A discussion on the paper “Scintillometry in urban and complex environments: a review”

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Outline

- Background
- Theory
- Progress
- Issues
- Summary & Outlook

Background

The most widely accepted technique for measuring surface fluxes is eddy covariance (EC). However, EC data are typically representative of a single field or neighbourhood. Moreover, EC requires a relatively homogeneous underlay surface. Therefore, EC can not give accurate flux values in many cases .

We need a new technology to measure flux which is scintellometry. Despite much of scintillometry theory assuming flat, homogeneous surfaces and ideal conditions, over the last 20 years scintillometers have been deployed in increasingly complex locations, including urban and mountainous areas.

Theory

The LAS is a device that derives the turbulent intensity through measuring the refractive index of air, $C_n^2(m^{-2/3})$, which can be expressed as : $C_n^2=1.12\sigma_{lnI}^2 D^{3/7} L^{-3}$

where σ_{lnI}^2 is the variance of the natural logarithm of intensity fluctuations, D is the aperture diameter(m), and L is the path length(m).

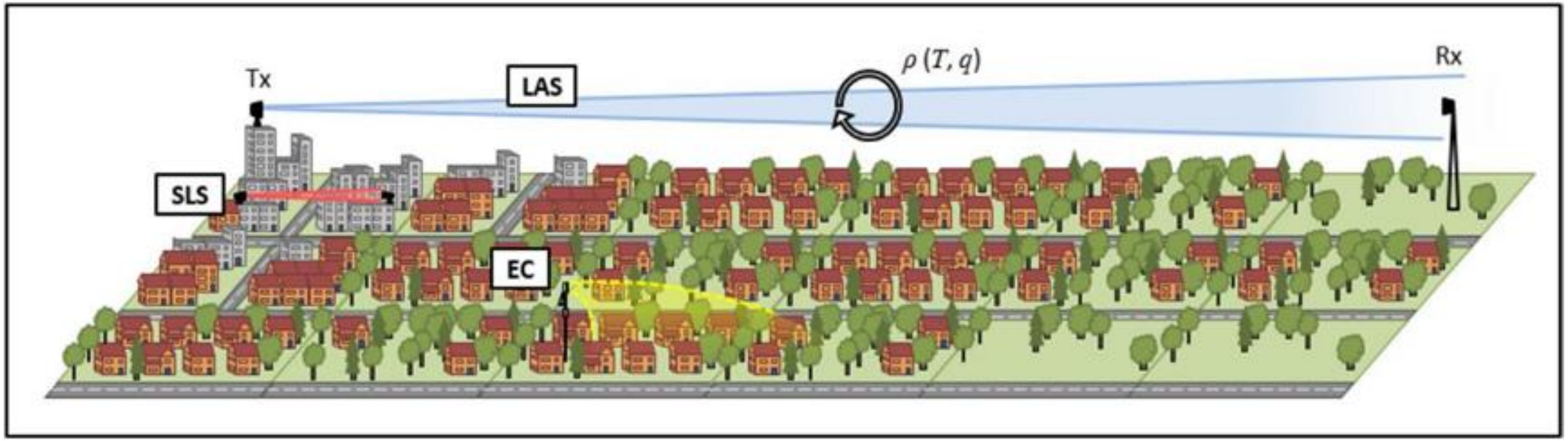

Figure 1. Schematic representation (not to scale) of a large-aperture scintillometer (LAS, blue), surface-layer scintillometer (SLS, red) and eddy covariance station (EC, yellow) deployed over a complex landscape. As the scintillometer beam propagates from transmitter (Tx) to receiver (Rx) it is scattered by turbulent eddies of density ρ at temperature T and humidity q.

