Measurement User Groups

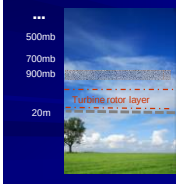
- Want better forecasts – a majority ← better NWP models
- Research – better understanding → better forecasts, NWP
- Wind energy (and solar) – apparent special needs

These users – actually closely connected

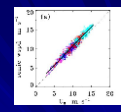
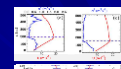
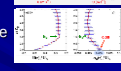
1. 'Dark zone:' a surprisingly poorly understood region of the atmosphere – blocking progress in NWP, forecasting
2. Instrumentation capable of illuminating this dark zone is now available.
3. Key to advancement – deploying this instrumentation in arrays
   1. Horizontal gradients important
4. Arrays expensive
5. Wind energy industry (*also solar energy*) need exactly this same information (in the dark zone)
   1. Huge financial incentives
   2. Missing the boat, if don't leverage the needs of wind energy
   3. Atmosphere abv sfc, even 50-150 m, not the same as at the sfc *most of the time*

Where and what ?

- **"Dark region"**
  - BL above tower layer
    - Mid - upper ABL
  - Diurnal, annual cycles, e.g., start at sfc, transfer upwards



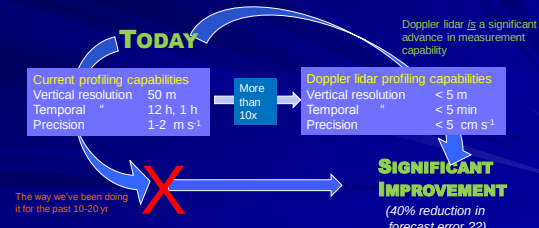
- **Doppler lidar – one of new instruments available**
  - High precision
  - High resolution, fast
  - In exact part of atmosphere where needed
  - 4 decades of experience at NOAA
  - Commercially available
    - Recent ~ past decade
    - Not mature, but in 'adolescence'
    - Will get better, cheaper
  - Real-time data examples given later (commercial systems)
  - Widely adopted by many wind energy institutions


Recent Workshop - Q: ***What would it take to improve NWP model skill by 40% ??***

Meteorology = empirical science

- Advances in measurement capability *precede* jumps in understanding /modeling
  - *As in other geosciences, science in general*



*NWP improvements are now *measurement limited*

Need multiscale arrays to capture multiscale phenomena that do the transport and mixing in the ABL… example is for a wind farm, but could equally represent a research study region --

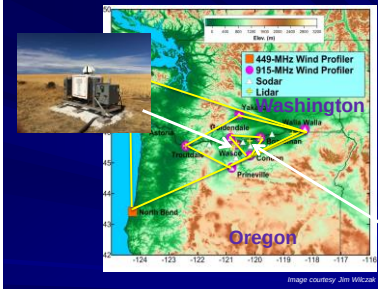
Nested array example – 1 farm

- Main site for verif.
  (part of regional)
- Regional array ~ US profiler array
- Regional arrays will overlap
- Local array 1-h+ circumference
- Tracking – from outer to inner arrays
- Turbc detection

Banta, R.M., Y.L. Pichugina, N.D. Kelley, W.A. Brewer, and R.M. Hardesty, 2013: Wind-energy meteorology: Insight into wind properties in the turbine rotor layer of the atmosphere from high-resolution Doppler lidar. *Bull. Amer. Meteor. Soc.*, **94**, 883-902.

Example / prototype of kind of multiscale arrays needed

Multi-Scale Measurements



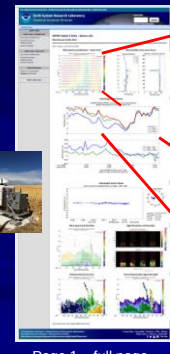
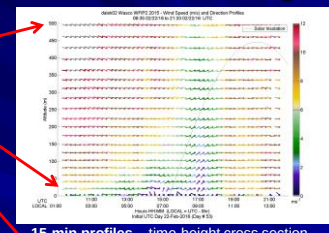
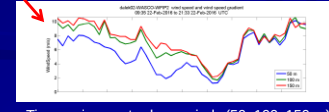
Remote sensing systems:
- 5 scanning Doppler lidars
- 5 wind profiling lidars
- 11 wind profiling radars (most w/ RASS)
- 17 sodars
- 4 profiling radiometers
- 1 Ceilometer

