ValidWind applications: Wind power prospecting and aerosol transport

Tom Wilkerson*, Alan Marchant, Tom Apedaile, Danny Scholes, Jed Simmons, and Bill Bradford

Energy Dynamics Laboratory, 1750 Research Park Way, North Logan, UT 84341

SPIE-Europe, Toulouse, France
Septembre 20 – 24, 2010

* tdw@sdl.usu.edu (435-760-2468)

ValidWind™

A rapid-response lidar balloon tracker for high-resolution wind profiling

Sensor should be **simple**, **inexpensive**, and **easily deployed** – and be **dependable** for wind energy prospecting and wind shear detection, and should:

- provide useful data down to resolutions ~1 sec & 5 meters res.
- profile wind down to 2 meters & up to 2000 meters alt./range
- provide wind profiles for groups lacking other remote wind sensors
- be capable of calibrating other wind sensors under development

Outline

- Balloon tracking system
- Equipment
- Wind measurements
- **Confirmation of ValidWind measurements**
- Regional applications (Utah)
- Conclusions and future work

ValidWind : Functionality & Basic Equipment

Retro-reflector on balloon

XL200 lidar rangefinder

- **<u>Function</u>: Profiles winds in the lower atmosphere by tracking lightweight, small balloons**

- **<u>Primary Data</u>: lidar range R, azimuth ϕ, elevation θ**
- **Result: Vector velocity of balloons in 3D and time**

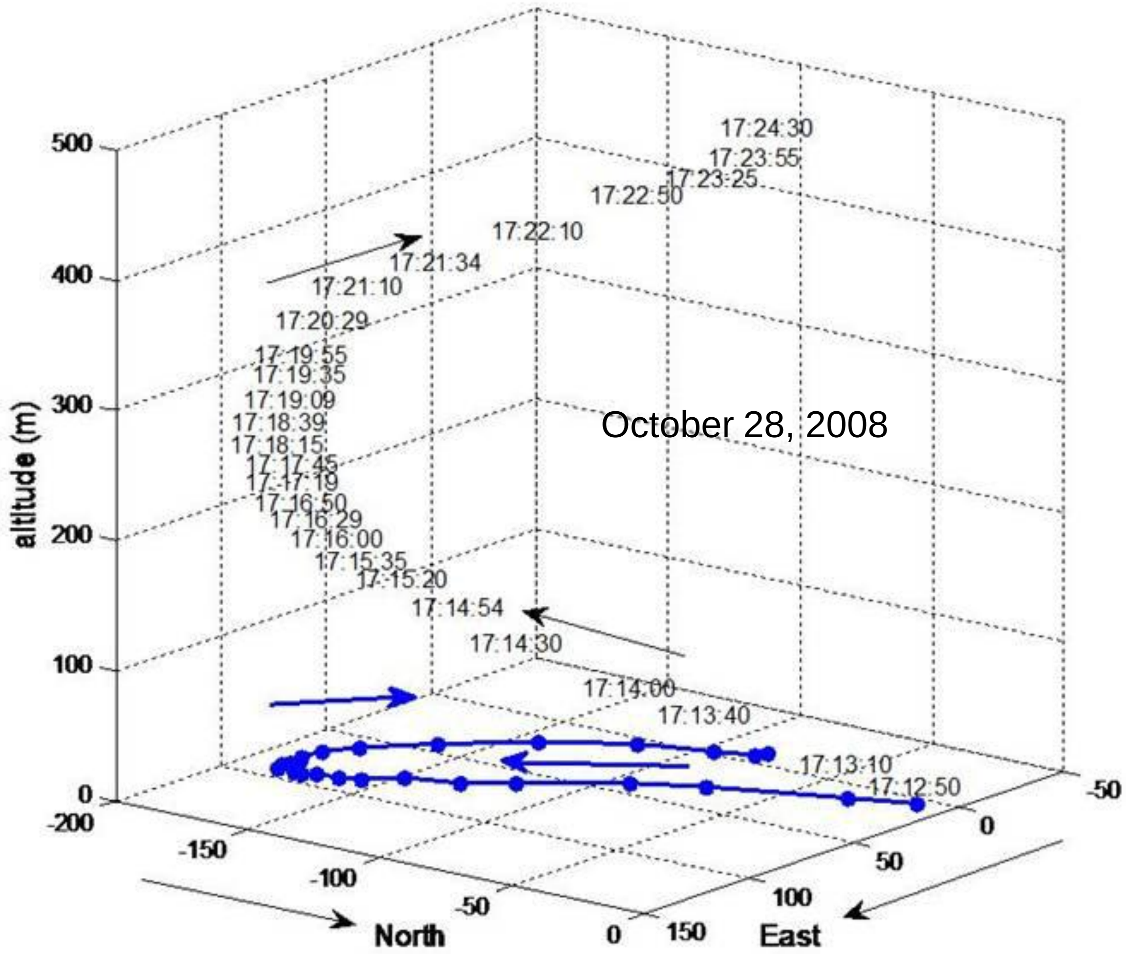
- **<u>Wind Parameters</u>**
- **Horizontal wind components**
- **Horizontal wind speed & direction**
- **Wind shear profiles**

