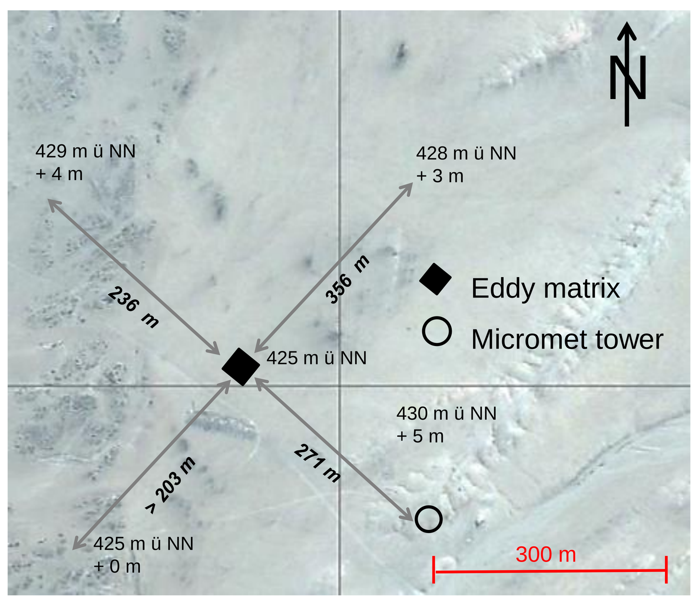
*Often ecologists and statisticians criticize micrometeorologists for employing only one tower. They claim that a measurement with one tower does not allow the experimenter to measure the ensemble average.* Instead the *micrometeorologist invokes the Principle of Ergodicity, where space-based ensemble averages can be substituted with temporal averaging.* This is equivalent to *Taylor's frozen eddy hypothesis to assess the ensemble average on the basis that distance is wind velocity times time, x = u t* (from D. Baldocchi at http://nature.berkeley.edu/biometlab).

The most versatile and popular method to measure surface fluxes with one tower is the eddy covariance or EC method. This involves the measurement of fluctuations of vertical wind speed w' and the co-located fluctuations of a concentration (of e.g. a trace gas c') to derive the vertical flux, here of the trace gas, and the averaging by building the covariance of the two for about 30 min (10 to 60 min). In case of the classical sensible heat flux $H_c$, this concerns w' and fluctuations of potential temperature θ'.

## An aerial set-up to test Taylor's hypothesis

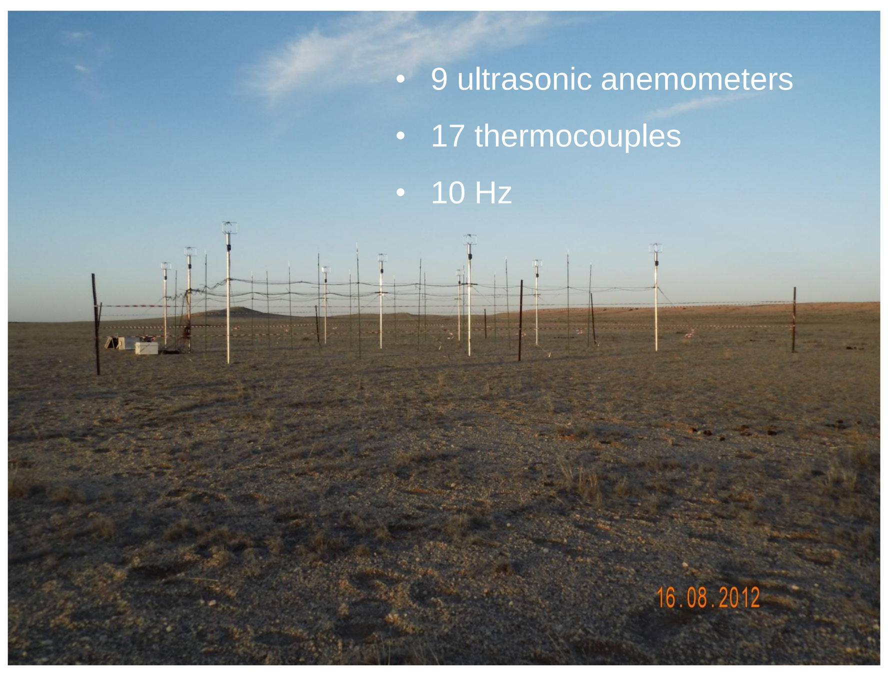
- The experiment took place from 16th to 23rd August 2012 at the Gobabeb Research and Training Centre, Namibia close to the micromet tower jointly used by the University Basel and KIT, Karlsruhe (Germany)
- The upper figures below shows the location in the desert and relative to the Basel/KIT tower, the lower figures the eddy matrix setup