Theory

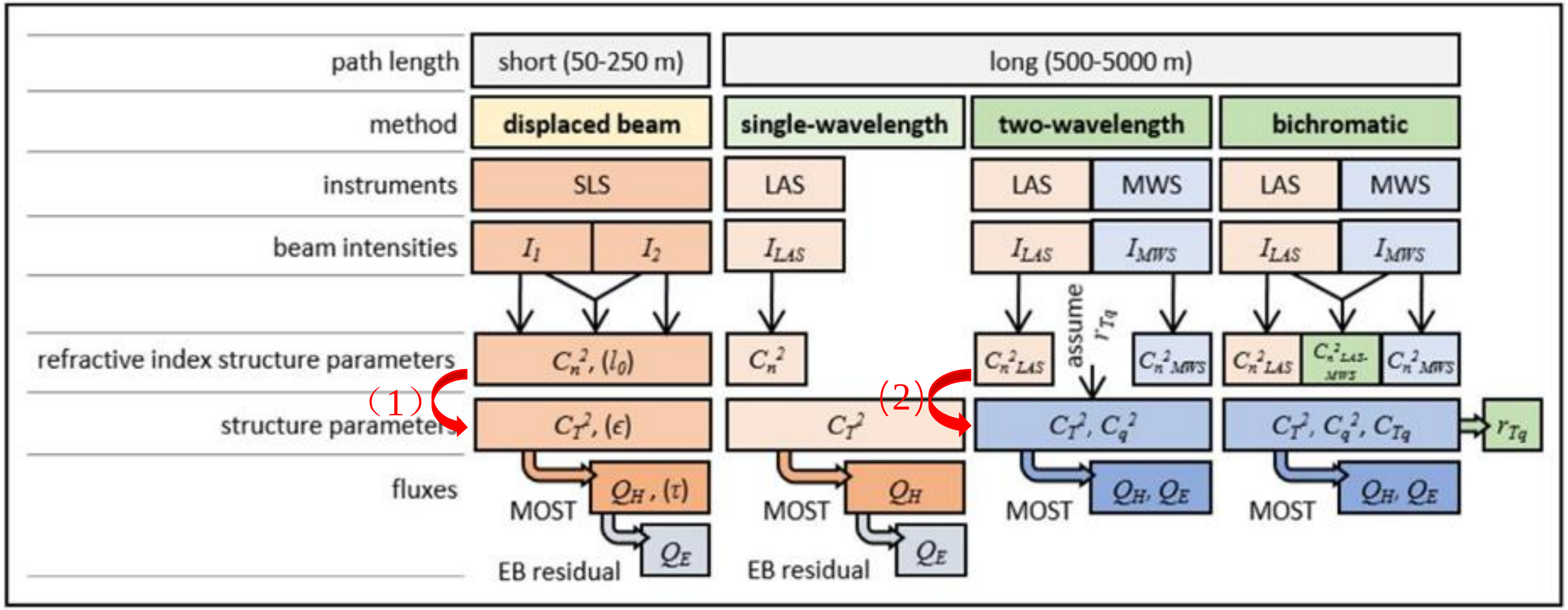

Figure 2. Summary of methods to obtain turbulent heat fluxes (and momentum flux, τ) from scintillometers via Monin–Obukhov similarity theory (MOST) or energy balance (EB) residual. I is beam intensity. Other notation is defined in the text.

(1): $$C_T^2 = C_n^2\left(\frac{T^2}{-7.87\times10^{-7}}\right)^2\left(1+\frac{0.03}{\beta}\right)^{-2}$$

(2): $$C_n^2 = \frac{A_T^2}{T^2}C_T^2 + 2\frac{A_T A_q}{T_q}C_{Tq} + \frac{A_q^2}{q^2}C_q^2$$

Progress

The performance of scintillometry is often judged by its ability to match EC. However, uncertainties with EC and differences between the techniques must be considered. Although EC is a direct method of measuring fluxes, data processing consists of a series of adjustments and corrections and different options can lead to differences of 10–15% in the fluxes. The main issue with EC is under-closure of the energy balance.

Other options for assessing scintillometer performance have emerged, including airborne measurements, numerical modelling (LES) and satellite products. These enable analysis to extend beyond the limitations of the now familiar EC-scintillometry comparison and provide a broader understanding (being limited by a different set of issues to EC).