- **<u>Region</u>: Boundary layer, troposphere: 2 – 2000 m**

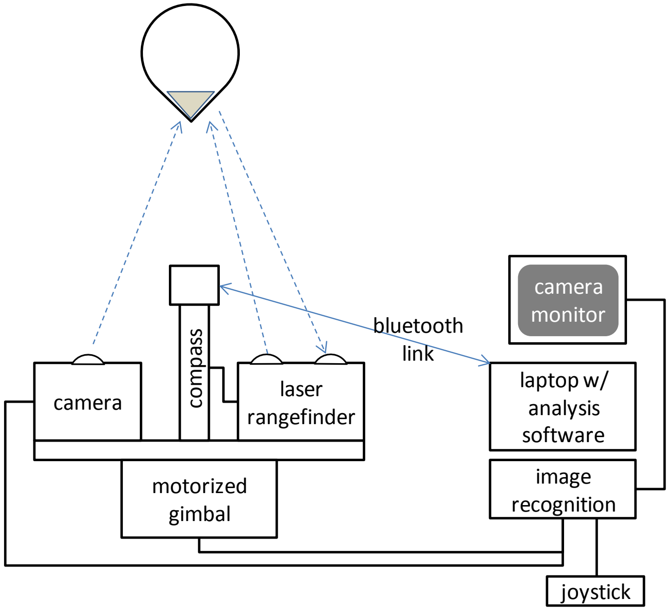
- **Day/Night operation**
- **Complex terrain**
- **Cost-effective, rapidly deployed anywhere**
- **New: Auto-tracking developed**

EDL | Energy Dynamics LABORATORY
Utah State University Research Foundation

Balloon Trajectories = 3D Views of Horizontal Wind and Vertical Wind + Terminal Ascent (Bouyancy)



Auto-Tracking Scanner System for *ValidWind*



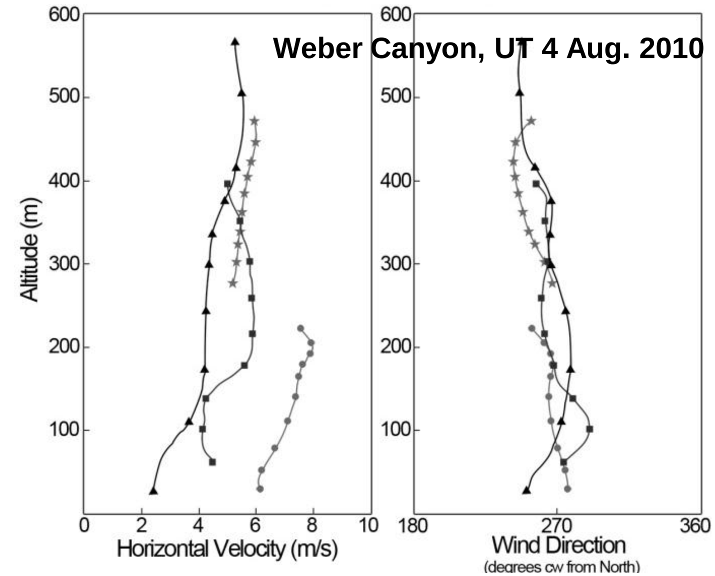
- Impulse 200XL, *Laser Technology*
- Biaxial, apertures 50 mm diam.
- Integrated range/direction sensor
- Range resolution 1 meter
- Inclinometer (+/- 0.1º res.)
- Compass module (+/- 0.01º res.)

- QuickSet Gemineye gimbal scanner
- Sony 36X optical zoom camera
- PerceptiVU PVU-TT-M6 image recognition

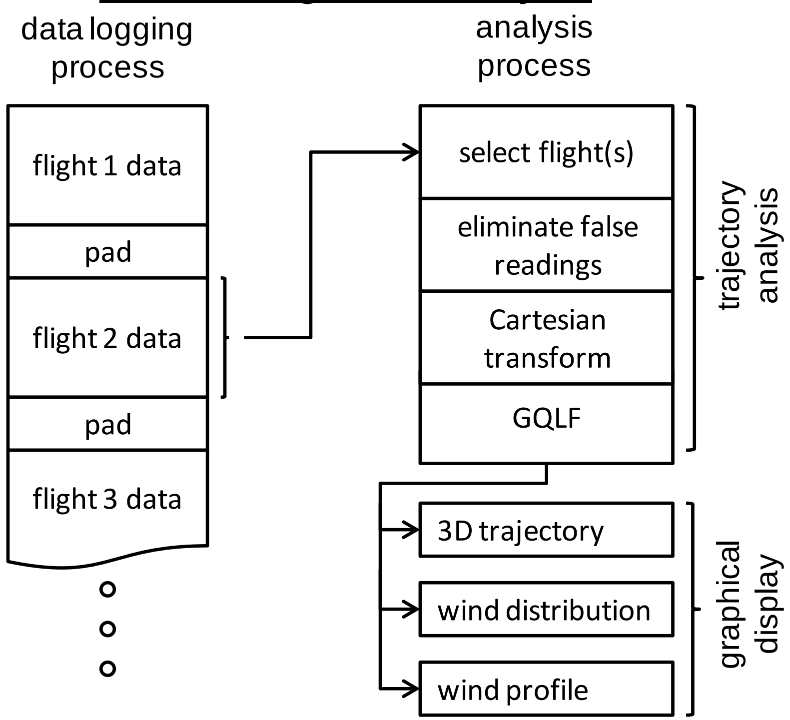
Scanner tracks on image of balloon once the balloon is acquired by joystick.

