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

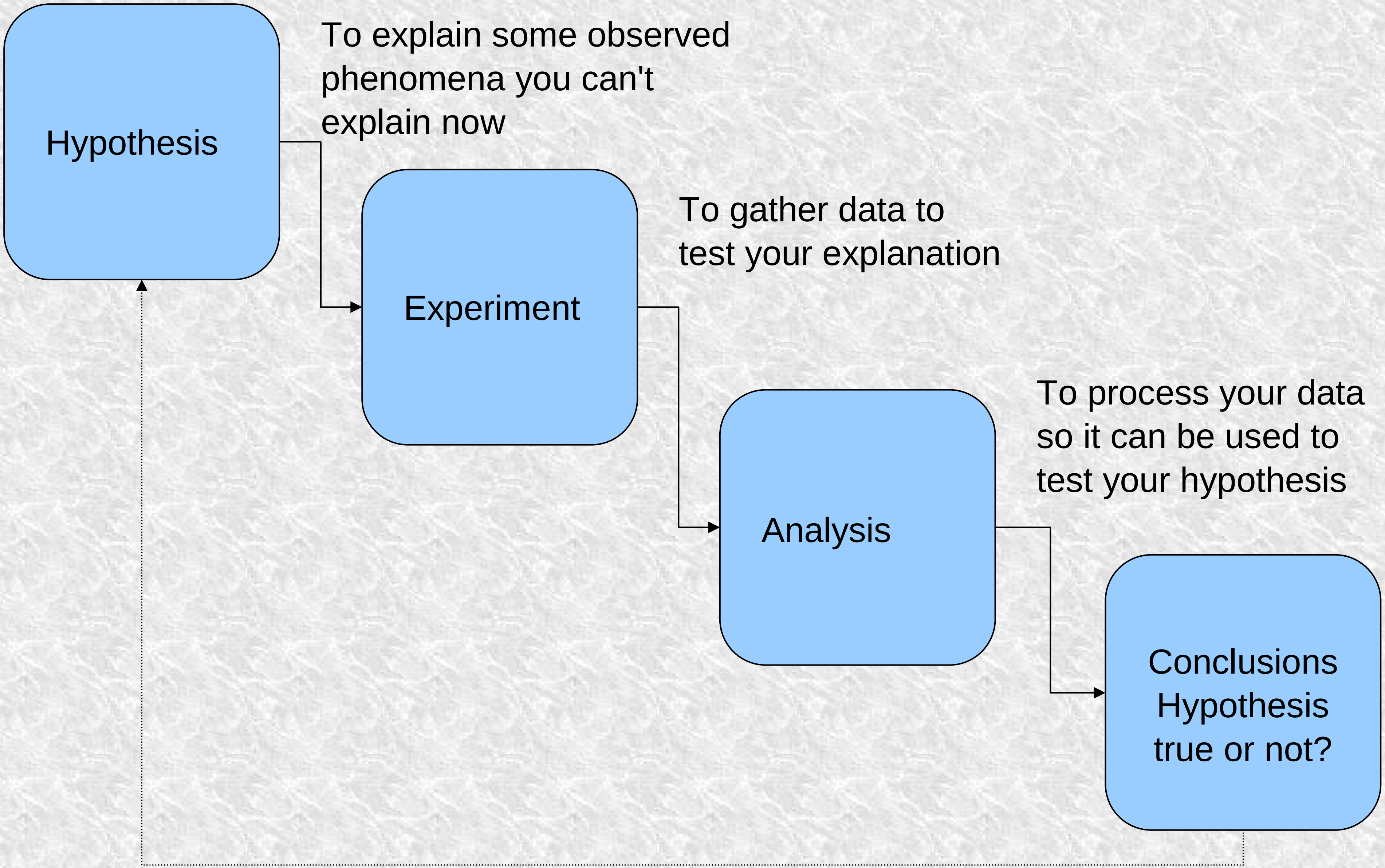
Things That Will Be Covered

- 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



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 CO_2 and H_2O 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?

