Investigating tropical lake surface temperature response to rainfall

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- Location
- Measurements
- Research question
- What can we get out of the data?
- Conclusions and future work

Lake Kivu, DRC / Rwanda border

Measurement site

Figure 7: Lake Kivu with the locations of the automatic weather station (AWS) and biological monitoring platform (BMP) ("Lake Kivu", 2°00' S 29°06' E. Google Earth. April 10, 2013. July 10, 2015)

Stijn Bruggen
Master's thesis
2015

Measurements on the lake

- Pressure
- Air temperature
- Relative humidity
- Wind speed
- Wind direction
- Precipitation
- up and down LW
- up and down SW

15s sampling
30 min averages

Data used here
Were collected between
Sept 2012 – Aug 2017

photos © Wim Thiery

Questions

Does rain have any appreciable effect on lake surface temperature?

Could be by $\Delta T_{rain\ /\ lake}$ …

…or by affecting the lake temperature structure via turbulent mixing.

These effects are not accounted for in models such as FLake.

Is it possible to assess this effect using Kivu data?

- Long dataset
- Uniform climate
- Frequent, heavy convective rainfall

…but maybe not all the measurements we would like.

Rain effects

- **Annual** to decadal effect of rain may be small (Verburg et al. 2011)
- Tropical **seasonal** means of order 2 Wm^{-2} ….
- … neglect of this flux may be apparent in climate model **biases** (Wei et al. 2014)
- On shorter (weather) timescales, rain effect on **land** has been studied (Taylor et al. 2012)
- May be required for accurate tropical **river** surface temperatures (van Beek et al. 2010)
- What is the rain temperature? (Byers et al. 1949)

Effects on a lake?

- **Heat flux** : 1 mm hr^{-1} ~ 1.2 $\Delta T_{rain\ /\ lake}$ Wm^{-2}
- **Mixing** : 5 mm hr^{-1} ~ KE flux of 0.02 Wm^{-2} (van Dijk et al. 2002, Yu et al. 2012)
  - comparable to stress-generated turbulence from moderate wind in the top few cm ?
- **Convection**?
  - interesting boundary-layer problem, buoyancy flux + momentum flux…
- LWST change may depend on lake near-surface **temperature structure**

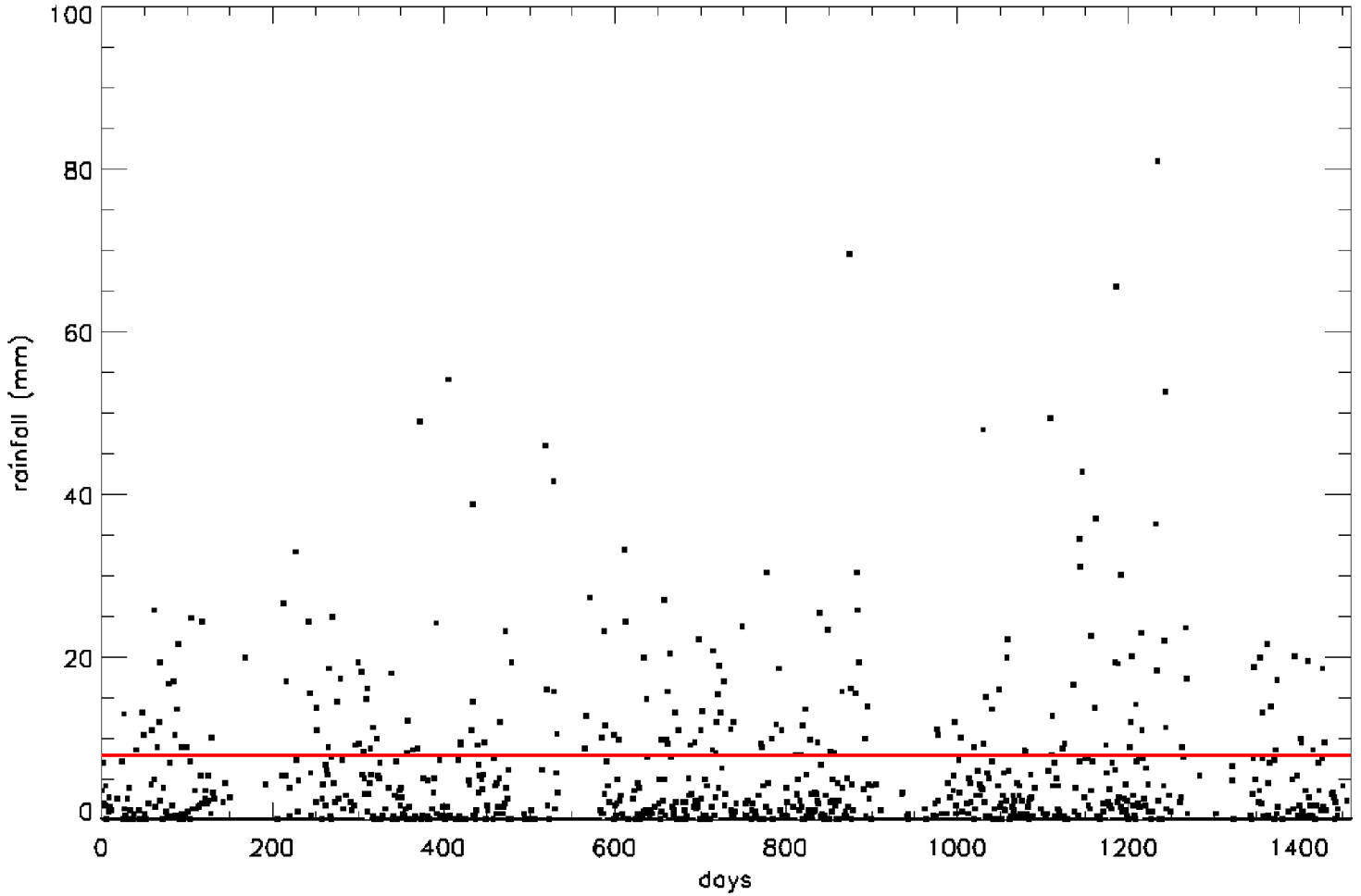
(LWST = lake water surface temperature)