ValidWind Data Flow

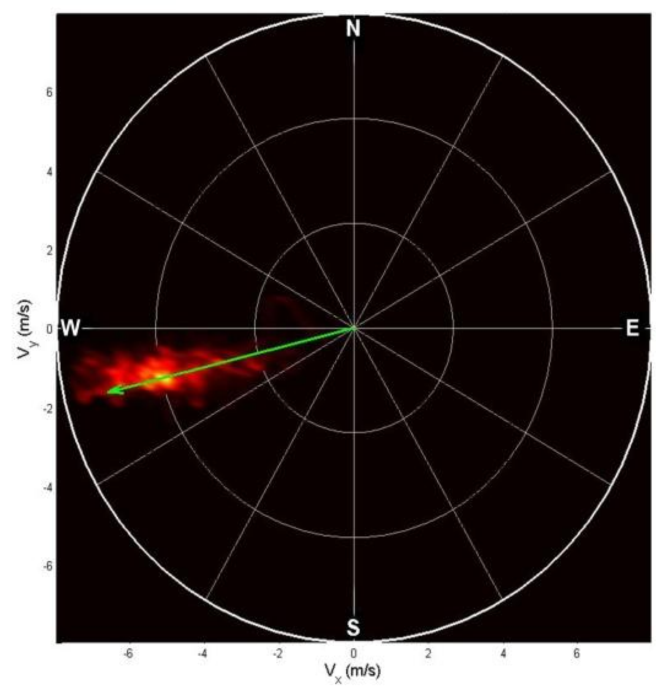
- Examples of quick-look results (Horizontal wind, direction)
- Capability for timely adjustment of balloon and launch parameters