Progress

1.Heterogeneous environment

Example 1: Chehbouni et al found 'fairly good' agreement between Q_H from a LAS spanning two patches (45% grass, 55% mesquite) and Q_H from EC stations in each patch aggregated according to the scintillometer path weighting function.

Example 2: Lagouarde et al also used a composite path, over wheat and bare soil, introducing a step change in crop height as well as vegetation type. Good correlation ($r_2 = 0.96$) was found, but Q_{H_sc} overestimated $Q_{H\_EC\_agg}$ by 11%.

Progress

1.Heterogeneous environment

Example 3: During LITFASS-2003 fourteen EC stations were operated over different crops and surface types. ‘Encouraging’ agreement was obtained between aggregated EC fluxes and fluxes derived from a two-wavelength scintillometer system (r_2=0.8–0.9).Scintillometer fluxes were higher than aggregated EC fluxes.

According to the examples above,we can conclude that: $Q_{H\_SC} > Q_{H\_EC\_agg}$

Explanations for this: 1) EC: under-closure of the energy balance;

2) The nonlinear relationship between structure parameters and fluxes;

3) Saturation of the LAS and uncertainty in similarity functions

Progress

1.Heterogeneous environment

To attempt to eliminate some of these issues:

1): Analysis of structure parameters

e.g. During LITFASS-2009 an automated unmanned aircraft flown along the scintillometer path revealed spatial variability in C_T^2.

2): High resolution modelling

e.g. Maronga et al used LES to investigate C_T^2 and C_q^2 for the surface layer above the LITFASS region.

Progress

2.Complex topography

Example 1: Few scintillometry studies have been conducted in very steep terrain. Weiss describes a series of experiments under increasingly challenging conditions: homogenous and flat terrain, heterogeneous and flat terrain, and heterogeneous terrain in an alpine valley as part of the Riviera Project. Although of short duration, comparison with EC data gives confidence in the performance of SLSs and it is concluded that scintillometers can be used to detect site-tosite differences in irregular terrain.

Example 2: As part of the i-Box network in the Alps, a LAS was installed across the valley with the centre of the path above an EC tower with three measurement levels: 4, 9, and 17 m. there is good agreement between the EC stations and LAS.

Progress

3.Urban environments

Good agreement of Q_H existed between scintillometers and EC. LAS paths in urban areas are usually selected so that they are above the roughness sublayer, thereby permitting use of standard similarity theory to calculate fluxes and sidestepping issues related to surface heterogeneity. For long paths traversing land use zones, such as from the city center to suburbs, conditions probably vary smoothly enough that MOST is not seriously violated.