Kivu data

Jan 2013 – Dec 2016 (4 full years)

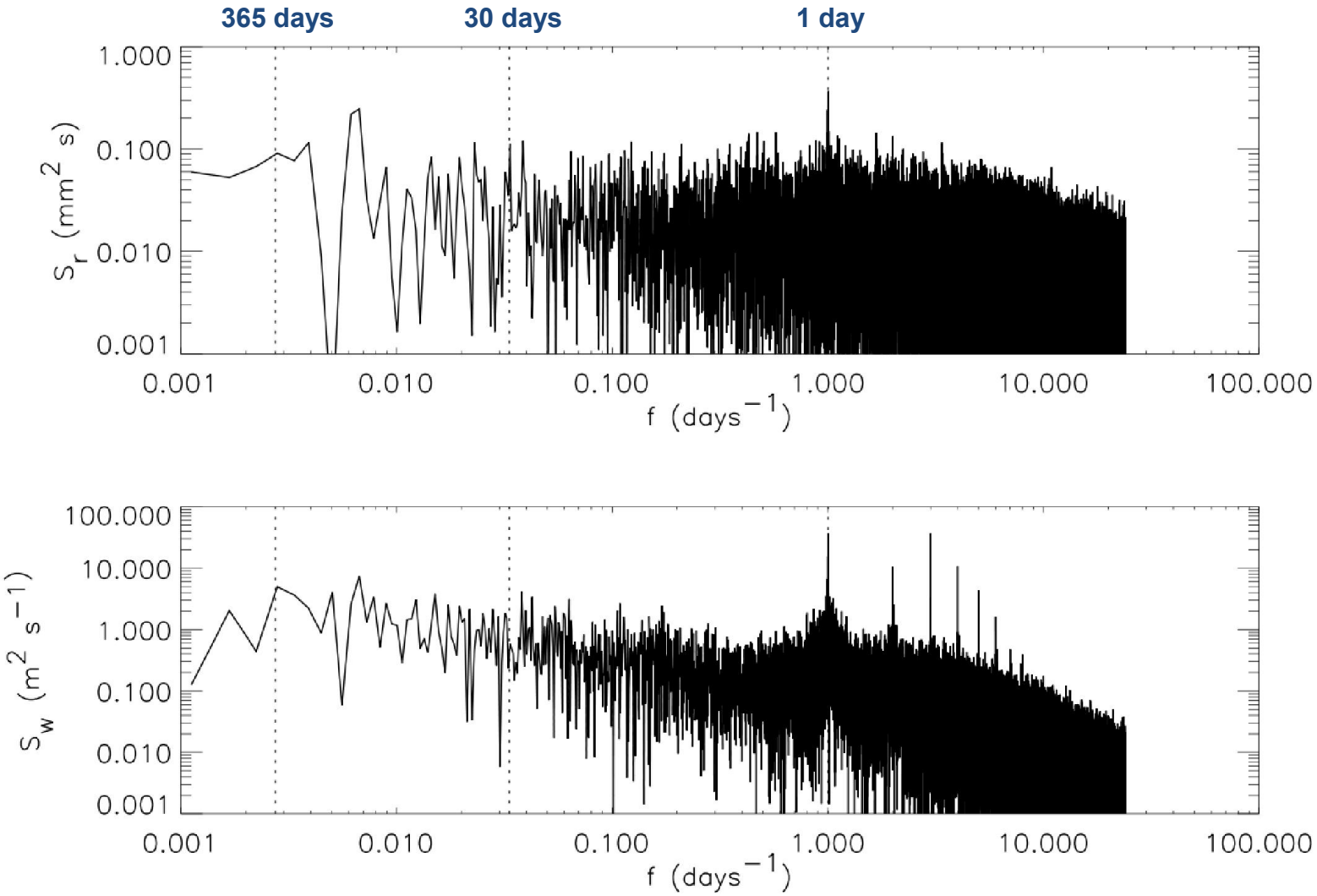
Daily rainfall totals

Red line at 8mm



Spectra of half-hourly data : Sept 2012 – Aug 2017 (full dataset)

- rain
- wind speed



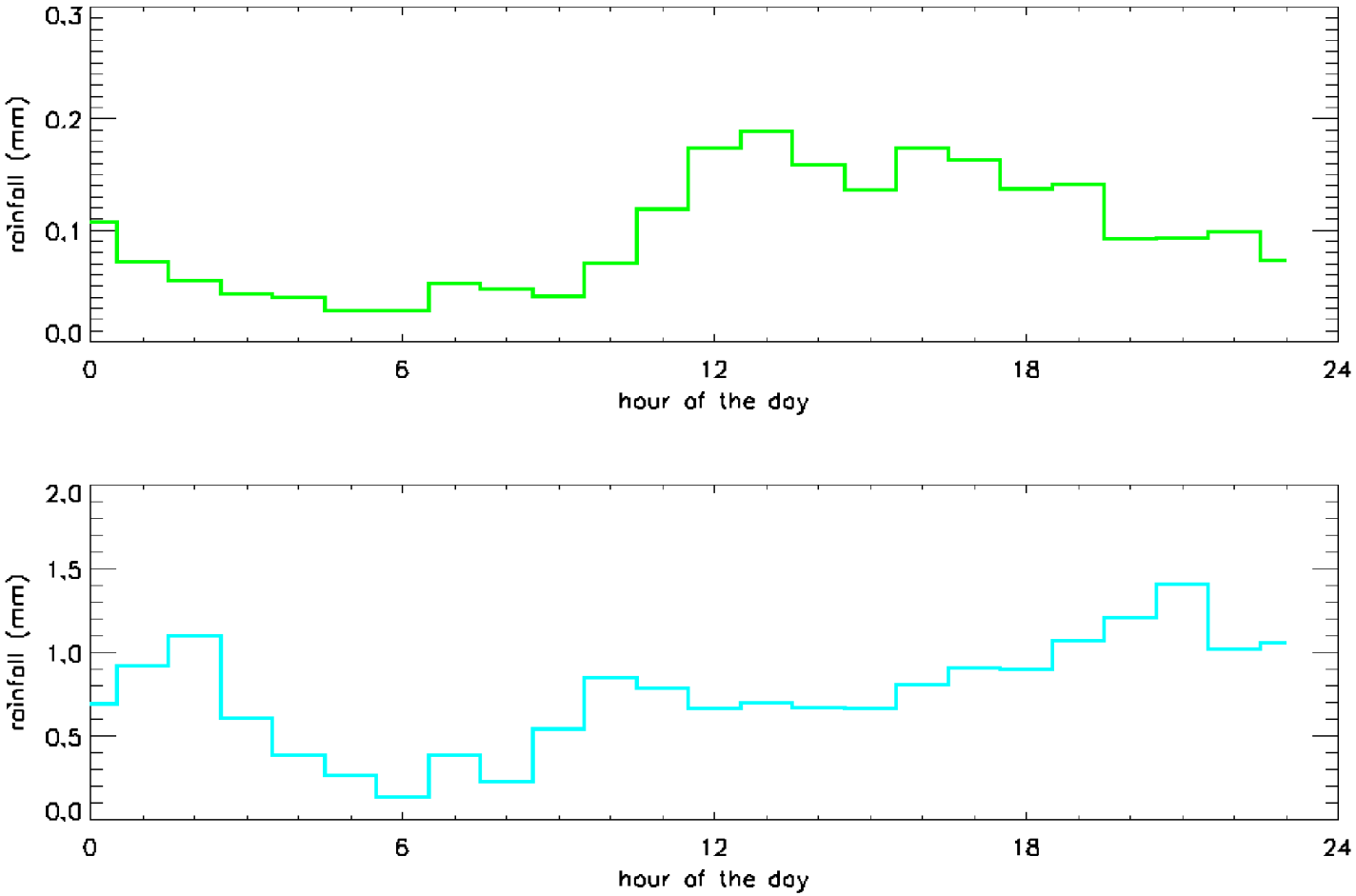
From now on restrict the data to Jan 2013 – Dec 2016 only.