<u>Data storage and analysis</u>

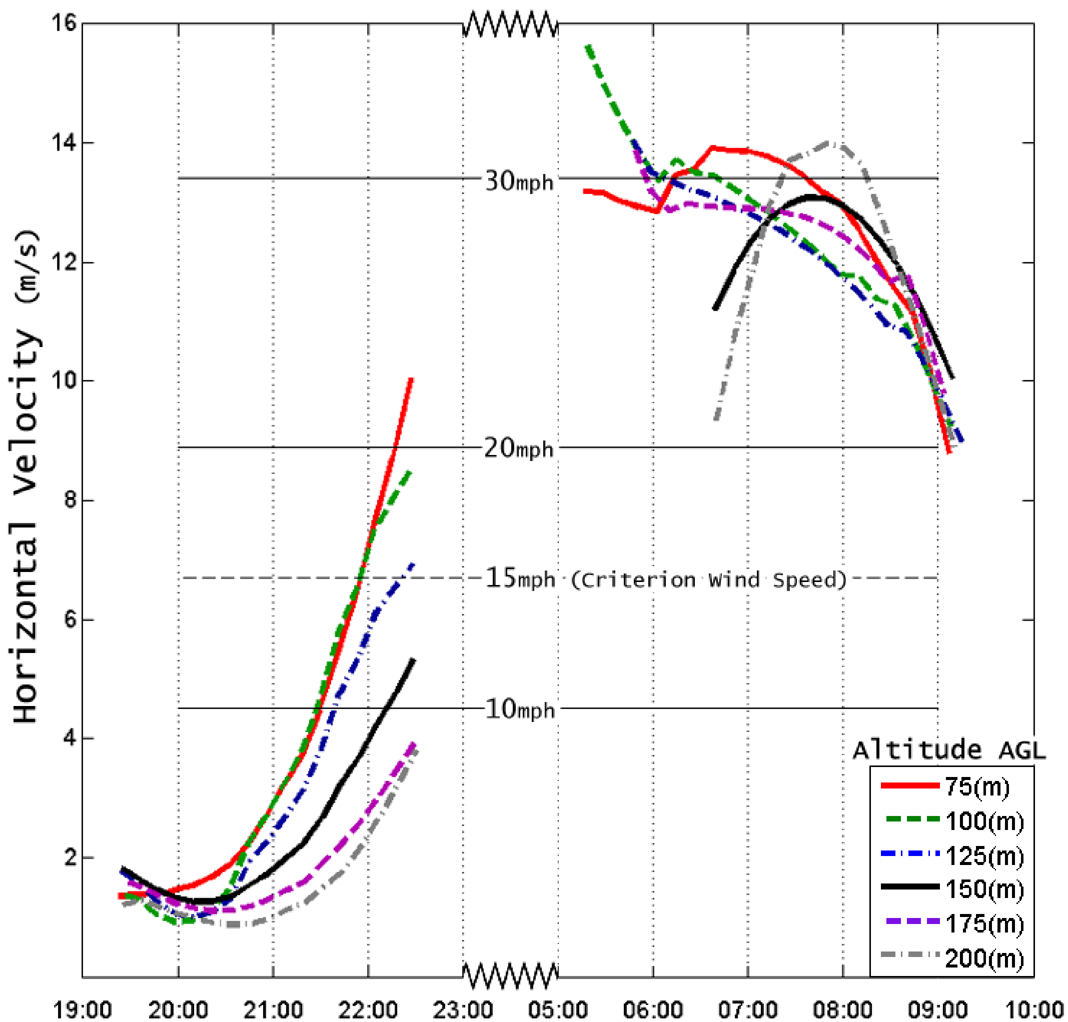


Weber Canyon, UT 12 Aug. 2010



EDL Energy Dynamics LABORATORY
Utah State University Research Foundation

Logan Canyon Winds, Aug. 19/20, 2009



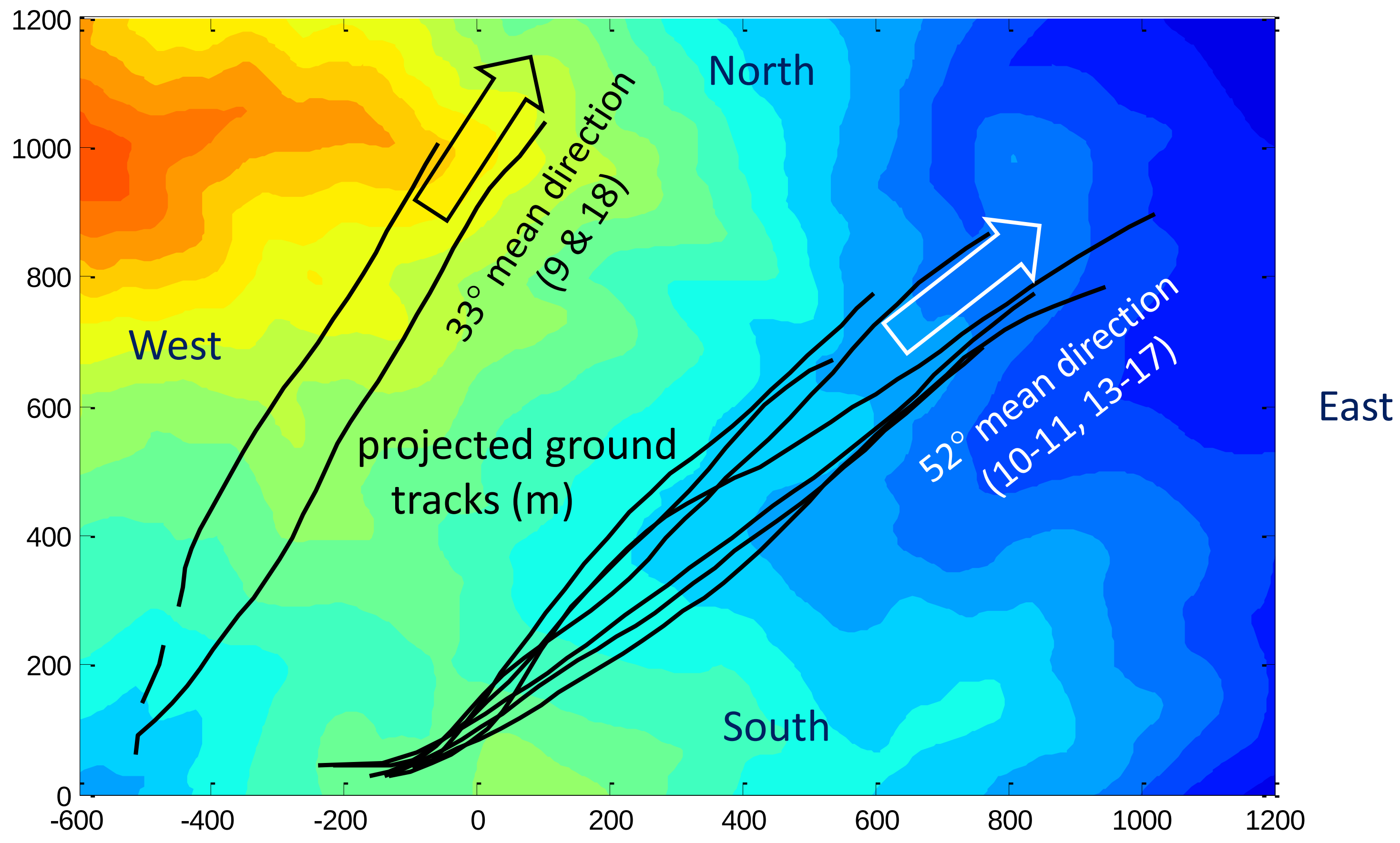
- Proposed wind turbine site at the mouth of Logan canyon
- Supplementary power for USU campus ?
- Exploit canyon drainage wind
- Nighttime operation with

  illuminated balloons

- <u>ValidWind Campaign results:</u>
  - Nocturnal jet develops from the bottom up, then decays coherently
  - Ideal turbine height ~ 100m (unobtrusive)
  - Jet duration 11 hours (winter evaluation needed)

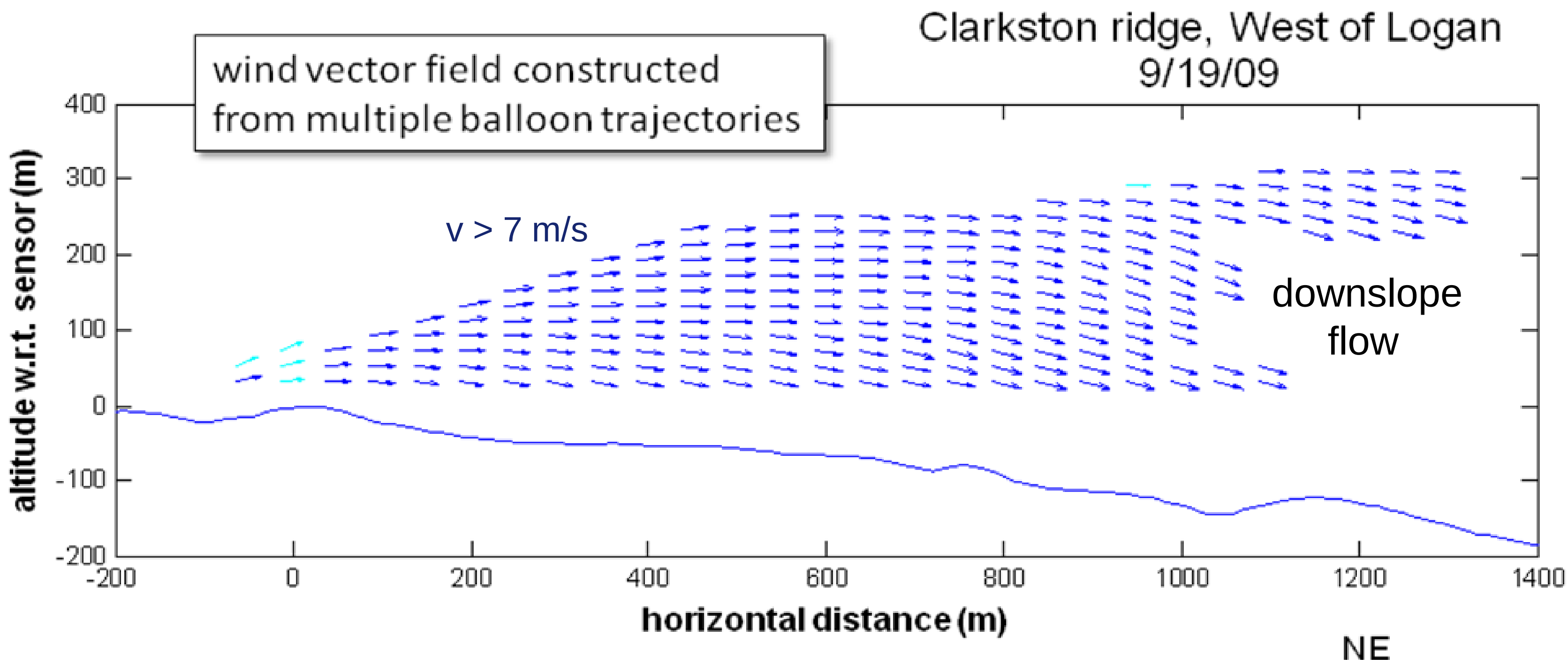
Mountain Ridge Winds above Clarkston, UT