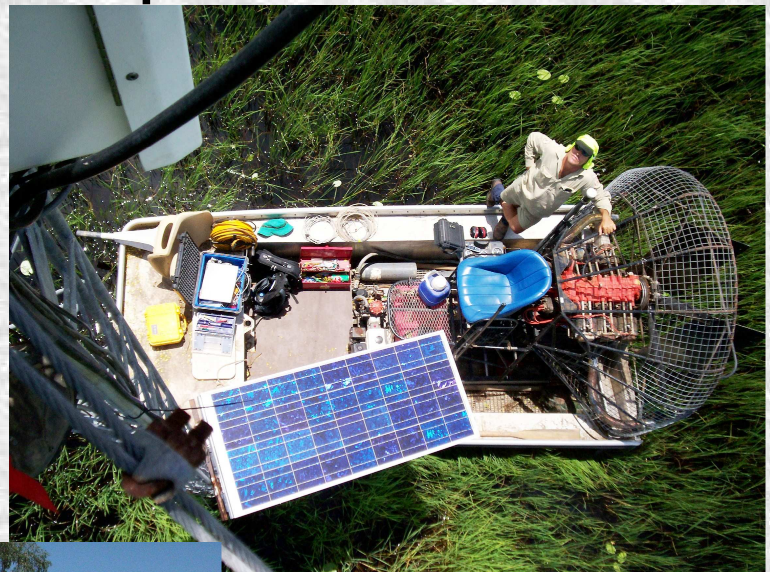
This is usually the bottom line

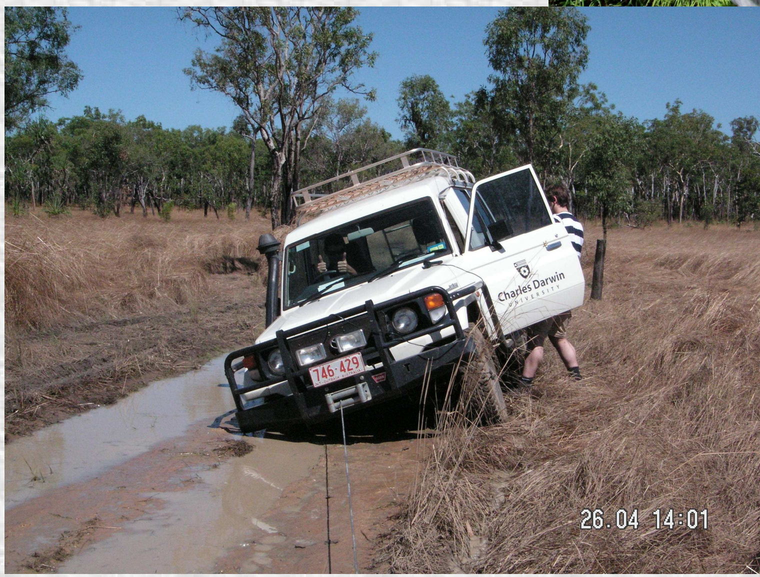
An Exercise

- 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 CO_2 fluxes
- Report back in 10 minutes