Surface instrumentation:
- 10 microbarographs
- 28 sonic anemometers
- 5 radiative flux systems
- 2 soil moisture systems

Two NOAA Doppler lidars deployed, providing real-time data in an operational setting

DOE / NOAA Second Wind Forecast Improvement Project (WFIP-2)

WFIP-2 Lidar Real-Time Web Page

Page 1 – full page

15-min profiles – time-height cross section

Time series – rotor-layer winds (50, 100, 150 m)

Renewable Requirements

The users: some of the requirements –

- Wind
  - Winds within the turbine rotor layer – many levels of need, for example:
    - Need high precision measurement of wind speed in rotor layer
    - Mean annual wind speed (resource assessment) + shear, ramp, turbulence encountered by turbines; horizontal variability over a region
    - Extreme values, icing
    - Forecasts of wind speed -- 'Hour-ahead,' 'day-ahead' + longer term outlooks

- Solar
  - Direct shortwave (for CSP – concentrating solar power)
  - Total shortwave normal to plane of PV cell array – includes scattered, reflected from clouds, surface objects (for Photovoltaic) [****wavelength dependence – materials design***]
  - Global horizontal irradiance not good enough for either
  - Aerosol optical depth thru atmosphere
  - **Clouds** !!!

Forum on Observing the Environment from the Ground Up, Washington DC. Presented by Robert Banta, NOAA/ESRL, Boulder CO , 8-9 Mar 2016 7

Backup

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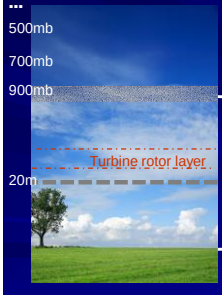
Very simply

What's different about WE ?



- **2 regions:**
  - **Slow processes**
    - Above ABL
  - **Fast** (diurnal)
- **Available measurements**
  - Slow, less precise
  - Slow, less precise
  - Fast, precise
    - near sfc

WE occupies "inverse sweet spot" in atmospheric science state of the art

Need to advance SOA to meet WE needs

Need to look at measurement capability = Instrumentation

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Solar Irradiance Primer:

Direct Normal Irradiance (DNI) – The amount of solar radiation from the direction of the sun per unit area striking a surface held perpendicular to the direction of the beam.

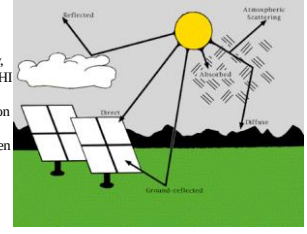
Diffuse Horizontal Irradiance (DHI) – Solar radiation per unit area from the sky due to scattering from molecules, aerosols and clouds.

Global Horizontal Irradiance (GHI) – Sum of the Direct and Diffuse solar irradiance striking a horizontal flat plate detector.

GHI = DHI + DNI * cos (Z)

Surface Albedo – The surface reflectivity, Upwelling solar irradiance divided by GHI

Aerosols scatter and absorb solar radiation affecting how much reaches the surface, as well as how the GHI is divided between the DHI and DNI.



Solar Renewable Energy Systems

- Concentrating Solar Power systems need forecasts of direct normal solar irradiance (DNI)
- Photovoltaic panel systems need to have the global horizontal solar irradiance (GHI) adjusted to the tilted Plane-of-Array (POA) reference

Solar Renewable Energy Needs

- Concentrating Solar Power systems need observations and forecasts of direct normal solar irradiance (DNI)
  - Measurements of direct solar irradiance (DNI) are needed
- Photovoltaic panel systems need to have the global horizontal solar irradiance (GHI) adjusted to the Plane-of-Array (POA) reference.
  - This requires knowledge of the partitioning between the direct and diffuse solar components and the surface albedo, thus measurements of DNI as well as diffuse horizontal irradiance (DHI) and surface upwelling irradiance are needed.
- <u>Global Horizontal Irradiance (GHI) measurements or forecasts alone do not serve either!</u>

NOAA Global Monitoring Division US Sites