Two types of trajectories from different launch sites, Sept. 19, 2009



Clarkston Mountain wind resources under consideration by State of Utah

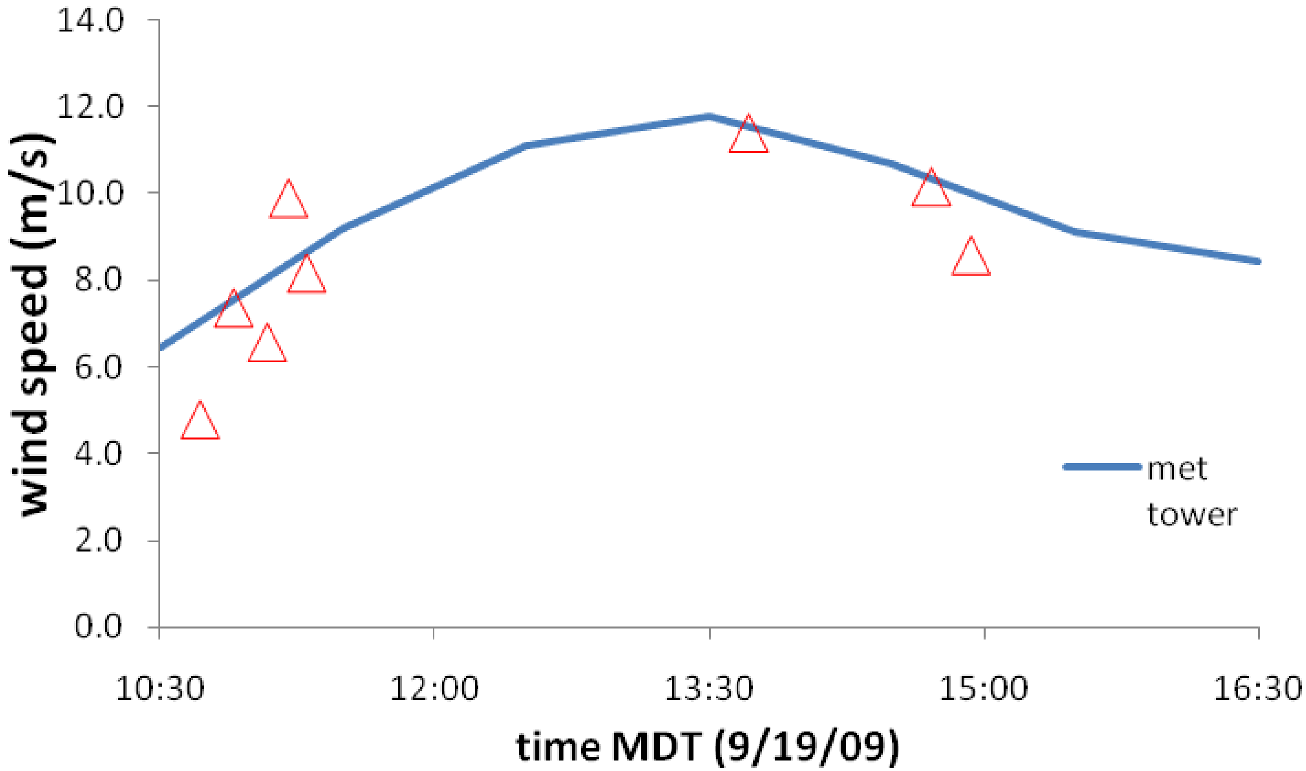
Wind Field Cross Section from Several Trajectories



- strong updraft at the ridgeline transitions to
  a strong leeward downdraft
- projected to plane **52°** from North (main group)
- horizontal velocity steady at **7.8 ± 1.3 m/s**
- vertical flow shifts dramatically from +1.6 to -3.5 m/s