General Guides: Location

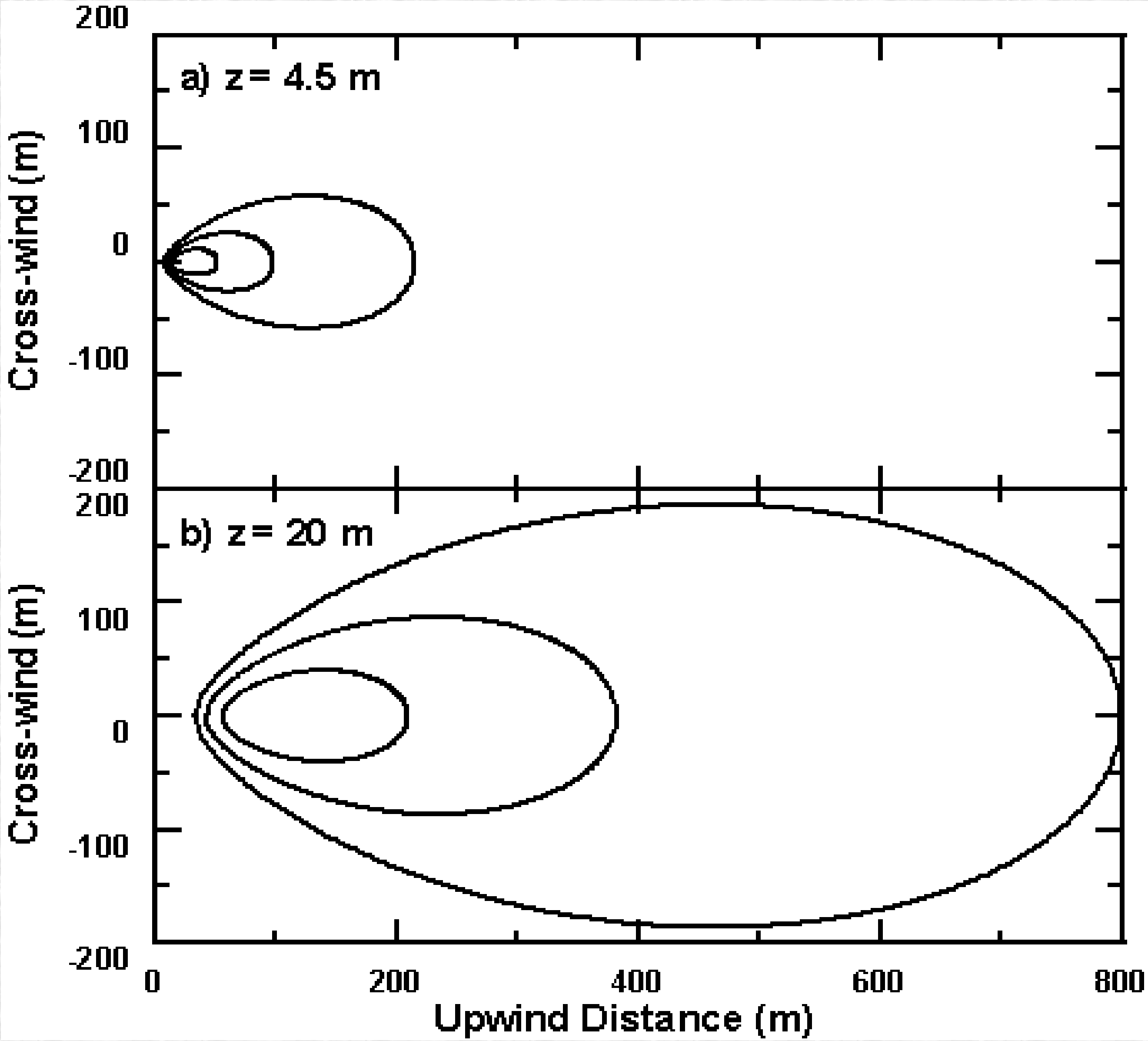
- Land use appropriate for hypothesis
- Minimise terrain slope, maximise upwind fetch
- Vehicle access (airboats OK)
- All else is a bonus
  - Proximity to mains power
  - Proximity to home
  - NextG coverage