First, partition the data by daily rainfall total,

colour-coded as follows:

type	condition	N days
ALL	all the data	1457
DRY	no rain	690
WET	0 < rain < 8mm	585
VWET	rain > 8mm	182

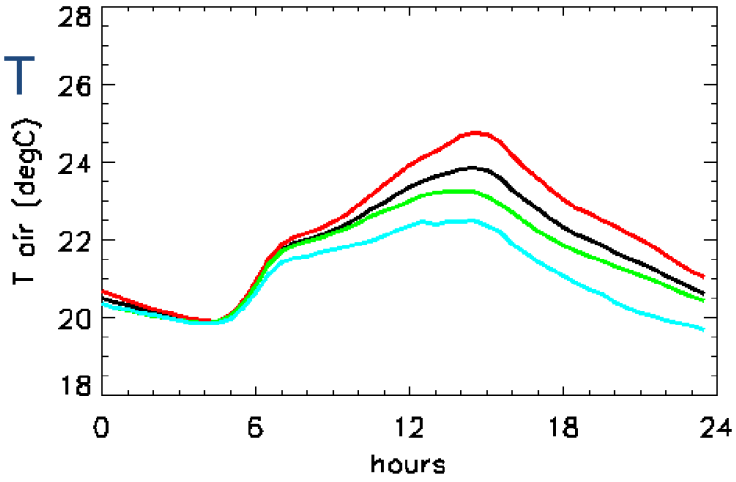
Average rainfall for each hour, WET and VWET days