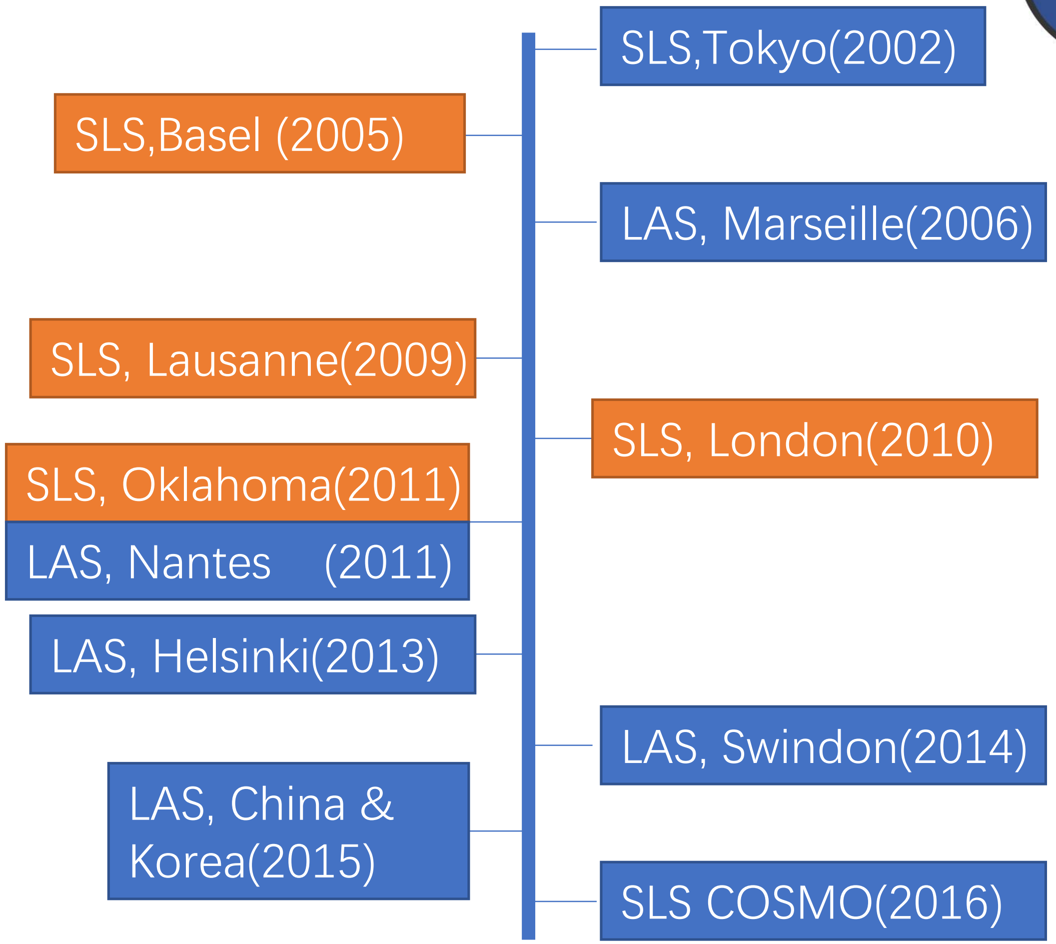

Figure 3. Scintillometers used in different urban regions

Issues

1.Applicability of MOST

MOST requires horizontal homogeneity, stationarity and negligible influence of processes occurring above the surface layer. Even over ideal surfaces, there are evidently times when MOST requirements are not fulfilled, simply due to the diurnal cycle. During strongly stable conditions weak turbulence, intermittency and the shallowness of the boundary layer create problems for observations. Complex environments increase the probability that ‘other’ processes will be significant enough to affect behaviour.

Issues

1.Applicability of MOST

1.1 Similarity functions

Even for homogeneous surfaces the lack of consensus around similarity functions has led to substantial uncertainty.

(1): Braam et al analyse similarity functions for C_T^2 and demonstrate that empirically-fitted coefficients are affected by the regression approach and the height and stability conditions for which the observations were made. They suggest using a regression approach that accounts for uncertainties in $(z_m - z_d)/L_{ob}$ and giving lower weight to unreliable data points.

(2): Kooijmans and Hartogensis (2016), hereafter KH16. KH16 are able to provide a new set of coefficients and reduce the uncertainty in Q_H from about 10–20% to 6%. Compared to An88 and DB93, the KH16 C_T^2 function has a larger neutral limit, which will act to reduce the often observed overestimation of Q_H under these conditions.

Issues

1.Applicability of MOST

1.2 Temperature-humidity correlation(r_{Tq})

In theory, accurate r_{Tq} improves structure parameters (and hence fluxes), although due to the high variability of bichromatic r_{Tq}, the two-wavelength method has been used to derive fluxes (Meijninger et al 2006, Ward et al 2015a). For the two-wavelength method, assuming $r_{Tq} \approx \pm 0.8$ will usually be more appropriate than ± 1.0.

