Sampling requirements

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Periphrase:
...not what you *know* you don’t know that hurts you

- it’s what you *don’t know* that you don’t know, that threatens success.
Investigating the unknown

Doppler Lidar

- Remote sensing system
  - Similar to Doppler radar
  - Transmits eyesafe infrared (IR) light
- Aerosol targets – excel. tracers of the wind
- > Hemispheric scanning
- Return signal includes aerosol backscatter in addition to frequency (Doppler velocity) data

Courtesy Scott Sandberg
NOAA/ESRL Lidar – Variety of platforms

NOAA research vessel
Ronald H. Brown

DLR Aircraft Falcon
Lidar beam

TEA CO$_2$

Mini-MOPA Doppler Lidar

HRDL: high-resolution Doppler Lidar
Lidar measurements = Types of scan

Azimuth - Conical scans

Elevation - Vertical-slice scans

Fixed-beam “scan”
Derived products — mean profiles

E.g., HRDL vertical-slice-scan data

Scan data

Profiles

Time-height cross section

Mean wind speed

Turbulence variance (TKE)

Other analysis products
Advantages of hi-res lidar

- Each scan → spatially ave’d profile (20-30s)
  - **Stationarity** important issue for **stable** conditions
  - Can further average in time, greater precision
  - 10-20 cm s\(^{-1}\) vs. 1-2 m s\(^{-1}\) - other r-sensors

- High time resolution  (30 s to 2 min vs sev. min)

- High vertical resolution  (1-10 m <rhi>)

- Turbulence profiles too
  - Useful quantity ~ TKE (vs. \(C_N^2, C_T^2\))
  - Quantitative profiles (vs. qual / semi-quant)
  - **Verification** → < we’ve done it >
Verification

– HRDL $\sigma_u^2$ vs. tower TKE

Mean speeds nearly equal (1- to 15-min averages) (<10 cm s$^{-1}$)

TKE vs. $\sigma_u^2$ - both sonic

[HRDL (lidar) $\sigma_u^2$ vs. TKE]

- (a) 3 min
- (b) 5 min
- (c) 10 min
- (d) 15 min

$r = 0.88$

$r = 0.90$

$r = 0.92$

Benefits of hi-res measurements

Great-Plains Low-Level Jet

(LLJ – nocturnal accel)
High-resolution Doppler lidar

Map of Great Plains site locations

Lamar CO

Lamar Wind Energy Project

CASES-99

CASES-99 Kansas
Different shapes of the LLJ – sometimes double, multiple maxima

LLJ: many definitions – here lowest wind-speed max
(contROLS SBL and wind in turbine layer)
Aside: LLJ/ SBL ‘factoids’

- Stable conditions 2/3 of diurnal cycle (Colorado, N.D. Kelley)
- Most of wind power generated during nighttime hours, all seasons (J.K. Lundquist, Pac NW, cx terrain) (later talk this am)
- Nocturnal channeled flows, mtn basin – LLJ structure evident (Great Salt Lake basin)
- Offshore wind profiles – LLJ structure evident (Gulf of Maine)
- Need to understand LLJs
LLJ examples
Cx terrain and offshore

Thermally forced down-basin flow
Topography hits

[Banta et al. 2004: J Appl Meteor., 43, 1348ff]
LLJ examples

Complex terrain and offshore

LLJ structure
LLJ conditions
1) Mean shear, profile shape
Colorado Green
Distribution of LLJ shear

Shear > 4 m/s per 100 m more than 90% of time
> 8 more than 50% of time

0.1 s⁻¹ = 1 m/s per 10 m of height, or 10 m/s per 100 m

Power-law profiles not applicable to LLJ profiles
LLJ conditions

2) Temporal changes at blade level

Big, deep ramp = cold front
Ramps (several m s\(^{-1}\)) beneath LLJ

Subjet ramps – affect uncertainty of power output predictions

Predictable?

- If so, need to learn how
- If not, need to characterize, assess uncertainty

Either requires high-quality measurements

Credibility: Variations visible in scans
High-quality measurements

3) SBL depth $h$
Hi-Res, hi quality measurements:

**SBL depth**

- A very basic SBL variable $h$ (NWP too)
- Traditionally difficult measurement
- Steeneveld et al. (2007) estimate $+/-$ 30-40% by current measurement technology
- Essential definition of BL:
  - turbulence based

Top of surface-based turbulent layer $h$ often coincides with LLJ height
Processed data – profiles $U, \sigma_u^2$
3 types of mean-wind profile

- Ty I - Nose
- Ty II - “Flat”
- Ty – III Layered below max

All 3 on any given night
Types I,II - well behaved
Type III - the problem type
Verification

If can identify & eliminate Type III profiles, MAE - 30% → 8% (in some cases <5%)

Need hi-res, high-precision profiles to ID Type III’s

Pichugina and Banta 2010: JAMC,
Max speed; top of SBL
Impact of hi-res

- Stable, nighttime period important for WE
- Lots of structure, dynamics crammed into a shallow layer (*turbines embedded in this layer*)
- Surface measurements not helpful
- Strong height dependence of U, other variables → need accurate meas of profiles through lowest few 100’s m
- Required vertical resolution $\Delta z$
  - 10 m ok
  - 40-50 m prob too coarse, esp shallow SBLs
  - 25 m prob marginal
Best help for WE

- Lack of meas aloft = much we don’t know
- Move SBL processes from
  - What we don’t know we don’t know
  - At least to ‘what we know we don’t know’
  - Hopefully some to ‘what we know’
Thank you!!

**LLJ impact:** strong shear produces turbulence, wave activity

*Newsom and Banta 2003: J. Atmos. Sci, 60, 16-33.*
120-m tower

Typical 48-hr diurnal variation of wind speeds at 3 heights over Colorado plains

Oct 19-20, 2001

5-min mean wind speed (m/s)

113 m
52 m
3 m

Shear exponent

Courtesy Neil Kelley, NREL
Role of LLJ in controlling fluxes

- Nocturnal LLJ after sunset
- LLJ accel. → Shear → Turbc
- Hi turbc → Hi turb fluxes

- LLJ and shear-driven SBL closely intertwined
- *Source for wind energy over Great Plains*

Top of surface-based turbulent layer $h$ often coincides with LLJ height
Samples of Ground-based Lidar Measurements
- calculated from vertical-slice (RHI) scans

** night-to-night differences significant!!
"Core of the jet tended to be higher and slower than… observed."
"…likely related to the enhanced mixing of the PBL schemes."

【 Small differences = big $$ 】

Storm et al. 2008; Wind Energy