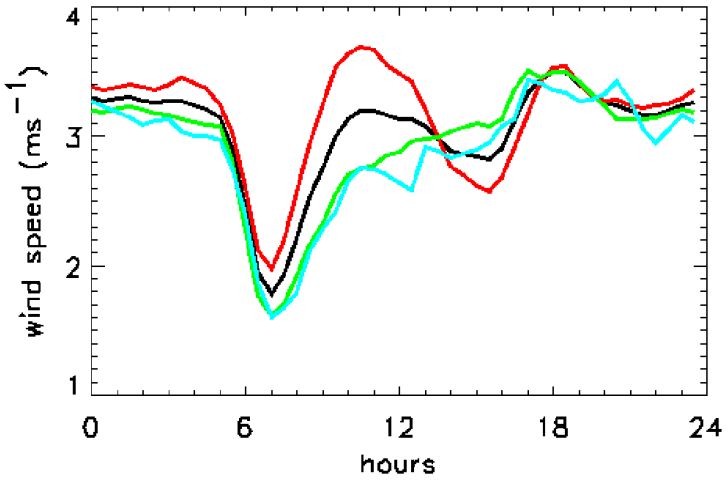


Mean diurnal cycles

ALL DRY WET VWET

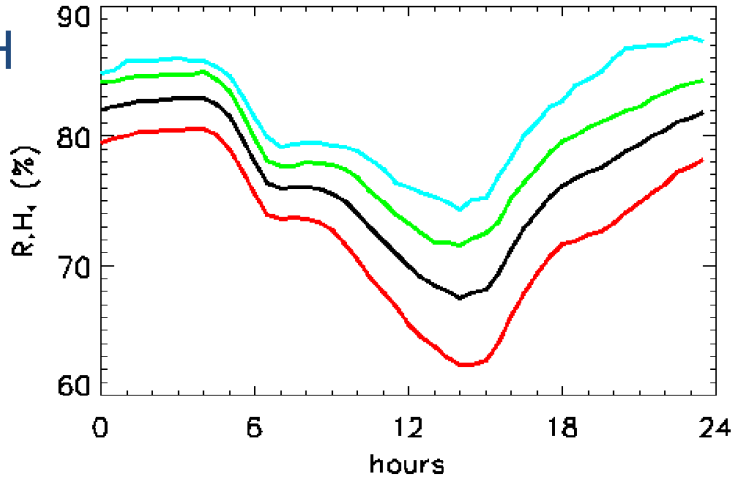
Air T

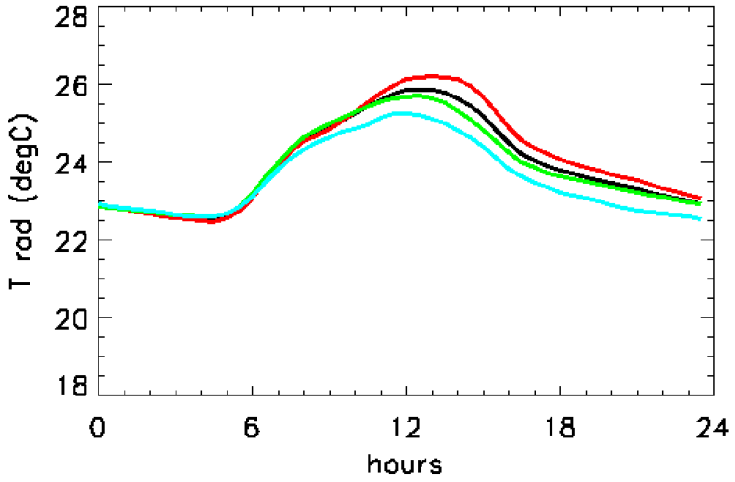




Wind speed

RH



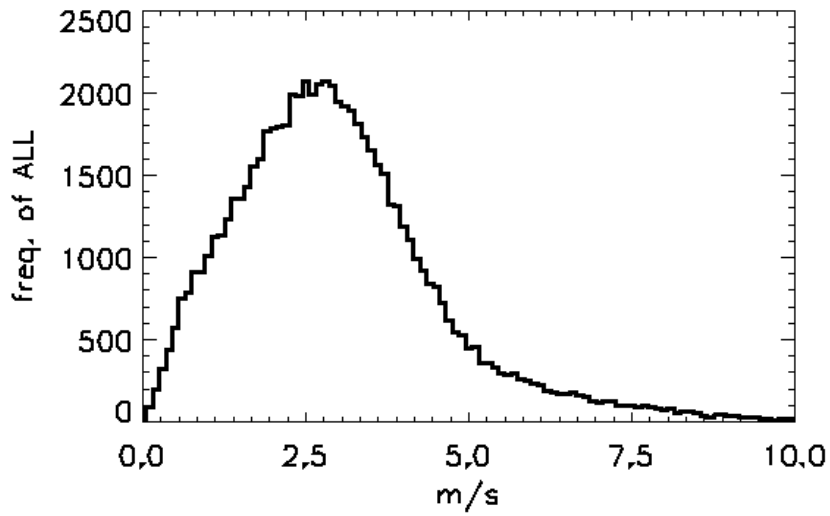


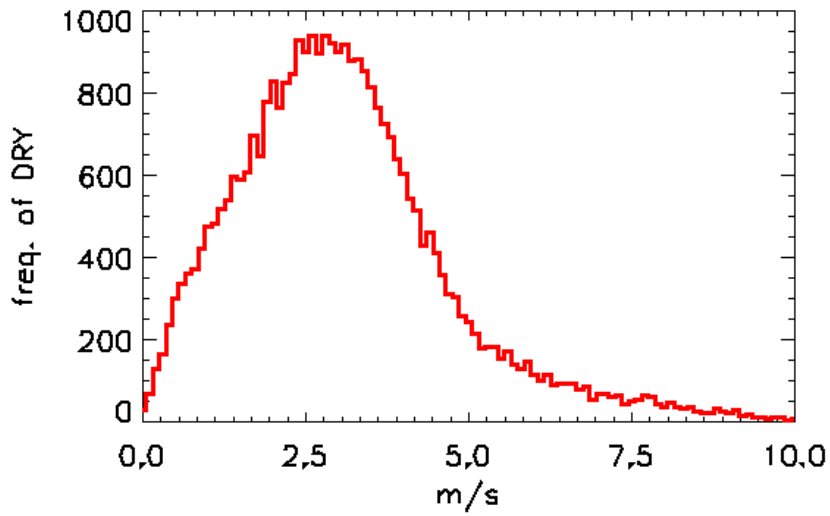
LWST

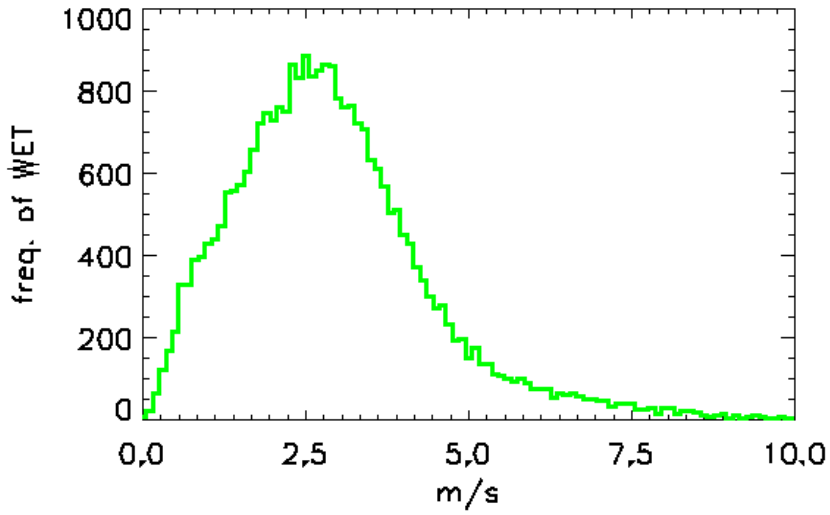
LWST – lake water surface temperature, assuming 0.99 emissivity.