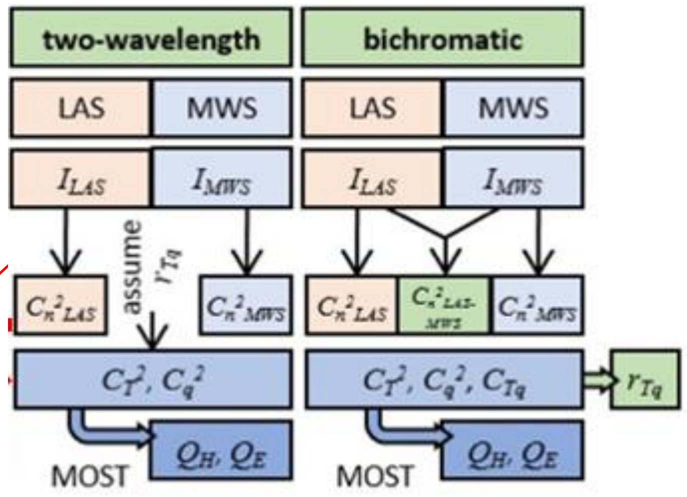

Table 1. Observed temperature-humidity correlation for various sites.

Reference	Location	Site description	r_{Tq}
Kohsiek (1982)	Table Mountain, Colorado	Flat homogeneous grassland	0.75 average.
Hill *et al* (1988)	Flatville, Illinois	Flat homogeneous agriculture	−0.99 to 0.98.
De Bruin *et al* (1993)	La Crau, France	Flat homogeneous grassland	0.0 to 1.0 (unstable), typical values 0.7 to 0.8.
Roth (1993)	Vancouver, Canada	Suburban residential	0.2 to 0.8 (unstable).
Katul *et al* (1995)	Maine; California; North Carolina	Mixed forest; uniform bare soil; grass field	−0.6 to 0.9.
Andreas *et al* (1998)	Sevilleta, New Mexico	Sandy soil with patchy vegetation; metre-scale heterogeneity	−0.9 to 0.9; typical magnitude 0.76.
De Bruin *et al* (1999)	Wageningen, The Netherlands	Flat, short grass	0.7 to 0.9 during daytime, −0.5 to −0.9 during evening.

Issues

1.Applicability of MOST

1.3 Blending height(z_b)

Typical values are of the order of some tens of meters for urban areas, are lower for small agricultural fields and increase with the scale of heterogeneity.

1) It is not currently known how the blending height for fluxes might relate to a blending height for structure parameters.

2) There is little evidence that findings are substantially different below z_b, whereas at greater heights, flux divergence and entrainment can become problematic and measurements made above the surface layer usually cannot be related to surface fluxes.

Issues

2. Scintillometer footprints

Scintillometer source areas can extend over several square kilometers. They are largest for winds perpendicular to the path but for winds parallel to the path the footprint is much smaller. It is generally advisable to install scintillometers so that the path is not aligned with the prevailing wind. Footprint modelling can be used to inform path selection and check measurements will be representative of the desired study area.