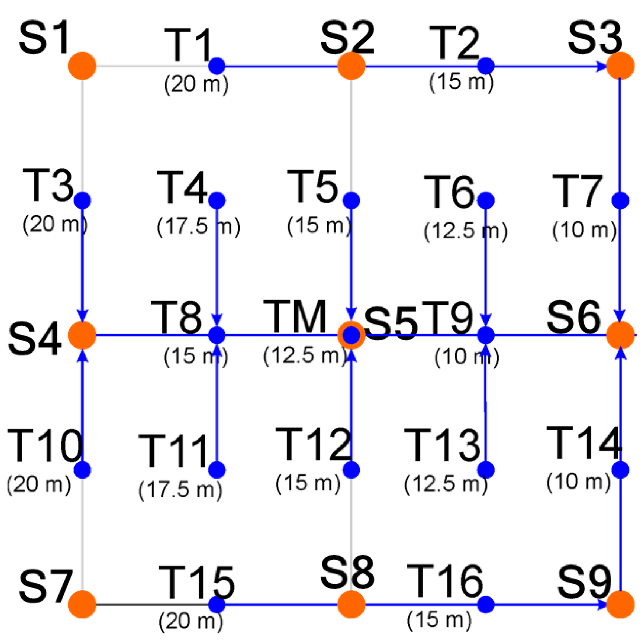





***Eddy matrix set-up at Gobabeb (site):*** *aerial photograph (left; courtesy of R. Vogt, Basel) and set-up scheme illustrating the favourable fetch and flatness of the site*

- To expand the 3x3 matrix (based on the sonic anemometers with a 5 m spacing) thermocouples were placed in the gaps resulting in a 5x5 matrix with a 2.5 m spacing (all sensors at height of 2.5 m)