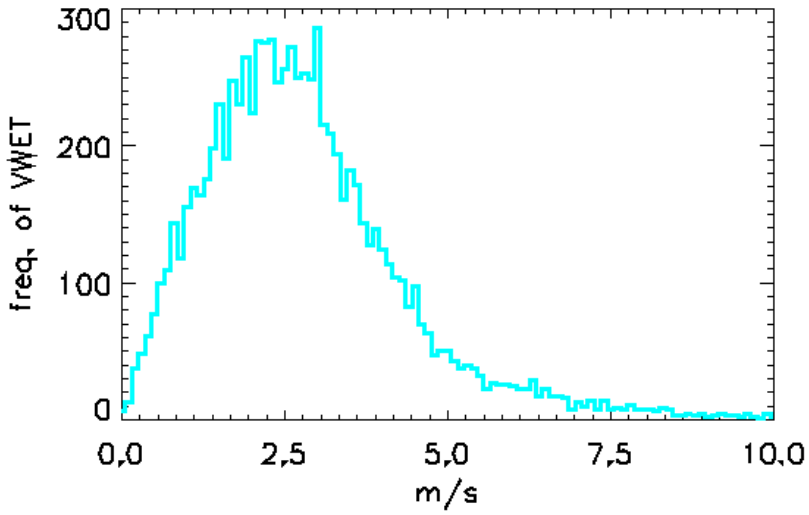
WET and VWET values diverge during the day, by ~0.5 K