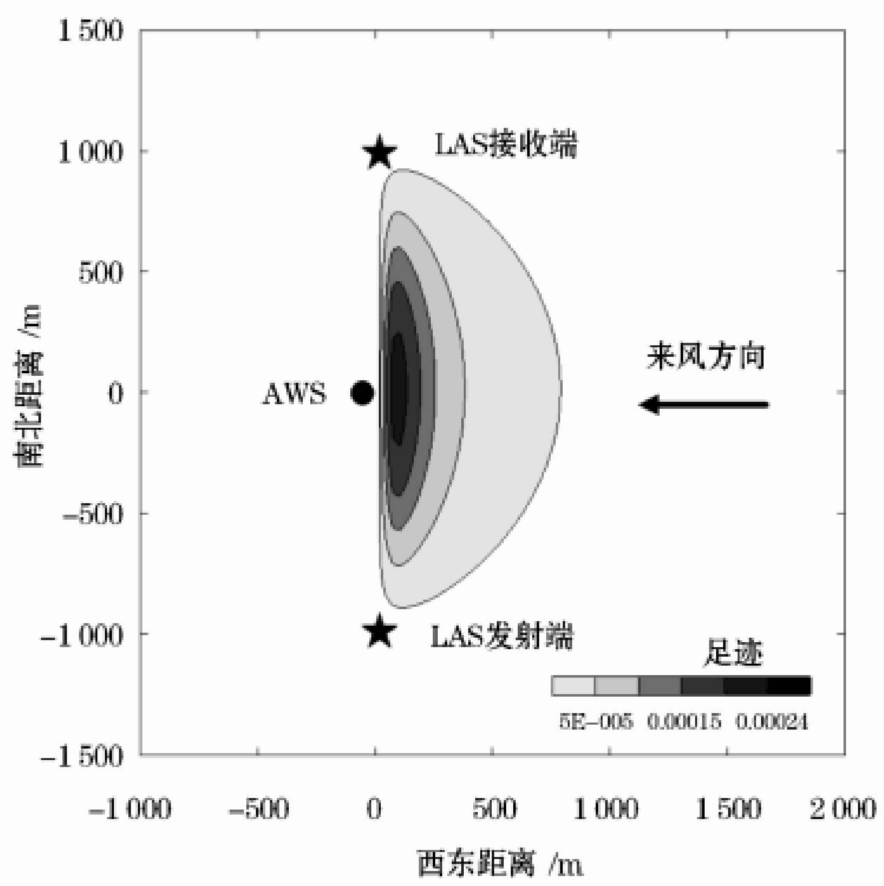

Figure 4. Sketch map of LAS source area

Issues

3. Obtaining accurate input information

z_0, z_{ef}, (and z_d) are important input parameters that can significantly impact scintillometer fluxes but can be very difficult to determine in complex environments. Accurate elevation information should be used to determine beam height, but for z_0 and z_d it is recommended to make an informed estimate and consider the uncertainties. Increasing beam height reduces the impact of the uncertainties on the fluxes. In urban areas, it can be a challenge ensuring measurements are high enough to be above the roughness sublayer, yet low enough that interference from fog, cloud or boundary-layer processes is minimised. （$z_0 = 0.1\ z_H, z_d = 0.7\ z_H$）

Issues

4. Surface energy balance considerations

In urban areas, the energy balance is far more complex :

$$\boldsymbol{Q_{*}+Q_{f}=Q_{H}+Q_{E}+\Delta Q_{s}}$$

The net storage heat flux ΔQ_s is much larger than in most natural environments and very difficult to measure. The anthropogenic heat flux Q_f is highly variable in space and time, also very difficult to observe directly and can be substantial, particularly for dense urban areas during winter.

Meanwhile, the complexity of the energy balance means estimation of Q_E as the residual is generally not feasible in urban areas. In future, it is possible that improved capability to model Q_f and ΔQ_s could enable more accurate estimates of these terms to be used in scintillometry calculations.

Issues

5.Saturation

$$\sigma_1^2 \propto C_n^2 l_0^{-7/3} L^3$$

Whilst instrument specifications may give an upper limit to the operating range of around 5000 m, the tendency for large Q_H in urban areas (as a result of little vegetation cover and/or the additional energy supplied by anthropogenic activities) may mean the beam saturates short of this distance.

The risk of saturation can be reduced by using a shorter path, a higher path, or a larger aperture. To some extent, saturation can be corrected for using look-up-tables generated from theory. but the uncertainty increases with increasing saturation.

Summary & Outlook

Over the last 20 years research has shown scintillometry to be a valuable technique for observing structure parameters and fluxes in complex (including urban) environments. Scintillometry offers several advantages, both practical and theory-based, compared to EC but importantly it should be seen as a complementary technique.

The fact that scintillometers measure structure parameters, rather than fluxes. The non-linearity between structure parameters and fluxes means scintillometers will tend to overestimate fluxes by a few percent. Future studies should focus on improved understanding of scintillometer observations for both ideal and non-ideal landscapes. Development of a standardised processing tool for scintillometer data would allow for greater consistency between studies.

