Thoughts on Flux Tower Design

Peter Isaac with Jason, Lindsay, Darren, Steve, Sam, Carol, Reza, Richard and everyone else
Survey

- Who does not have a flux tower?
  - Who intends to install one this year?
- Who already has at least 1?
- Who has at least 2?
- Who has at least 3?
- 4? 5? 6? More?
- Who can't remember?
Outline

- What are we doing and why?
- What are the most important design criteria?
- Exercise in design
- Location, fetch and footprint
- Tower type and height
- Instrument suite, mounting and orientation
- Power and communications
Things That Will Be Covered

- A basic TERN/OzFlux flux tower
- Factors that affect
  - Design of facility
  - Choice of instruments
  - Choice of mounting height
  - Choice of location
Things That Will Not Be Covered

- Specialist or specialised systems
  - Non-CO$_2$ greenhouse gases
  - Profile systems in canopy
  - Slow response CO$_2$ systems
  - Respiration (chambers) measurements
  - PAR, total and diffuse radiation components
  - Ancillary data
The Scientific Method

Hypothesis

To explain some observed phenomena you can't explain now

Experiment

To gather data to test your explanation

Analysis

To process your data so it can be used to test your hypothesis

Conclusions

Hypothesis true or not?
Steps In Design

- Decide what data is required to test your hypothesis
- Decide the accuracy to which it is required
- Decide on the instruments, tower and data collection program to gather the required data to the required accuracy
- Iterate over the objectives and the number and quality of instruments until the budget balances
What Data Is Required?

- Depends on the hypothesis being tested
  - Generic hypothesis chosen for presentation
  - “Observations of CO2 and H2O fluxes can be used to parameterise a LSM to predict continental scale carbon and water budgets”
What Accuracy Is Required?

- Depends on the hypothesis being tested?
- What accuracy do modellers require for parameterisation and validation?
  - What accuracy do hydrologists require?
  - What accuracy do ecologists require?
- What accuracy can micro-meteorologists supply?
What Data Collection Rate Is Needed?

- Data collection rate before quality control
  - 95%, 90%, 80% ... ?
- Data collection rate after quality control
  - 90%, 70%, 50% ... ?
- High data collection rates can be expensive
  - High quality equipment
  - Redundant instruments
  - Resources for quick response to problems
  - Near-real time data retrieval via modem or similar
What Budget Is Available?

- How much money will it cost?
- Does the group have the people?
- Do the people have the skills?
- What else could you do with the money?

*This is usually the bottom line*
An Exercise

- Decide now if you are going to:
  - Use flux tower data to run models
  - Use flux tower data directly to interpret ecosystems
  - Use flux tower data to study micro-meteorology
  - Provide flux tower data to the other 3

- Separate into 4 groups as above

- Discuss the accuracy you require or can deliver
  - Radiation
  - Sensible heat, latent heat and CO2 fluxes

- Report back in 10 minutes
General Guides: Location

- Land use appropriate for hypothesis
- Minimise terrain slope, maximise upwind fetch
- Vehicle access (airboats OK)
- All else is a bonus
  - Proximity to mains power
  - Proximity to home
  - NextG coverage
Instrument
Footprint
2D Footprint

- Isopleths of contribution to measured flux (80%, 50% and 20%)
- Unstable conditions
3D Footprint

- Outer isopleth is 99% contribution
- Unstable conditions
Cross-wind Integrated Source-area Weight Function

- Unstable conditions
  - $L = -30m$, $u_* = 0.5m/s$, $z_0 = 0.03m$, $z_m = 4.5m, 20m$
Upwind Fetch

- Landsat 5 NDVI
- Radial arms indicate upwind extent of 80% contribution
- Unstable and stable conditions
- $Z_m \sim 2m$
Tower

- Must remain upright at all times
  - Kinglake (twice), Fogg Dam, Dry River
- Must be safe and easy to work on
- Must get instruments to correct height
- Type can be
  - Open lattice guyed tower
  - Walk-up tower
How High is High Enough?

- Surface layer depth $z_s$
  - Somewhere between $|z/L| < 1 - 2$ and $0.1z_i$
- Roughness sublayer depth $z_r$
  - Up to twice canopy height
- Ideally want to be above $z_r$ and below $z_s$
- What if instruments below $z_r$?
  - Katul et al (1999), BLM, 93, 1-28
  - “When comparing net carbon uptake and water budgets between different ecosystems derived from single-tower measurements within each system, it is necessary to interpret budget differences that are less than 20% with great caution”
How Low is Too Low?

- Twice canopy height (see previous slide).
- Five times canopy height if canopy patchy.
- Not less than 5 times path length, preferably more than 18 times.
- Loss of high frequency contribution to fluxes.
  - Burba and Anderson, “Introduction to the Eddy Covariance Method: General Guidelines and Conventional Workflow”, Li-Cor Biosciences
Instrument Suite

- Instrument suite determined by the hypothesis
- Balance between accuracy, reliability and budget
- Redundant instruments improve data collection
- Pairing fast and slow instruments improve data quality
  - LI-7500 and HMP45 for water vapour
- TERN/OzFlux instrument suite neglects some important terms
  - $\text{CO}_2$ accumulation in canopy at night and loss through drainage flows
  - Slow $\text{CO}_2$ measurement at LI-7500 height
Instrument Mounting

- Method should be easy to use, keep instruments stable and level when moved from maintenance to measurement position.

- Sonic/IRGA separation should be minimised without causing flow distortion around sonic.

- Avoid the shadow (wind and light) of the tower
  - Above tower top is good

- Raingauge above canopy, another at ground level
CMAR Tumbarumba
Instrument Orientation

- Radiation sensors point north (in SH)
  - Avoid shadow of tower
- Orient sonic into predominant wind direction
  - Minimise flow through tower
  - Mike Liddell has examined this
- Acceptance angle for sonic anemometer?
  - Does anyone reject outside this?
  - Does anyone use 2 sonics?
Calibration And Maintenance

- LI-7500 calibrated every few months
  - In the laboratory
  - CO$_2$ span gas at +/- 1ppm
  - LI-Cor 610 dew point generator

- CSAT calibrate/repair every 2 – 3 years
  - Transducer pitting, electronics

- CNR1/4 re-calibrated every 2 years

- HMP45 re-calibrated every year

- Replace cables every few years
Calibration And Maintenance

- Have a maintenance plan and a calibration schedule
  - Spare instruments reduce data gaps
  - Community pool for big items?
- Site visit every week, at least every month
- Site check list
  - Regular items e.g. raingauge, clean solar panels
- Site log book
  - Record everything (iPhone voice recording)
Communications

- Single best purchase to improve data quality and collection rate
- Maxon Modmax NextG modem $450
  - Fast enough to get 10 Hz data
  - Used out to 45km with 15 db yagi
  - Not quite line of sight, some refraction at 850 MHz
- Iridium satellite modem $2500
  - When site out of NextG coverage
  - 2400 baud, OK for 30 minute data
Power

- Solar panels
  - Install 5 times the load, 10 times in NT
  - Don't mount under radiation sensors
  - Mount above ground to keep cool
- Auxiliary generator
  - Noisy, costly, local source of CO$_2$
- 240 VAC Mains
  - If available but buy Green Power!!
Summary

- It’s easier to collect good data from the start than to clean up messy data later.
- Put time into thinking about what you’re doing and why, be clear about what data you need.
- Resist the temptation to expand your objectives at the expense of the gear.
- Buy the best instruments you can afford and install redundant instruments.
- Pay for near-real time communications with your site.
“Don’t do as I do, do as I say”