Histogram of half-hourly mean wind speed

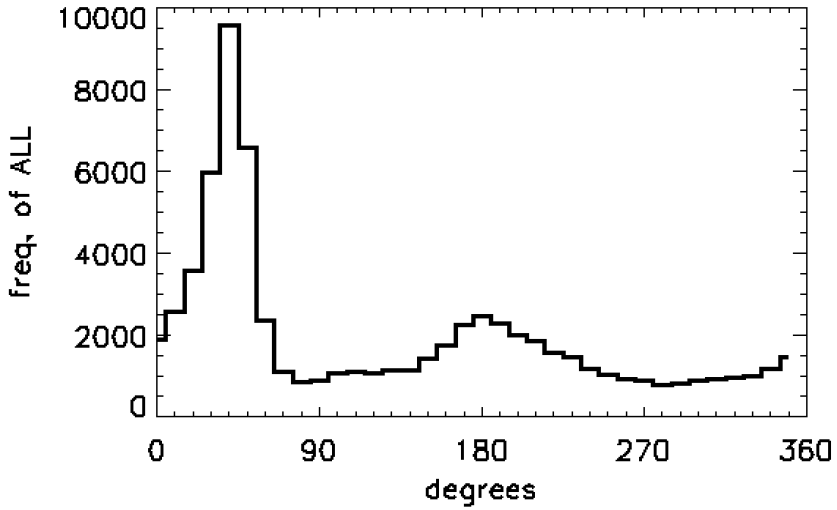


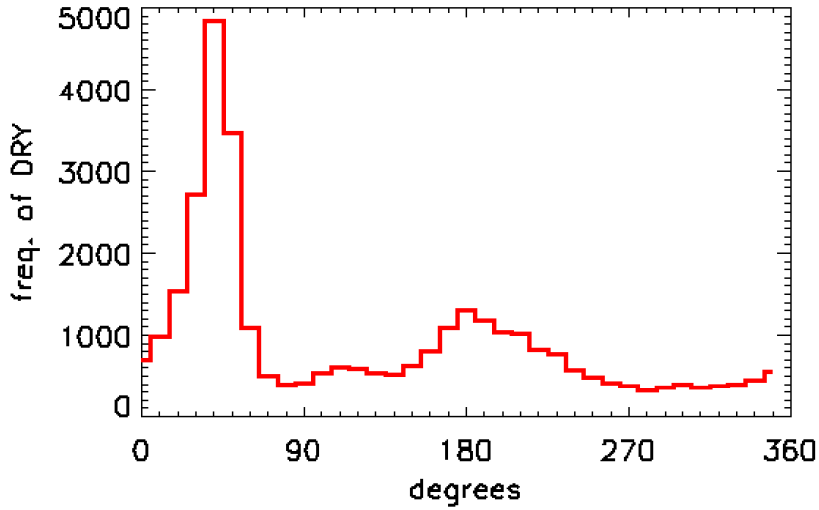


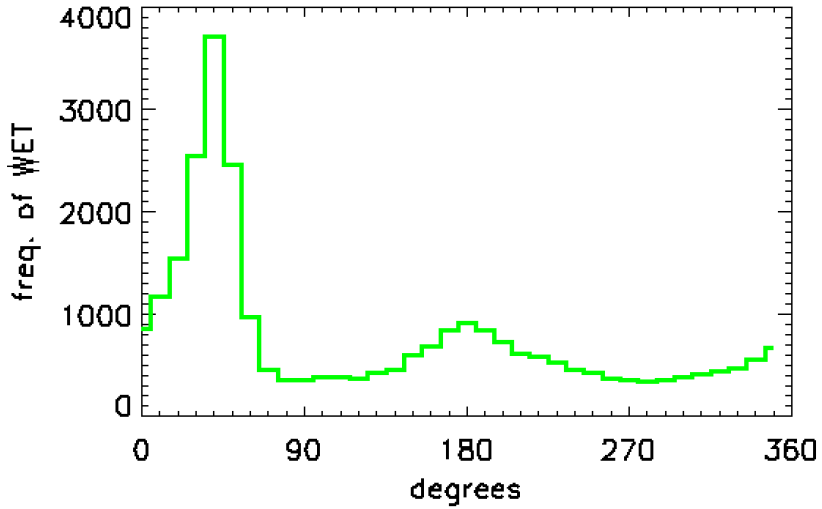


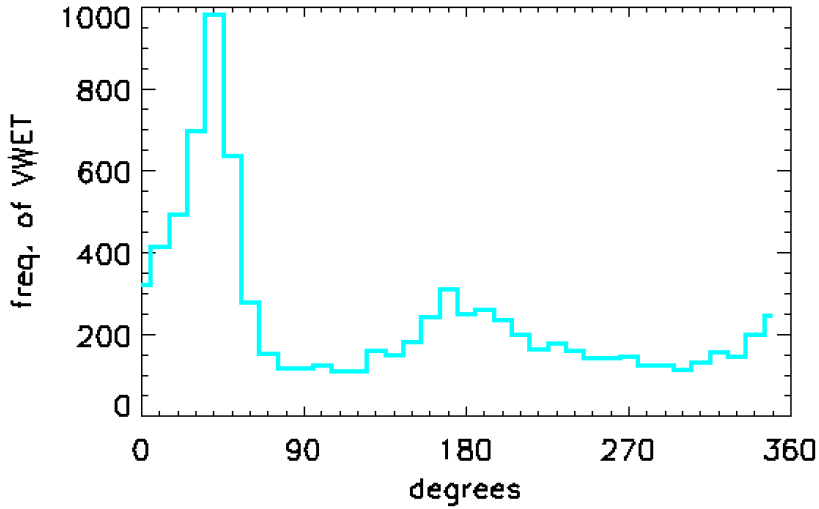


Histogram of half-hourly mean wind direction

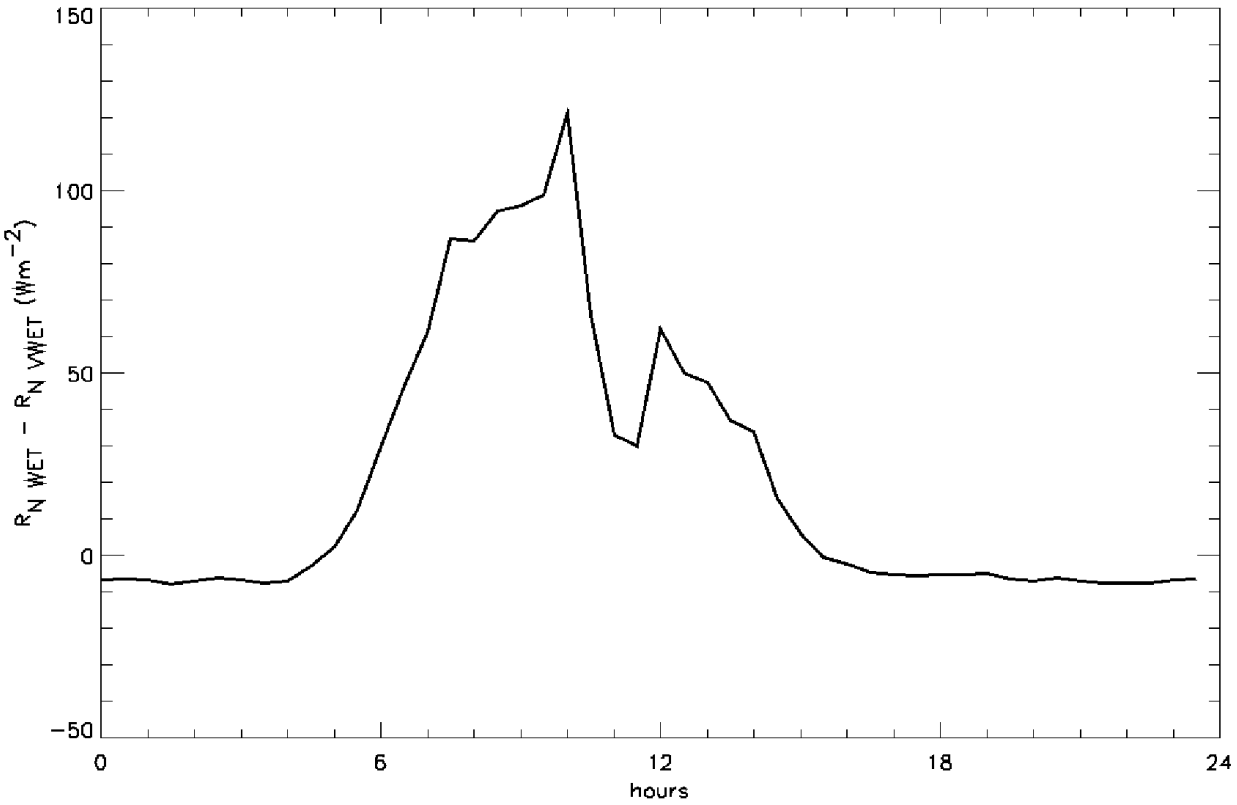








There is a difference in net radiation between WET and VWET which will affect LWST.



To minimise / remove this difference,
re-sample the data to include only “dull” WET days:

New category **DWET**.

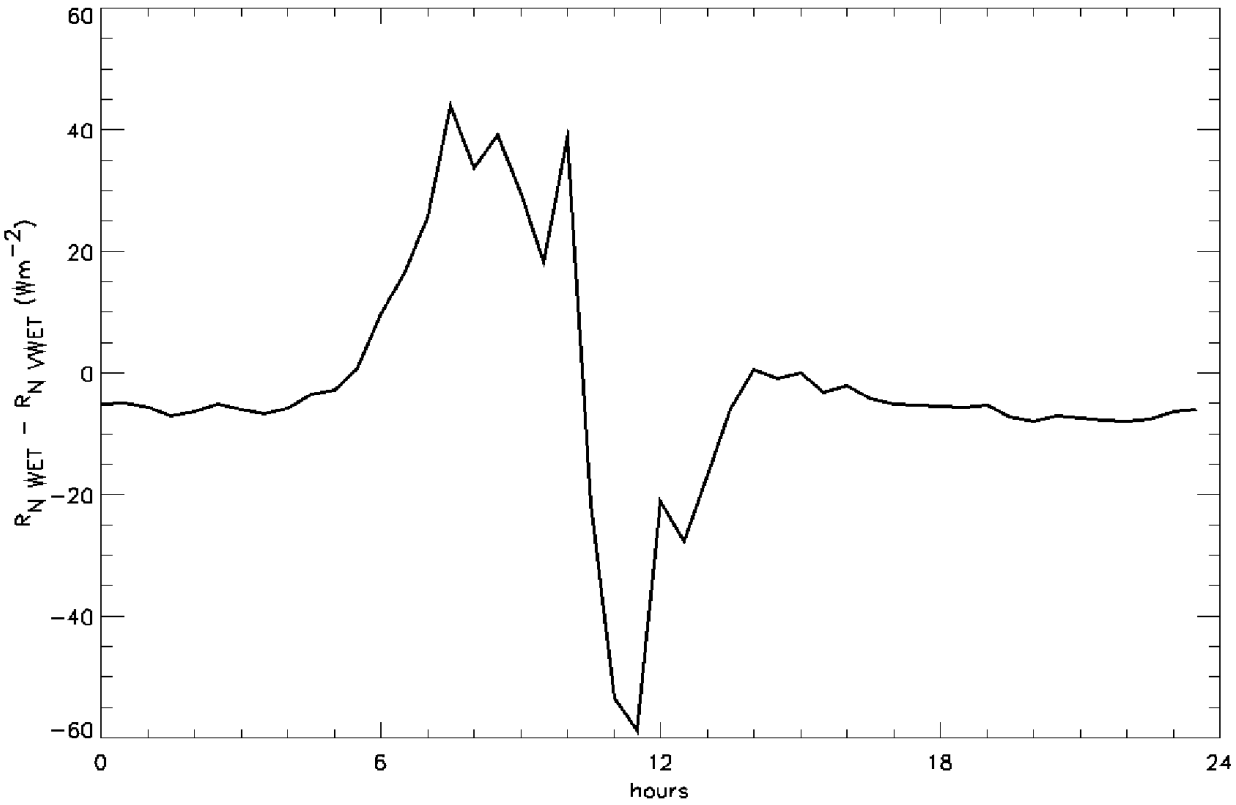
Three categories remain the same, DWET is different.