Confirmation of *ValidWind* Data: Clarkston Mtn. Winds

ValidWind (Δ) at 60 meters vs. anemometer on 60 meter MET tower



EDL | Energy Dynamics Laboratory
Utah State University Research Foundation

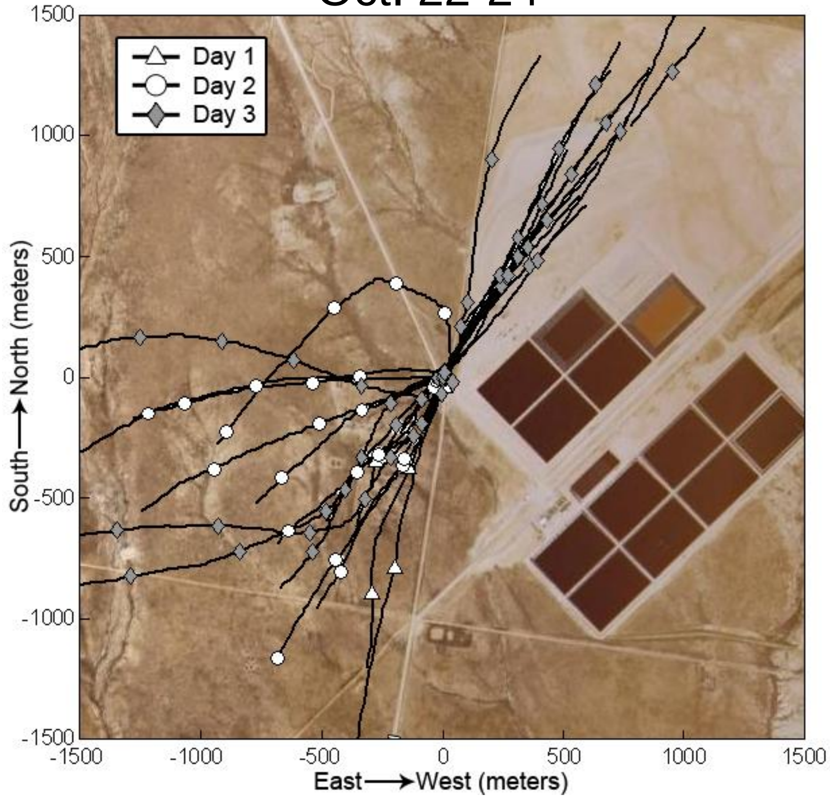
Study of Airborne Emissions: Aerosols and Wind

Danish Flats, Grant County, UT   October 22-27, 2010

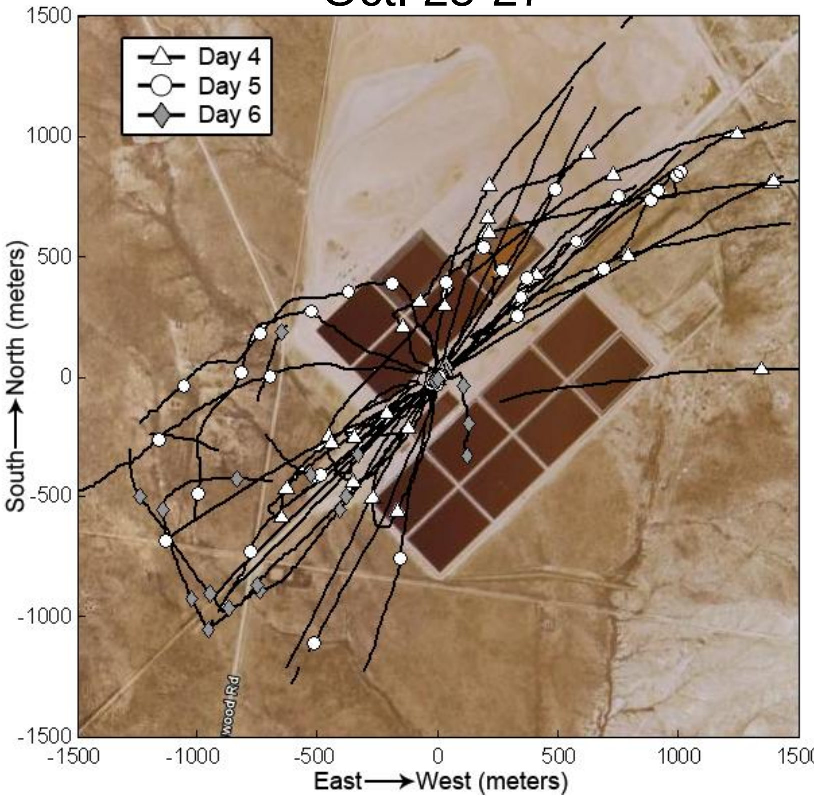
Waste WaterTreatment Facility

50 *ValidWind* flights during AGLITE lidar measurements of particulate fluxes.
Balloon winds compared with MET tower data at 15 meters alt.