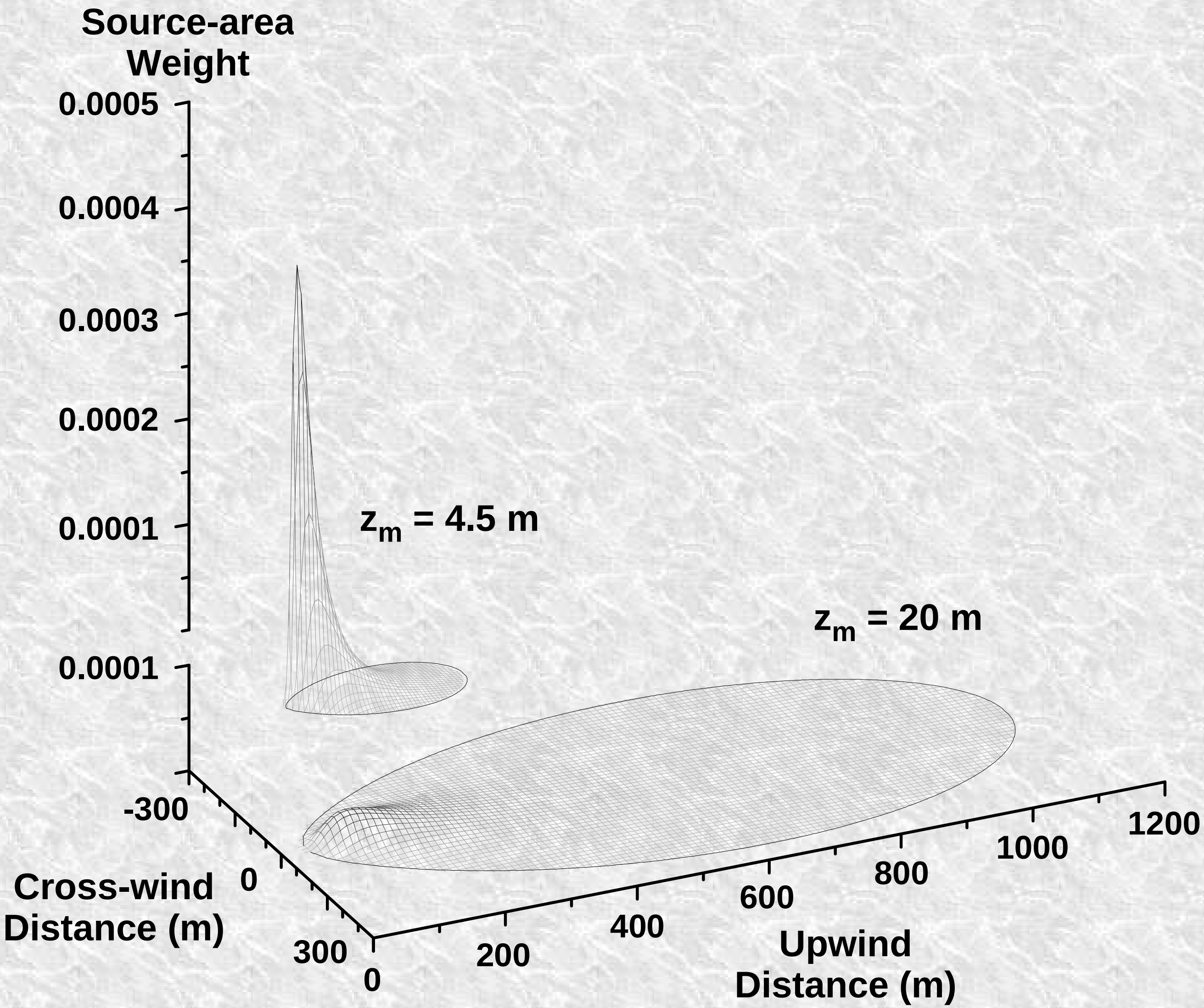
Instrument Footprint

2D Footprint



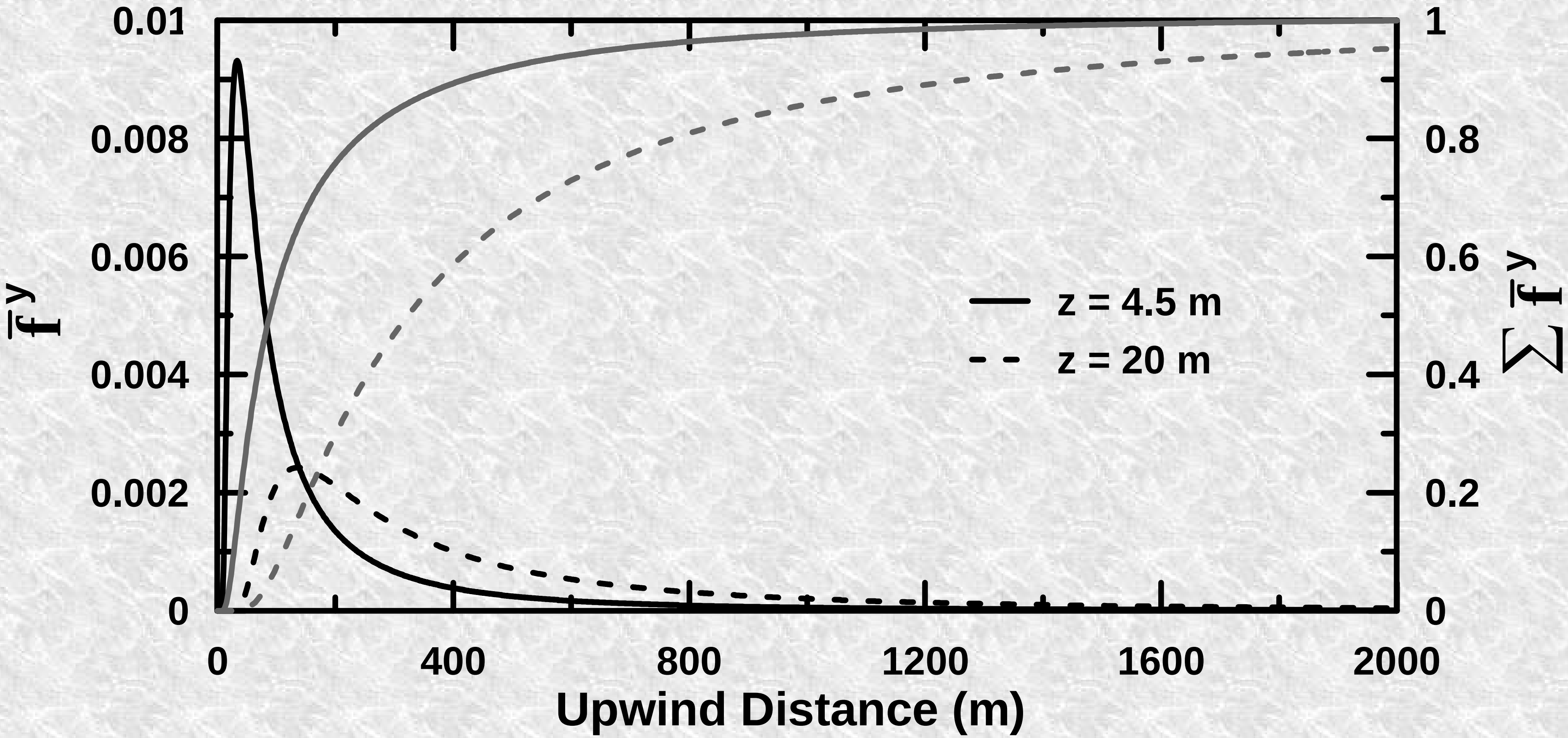
- Isopleths of contribution to measured flux (80%, 50% and 20%)
- Unstable conditions