(reminder: there were 585 days in the WET category.)

type	condition	N days
ALL	all the data	1457
DRY	no rain	690
DWET	0 < rain < 8mm & *	425
VWET	rain > 8mm	182

* integrated net radiation < 1.5e7 Jm^{-2}

DWET – VWET net radiation

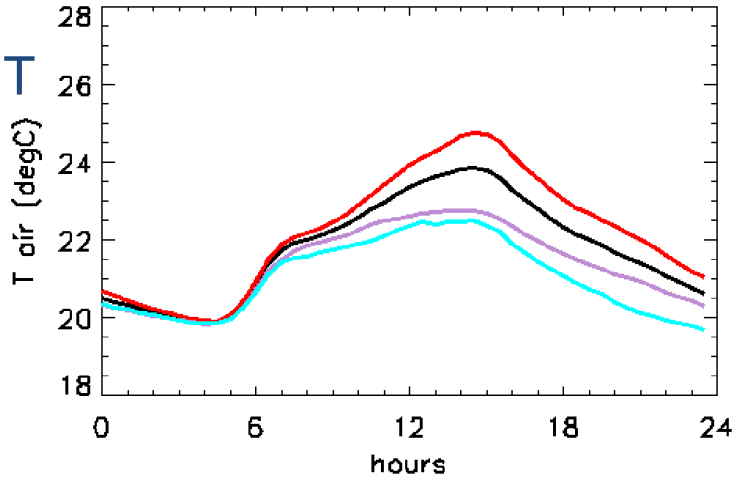


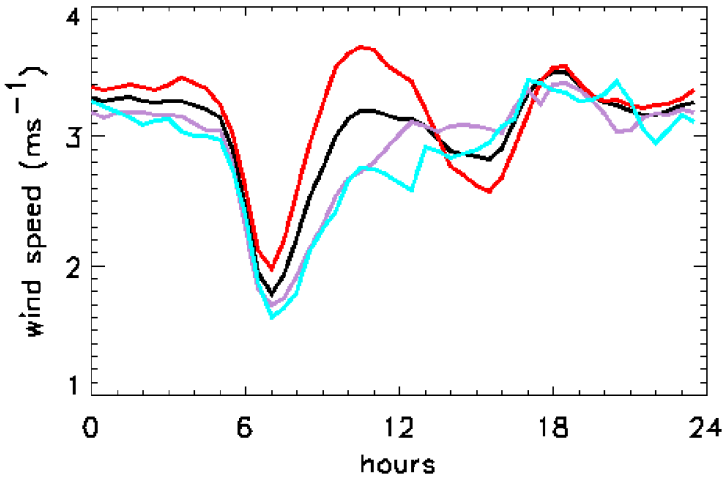
Re-sampling for days with total integrated net radiation below a threshold value reduces the integrated radiation difference to zero.

Mean diurnal cycles

ALL **DRY** **DWET** **VWET**

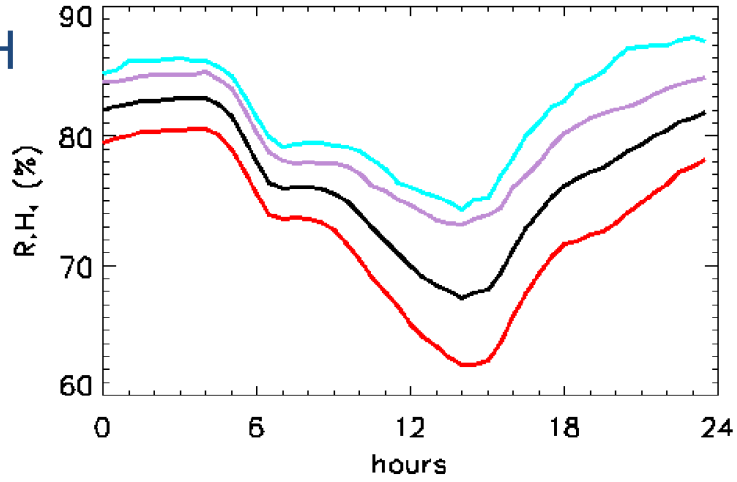
Air T

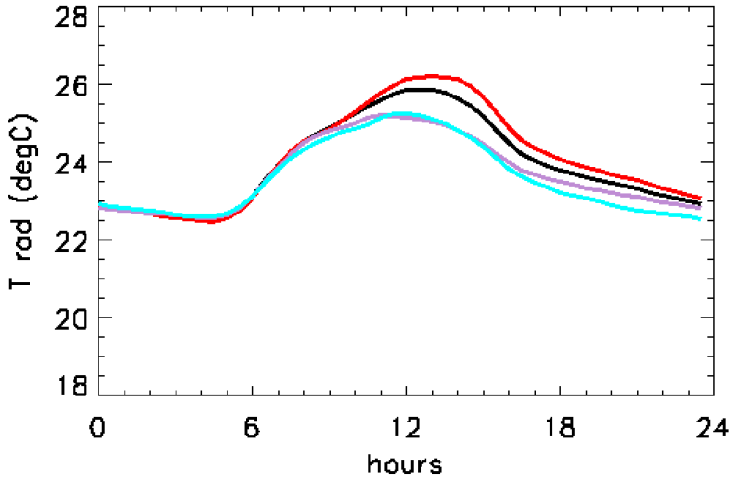




Wind speed

RH





LWST

Peak Air T and RH are closer together. Peak LWST almost the same.