Oct. 22-24



Oct. 25-27

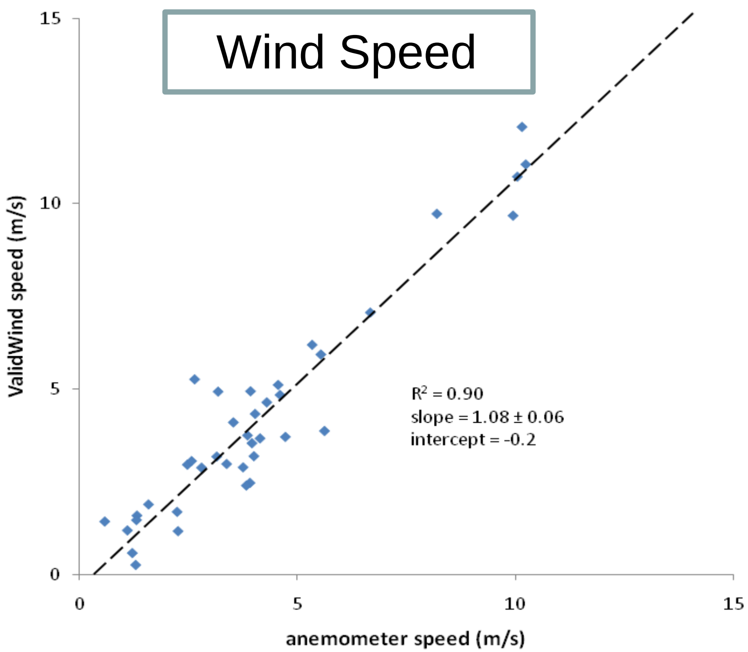


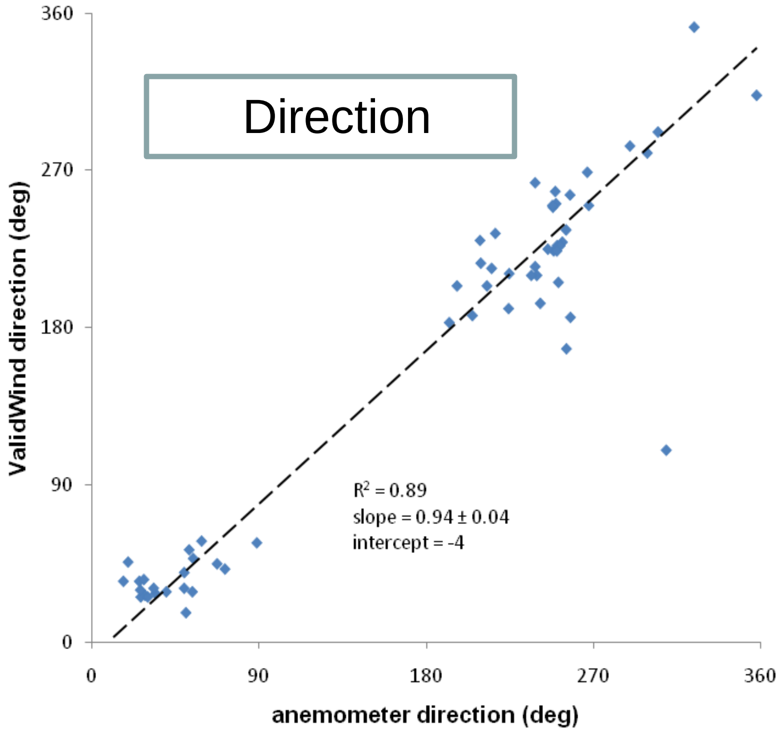
EDL | Energy Dynamics LABORATORY
Utah State University Research Foundation

Confirmation of *ValidWind* Data on Winds Danish Flats, UT

ValidWind vs. anemometer on MET tower

Agreement: Correlations 0.89 – 0.90, Slopes 0.94-1.08





Conclusions

- ***ValidWind*** profiles
- Excellent spatial and velocity resolution
- Access to wind in 3D space above and downwind of site
- Low cost system
- Easy setup, rapid data acquisition and results
- Many Applications
    - Boundary layer meteorology
    - Inversions
    - Diurnal wind patterns
    - Topography effects
    - Wind shear profiles
- Wind prospecting: Critical data for prospective wind turbine sites and MET tower placement
- Current USU development program will move toward greater automation, broader wind surveys, and development of other remote wind sensors

Backup Slides for *ValidWind* Presentation

SPIE-Europe, Toulouse, Septembre 2010

Tom Wilkerson*, Alan Marchant, Tom Apedaile,
Danny Scholes, Jed Simmons, and Bill Bradford

Energy Dynamics Laboratory, 1750 Research Park Way,
North Logan, UT 84341

EDL | Energy Dynamics LABORATORY Utah State University Research Foundation

Trajectory Analysis for *ValidWind*

Lidar Observations: range $\mathbf{R(t_i)}$; elevation $\boldsymbol{\theta}\mathbf{(t_i)}$; azimuth $\boldsymbol{\phi}\mathbf{(t_i)}$; and corresponding timestamp $\mathbf{t_i}$.
Lidar sampling intervals $\Delta t_{i-1,i} = t_i - t_{i-1}$ are irregular.

Raw Local Coordinates:
$x_i = R_i \cdot \cos(\theta_i) \cdot \sin(\phi_i)$ (+**x** points East)
$y_i = R_i \cdot \cos(\theta_i) \cdot \cos(\phi_i)$ (+**y** points North)
$z_i = R_i \cdot \sin(\theta_i)$ (+**z** points upward)

Trajectory Smoothing. At each evaluation time, t, perform a <u>Gaussian Quadratic Least-squares Fit,</u> (**GQLF**): $x_i = b_0 + b_1 \cdot (t_i - t) + ½ \cdot b_2 \cdot (t_i - t)^2 + \varepsilon_i$
with Gaussian weights $w_i = \exp(-½ \cdot (t_i - t)^2 / \sigma^2))$.
b_0 is the estimated trajectory, x(t); b_1 is the velocity component, $v_x(t)$; and b_2 is the acceleration, $a_x(t)$.

Smoothing interval σ = 10 sec provides effective smoothing of measurement noise with minimal distortion of the balloon trajectory. Smoothing for y & z is similar

This method handles the asynchronous lidar data and provides estimates at arbitrary evaluation times.