3D Footprint

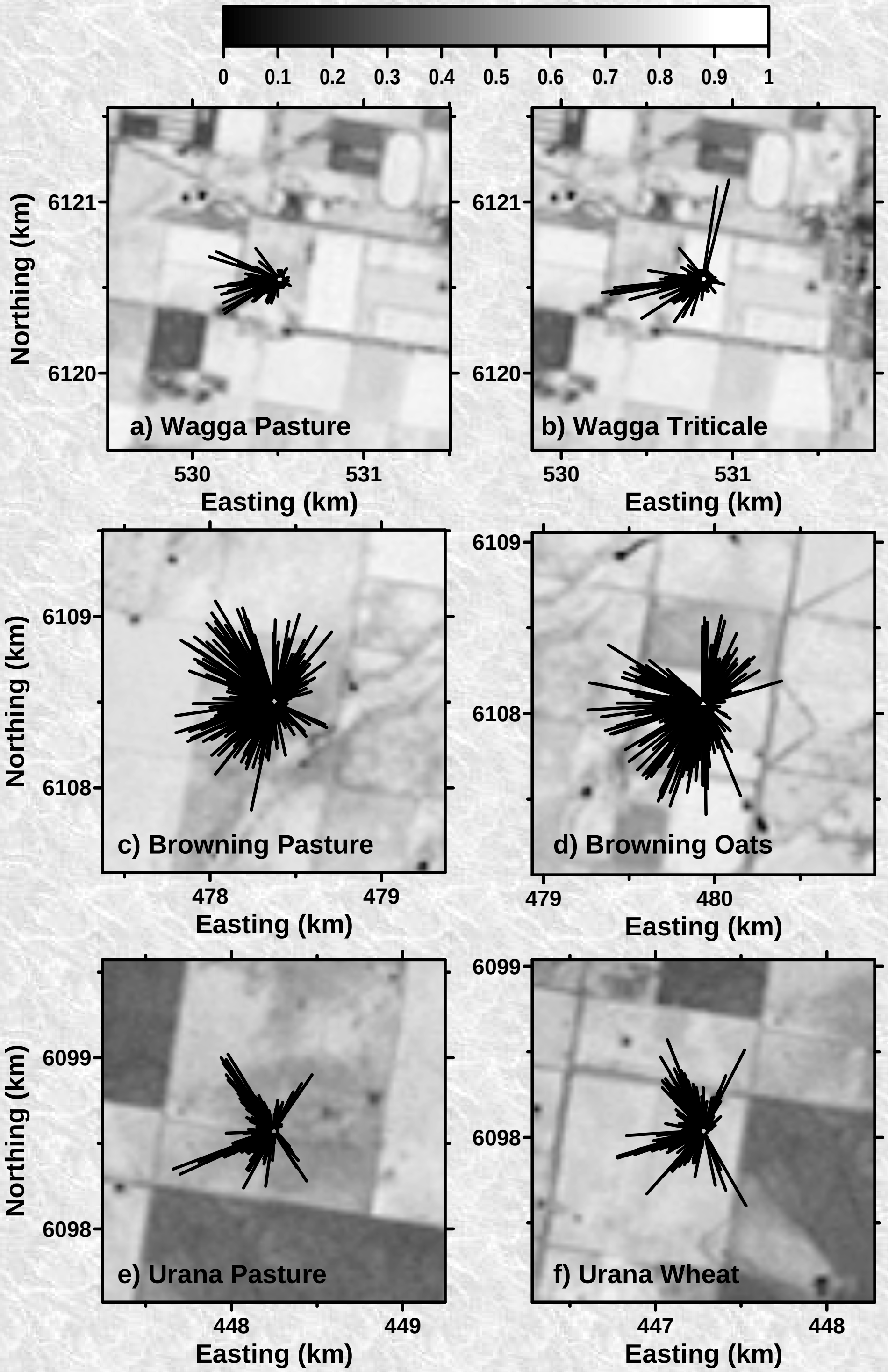


- Outer isopleth is 99% contribution
- Unstable conditions

Cross-wind Integrated Source-area Weight Function



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



Upwind Fetch

- Landsat 5 NDVI
- Radial arms indicate upwind extent of 80% contribution
- Unstable and stable conditions
- Z_m ~ 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
  - CO_2 accumulation in canopy at night and loss through drainage flows
  - Slow 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

Monash/CDU

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”