Summary & Outlook

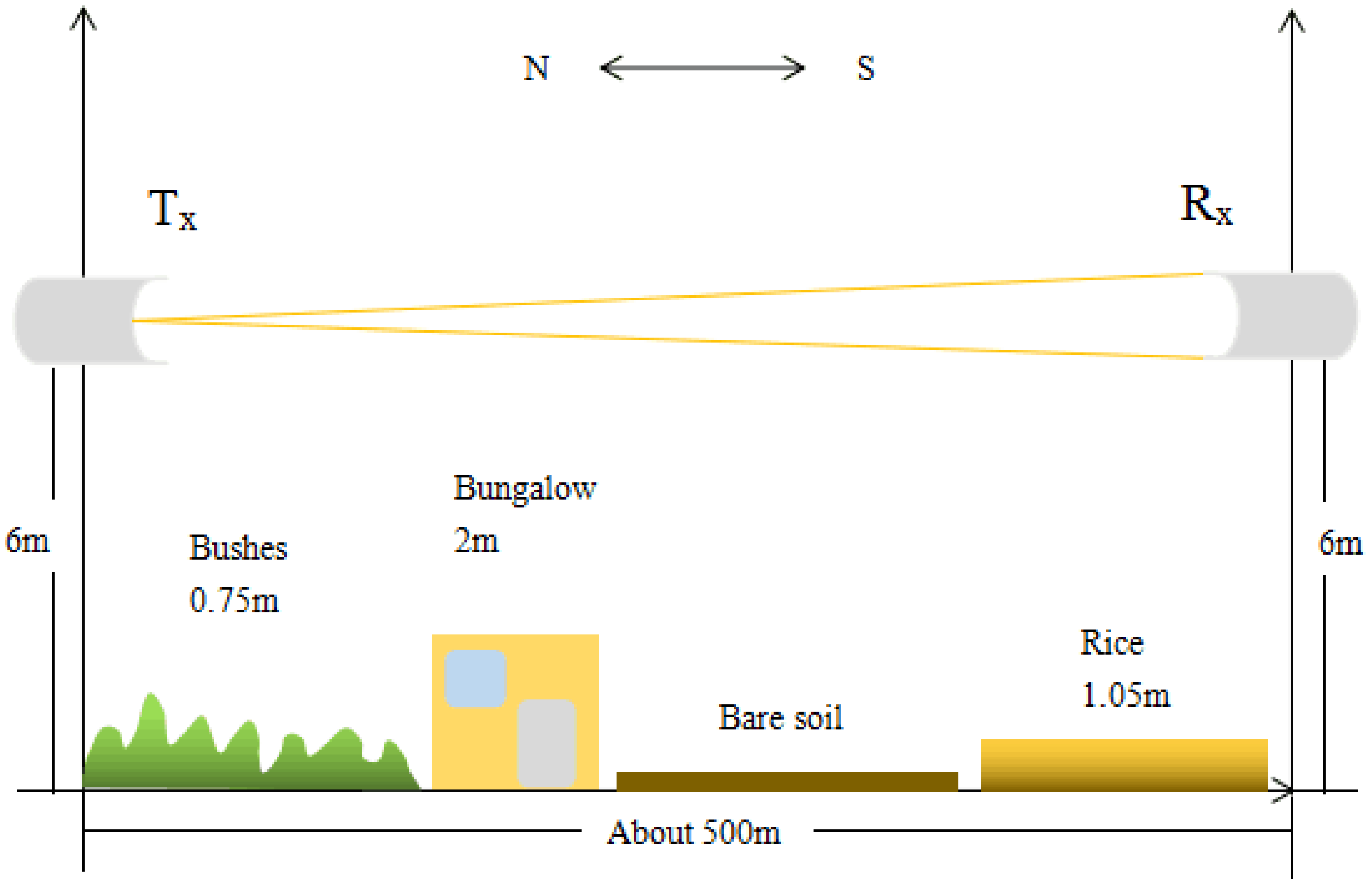

Figure 5. A Simple diagram of LAS

Notes : Direction of prevailing wind in Nanjing is east-west. In addition, the screen of LAS can not be exposed to sunlight. Therefore, the direction of the beam path should be south-north. The installation height is obtained from the literature.

Thank you for your listening!