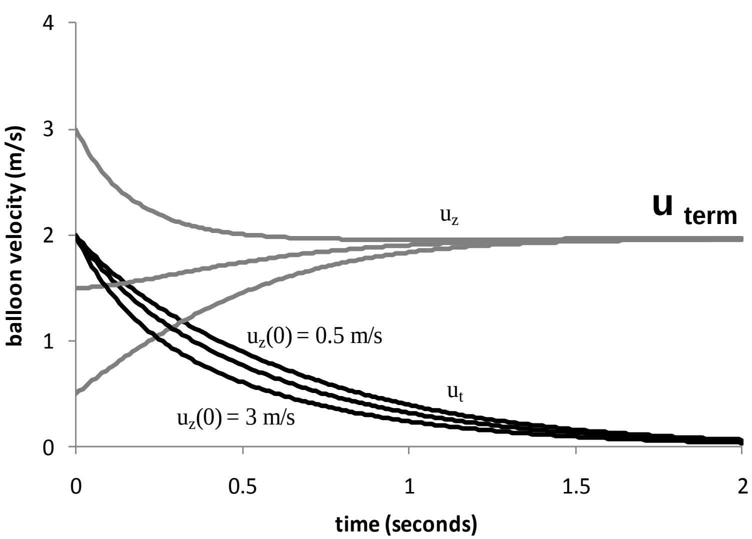
EDL | Energy Dynamics LABORATORY
Utah State University Research Foundation

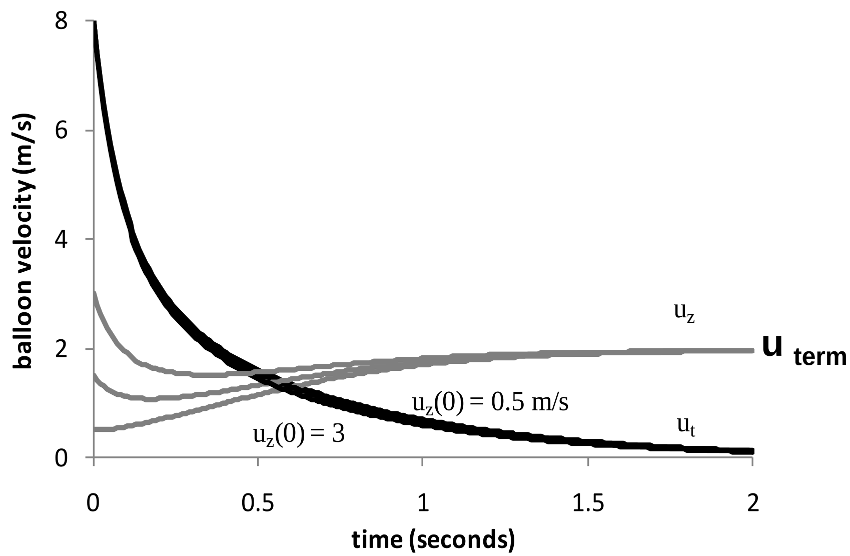
Balloon Dynamics: Balloons Follow the Wind

Derivations from **: Fichtl, G. F., R. E. DeMandel, and S. J. Krivo: "Aerodynamic Properties of Spherical Balloon Wind Sensors,“ J. Appl. Meteor. 11, 472-481, (1972).**

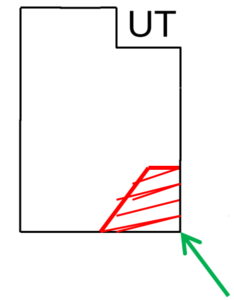
We have shown that the coupled, nonlinear horizontal and vertical motions of balloons rapidly respond to horizontal wind shear imposed at $t = 0$.

They quickly (1 – 2 seconds) take on the new horizontal velocity and, just as rapidly, settle back into their drag-limited,‘’terminal” vertical ascent rate (**u** $_{\text{term}}$.).





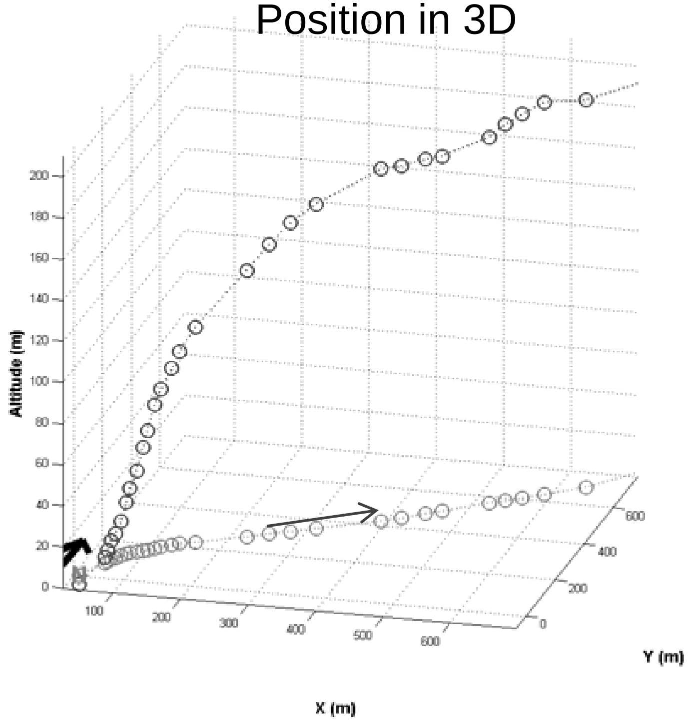
ValidWind Application: San Juan County, UT



Exploration for Possible Wind Energy Sources
June 2009

Wind directions strongly to NE
Wind speed = <u>12 – 24 mph</u> above 100 meters altitude

Position in 3D



Velocity & direction