Most of the end-of-day difference in LWST remains.

Re-cap : what can affect LWST day-to-day

- *Net radiation*
  - Integrated net radiation is the same
  - although timing of peak is different.

- *Turbulent heat fluxes*

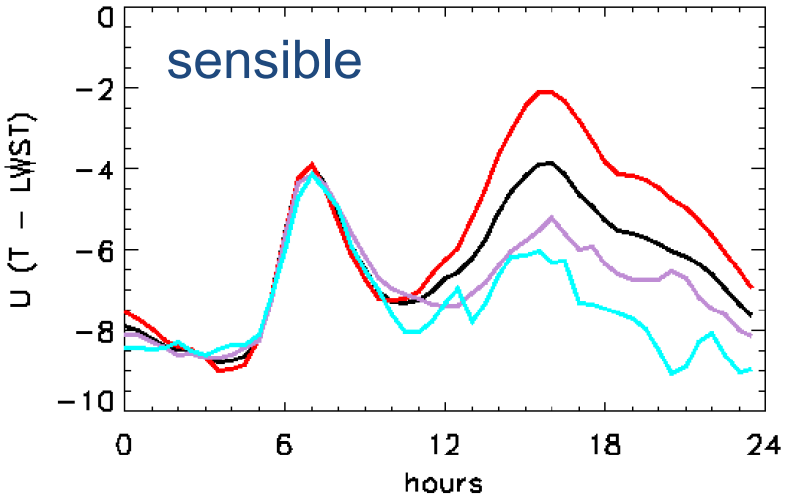
$$H = \rho_a C_P C_H U(T_a - \mathsf{LWST}) \qquad E = \rho_a L_v C_E U(q_a - q_{sat}(\mathsf{LWST}))$$

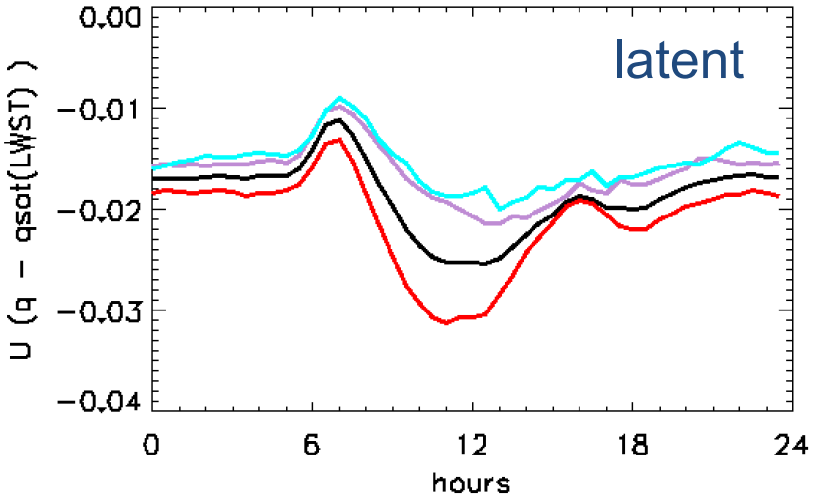
  - Mean wind characteristics are similar across categories.
  - Turbulent exchange coefficients may depend on stability
  - although main stability variation will be diurnal.
  - Latent heat flux is usually more significant than sensible
  - although DWET has a lower R.H. than VWET.

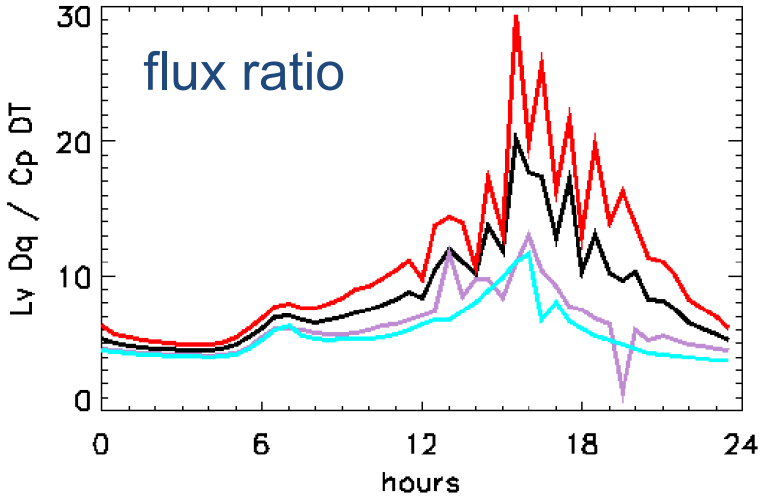
    …more on this on the next slide…

- *Circulation in the lake*
  - Unknown in this instance
  - but also assumed unimportant in NWP lake modelling.

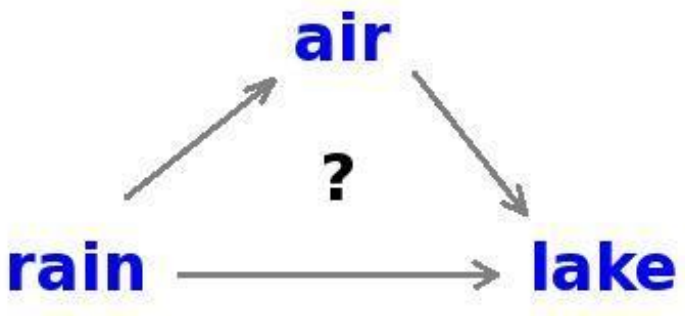
Elements of turbulent flux parametrisations (mean diurnal evolution)







The main **DWET / VWET** difference is UΔT during the last few hours of the day.



Conclusion and future work

- Heavy rainfall on Kivu is associated with an additional fall in LWST of a few tenths of 1K by the end of the day
- The uniformity of the Kivu data helps to isolate this correlation
- Rain effect mediated by air cooling is represented in models but the “direct” rain effect is not
- The possible mechanisms of the effect include cooling as well as turbulent mixing
- Possible future work could include a targeted observation campaign, or the coding/testing of these effects in lake models