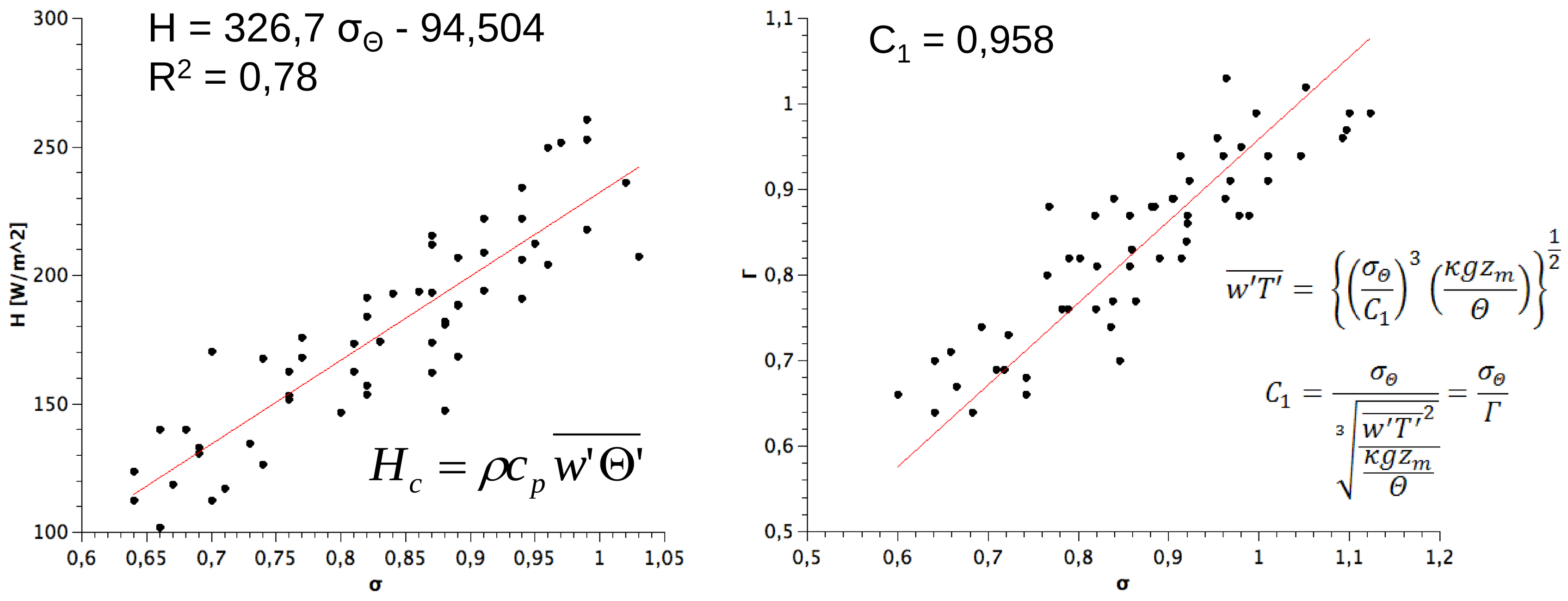



***Eddy matrix set-up at Gobabeb (instruments):*** *photograph facing S (left) and matrix scheme (right); S1 through S9 US anemometers, T1 through T16 & TM thermocouples*

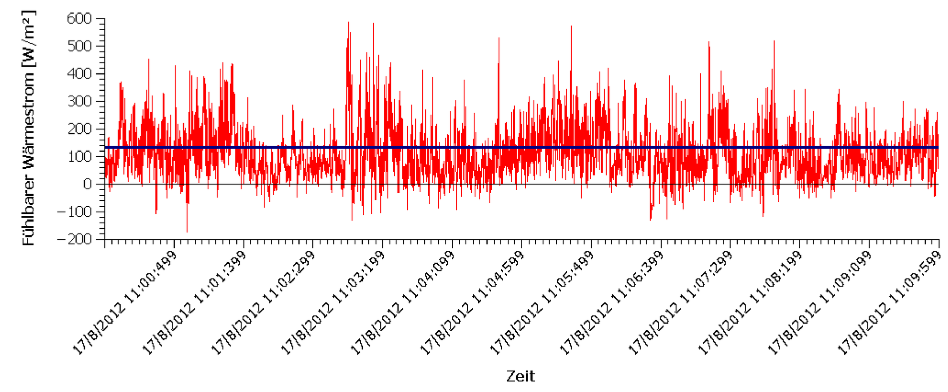
## Similarity relationships of single and multi tower (co)variance

- Similarity between covariance based and variance based H was tested using the central sonic anemometer and thermocouple during midday periods of free convection (Tillman 1972: $C_1$ = 0,95)

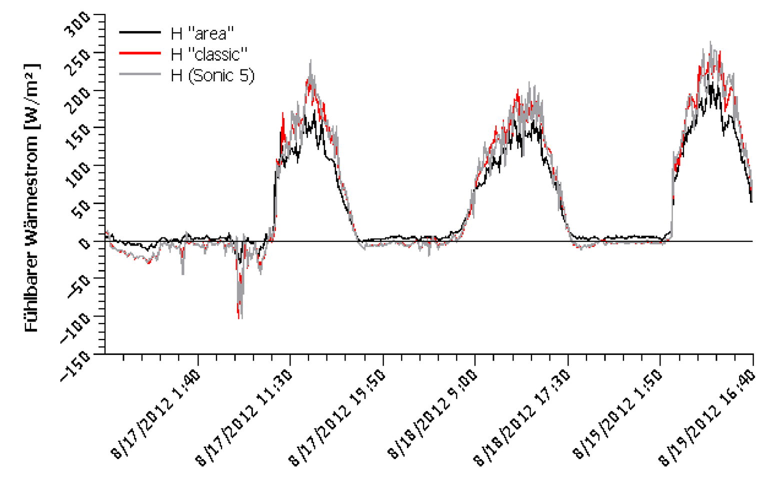


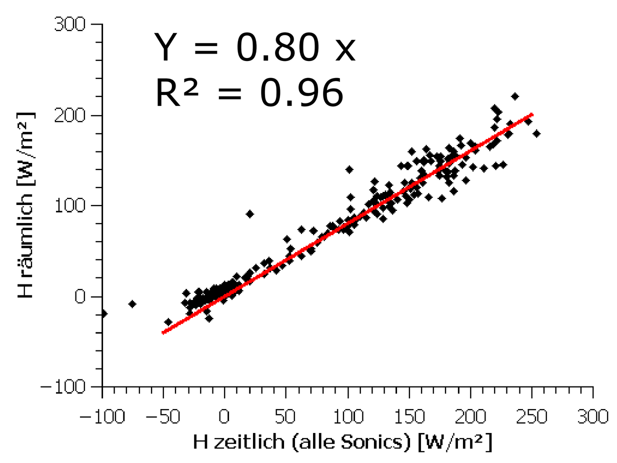

***Similarity between fluxes (single tower):*** *linear regression of variance (thermo-couple) vs. Hc (US anemometer (left) and compared to literature data (right)*

- The trace of the areal flux showed a large variability of up to 1000 W/m² in a single averaging period of 10 min




- Similarity between single tower and multi tower covariance could be shown for the complete diurnal course of the sensible heat flux




***Similarity between fluxes (multi tower):*** *diurnal course of classic and aerial EC fluxes (left) and linear regression between classic* $H_c = \rho c_p \overline{w'\Theta'}$ *and areal* $H_a = \rho c_p \overline{<w'\Theta'>}$ *(right)*

## Results

- The eddy matrix showed an extremely consistent data set of sensible heat fluxes (virtually no difference between the 9 single tower EC measurements; not shown)
- The thermocouple based sensible heat flux allows constructing a 5x5 matrix with a 2.5 m spacing at least for the periods of free convection around noon
- The areal EC measurements based on areal covariances compare very well with the classical EC but give only around 80% of the single tower fluxes
- The areal variances still need to be tested in comparison to the classic single tower measurements of H
- Taylor's frozen eddy hypothesis could not be falsified and is therefore a good rational to perform single tower measurements instead of areal ensembles

## Perspectives

- Here, preliminary data are shown with rough 'rule-of-thumb' approximations of fluxes (e.g., no rotation, no Schotanus correction); the already good relationships will probably improve through careful data processing
- The eddy matrix set-up can be enlarged for a better representation of the source area (footprint) of a single tower EC measurement
- The missing 20% of flux could be substituted by a classical time averaging EC of the instantaneous deviations of the areal <w'Θ'>


**Acknowledgement:**

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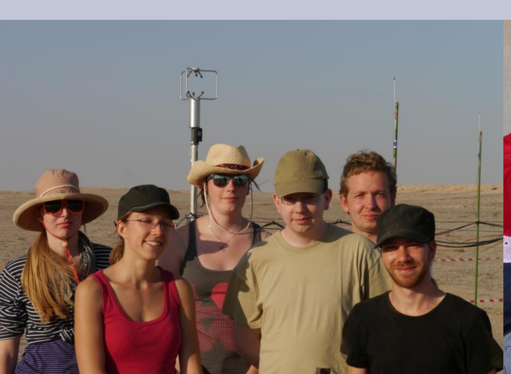


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