Research Experiences for Undergraduates
Crop-Wind-energy Experiment (C-WEX)
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This project seeks to add an educational component to a collaborative experiment between the University of Colorado (CU) and Iowa State University (ISU) to study the interaction of wind turbines with agricultural crops. In summer 2010 CU and ISU launched a pilot study in conjunction with the National Laboratory for Agriculture and the Environment (NLAE) and the Ames Laboratory (AL/DOE) to measure surface mean and turbulent conditions as well as vertical profiles of wind and turbulence in a wind farm co-located with agricultural crops. The pilot study produced numerous conference papers and launched a plan for an expanded field campaign in 2011. This request for NCAR facilities will provide field observations for a new NSF REU site program at ISU and enable graduate students, additional undergraduates, and K-12 students to benefit from the programming currently limited to a few undergraduates in the REU program.

Background
A brief overview of related activities at ISU provides context for our current request for an NCAR instrumentation deployment for educational purposes. Over the last year the ISU College of Engineering has launched a broad interdisciplinary wind research and educational program. As components of this comprehensive plan, an interdisciplinary team has submitted proposals to NSF for a Research Experiences for Undergraduates (REU) Site grant (Takle as PI) and an Integrated Graduate Education, Research and Training (IGERT) grant (Takle as Co-PI). Both programs are entitled Wind Energy Science, Engineering and Policy (WESEP). The REU has been approved for a June 2011 start date, and the IGERT has received provisional approval. The REU is envisioned as a feeder program for the IGERT.

The WESEP REU will include ten undergraduate students arriving 1 June 2011 for ten weeks. They will be receiving a range of lectures covering all WESEP topics (i.e., blades, towers, gear boxes, aerodynamics, siting, transmission, grid, wind forecasting, environmental impacts, land contracts, etc.), brown-bag lunch-and-learn events, field trips, group research projects, and individual research projects. Also, participants in other ISU REUs, the Ames Laboratory Science Undergraduate Laboratory Internship (SULI) program, and other individual undergraduate research projects will be provided with tours of the C-WEX field site and an overview of the project and data being collected. Participation in C-WEX by students in these related programs will be encouraged at a variety of levels. Examples include use of surface data for research projects, participation in deploying equipment and calibration activities, making visual observations of turbine influences during periods of fog, low clouds, etc.

Field Site and the 2010 Field Campaign
The overall long-term objective of the field program is to answer the question “Do wind turbines have an influence on agricultural production within wind farms?” Given the natural interannual variability of weather and plant response, a more realistic short-term question is “Do wind turbines create measureable influences on fluxes of quantities important to crop development and yield?” Although 2010 brought record flooding to parts of nearby areas, the qualified answer to this second question is yes.
This project is of high interest, because the prices of commodity crops (e.g., corn and soybeans) have risen substantially since last fall, with prospects for global shortages after the 2011 harvest season. Land prices also have risen 24% in the last year. Turbines create impediments to some agricultural management activities; rising agricultural income potentially creates less enthusiasm for farmers to allow further turbine deployment. However, early results of our study suggest that the impacts of turbines might be positive for production. The 2011 campaign will provide more information on the nature of turbine-crop interaction, particularly if 2011 does not bring the flooding conditions of 2010.

Field Site
A wind farm north of Colo, IA (~20 miles east of the ISU campus) operated by NextEra Energy consists of approximately 100 1.5 MW GE1.5 turbines scattered over about 50 square miles to the north and west of Colo. Another 100 turbines are scheduled to be deployed in the next several months. All turbines are located in intensively managed agricultural fields that are annually rotated between corn and soybeans. Field operations on farms in the vicinity of these turbines are carried out under contracts with between owners and farm operations managers. The patchwork of ownership and operations within the wind farm may require agreements with numerous entities to enable optimal siting for meteorological observations. Fortunately, the five locations used for siting instruments in 2010 required agreements with only one land-owner and one operator (see Fig. 1). Flux stations used in 2010 enabled measurements of surface exchanges of momentum, moisture, heat and CO2 at an “undisturbed” site and three sites located successively downwind (under prevailing S to SE winds this time of year). Analysis of data from the 2010 is still in process, but some reproducibility in flux differences has been documented and spectra of turbulence at the surface show signatures of turbine waves passing over the flux stations.

2011 Field Campaign
Measurements during 2011 generally will follow the plan of 2010 with the possibility of creating two parallel lines of flux stations perpendicular to the southern-most line of turbines and alternative locations of the lidars. Exact locations are yet to be determined. C-WEX 2011 will include wind-farm deployment of two surface flux stations provided by the Department of Agronomy and the Department of Geological and Atmospheric Sciences and two vertically pointing lidars provided by Professor Lundquist from the University of Colorado. The deployment of the flux stations will be from late June through August (depending on agricultural field work), and the lidar deployment will be a yet-to-be-determined subset of this June-August window.

The 2011 cropping pattern is shown in Fig. 2, and the terrain map for the region is shown in Fig. 3. Data collected allow for a wide range of sophistication in analyses, including differences (due to turbines) in mean temperature and wind speed, differences in turbulent properties and surface fluxes, differences in turbulence spectra, and differences in 3-dimensional structure if one of the lidars is upwind and one downwind straddling the windward line of turbines. This will allow for a wide range of investigations by our projected cohort of students (K-12 to graduate students – see table below).

Student Engagement
Primary users of the data will be the ten REU students and two PHD students whose dissertations will include results of the field study. For the REU students, visits to the wind farm will provide context and data for follow-on activities related to a variety of science and engineering topics. Hands-on contact with the instruments will be folded into individual and group research projects (see above). Data streams also will be used to examine micrometeorological and biophysical
(e.g., CO2 flux data) principles. Events of opportunity (i.e., influence on low clouds or fog, storm passage, strong low-level jet events) will provide points of discussion for brown-bag lunch-and-

Central Iowa Wind Farm Meteorological Field Measurement Site, Summer 2010

Figure 1. Field site with turbines (Ax, Bx), flux towers, and lidar positions indicated

Proposed crop layout plan 2011

Fig. 2  Distribution of turbines and crops for 2011. Map is approximately 4 miles E-W and 3.5 miles N-S
Fig. 3. Terrain map for wind farm with 2011 crops indicated.

learn sessions and examples for the foundational lectures (which may be scheduled throughout the 10-week period to take advantage of such opportunities).

In addition to the core group of REU students and graduate students, we are arranging for a variety of other student groups, from MS students to junior and senior high-school students, to benefit from this field instrument deployment. In addition, two faculty members, who have course work related to environmental measurements, will be participating in field measurements. The following is a tentative list of student groups we are engaging.

Projected student engagement in the field measurements and data analysis

<table>
<thead>
<tr>
<th>Number</th>
<th>Group</th>
<th>Period of engagement</th>
<th>Candidate activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>REU students</td>
<td>2 weeks of 10 week program</td>
<td>Assisting in deployment, data organization, error analysis, uncertainty, analysis of differences in temp, moisture, CO2, spectra</td>
</tr>
<tr>
<td>3-5</td>
<td>REU “Affiliates”</td>
<td>2 weeks</td>
<td>Same as REU students. These are undergrads on other support that are interested in wind energy</td>
</tr>
<tr>
<td>5-10</td>
<td>grad students</td>
<td>1 week</td>
<td>Attending lectures on instrumentation, sample analyses</td>
</tr>
<tr>
<td>2</td>
<td>grad students</td>
<td>1-3 months</td>
<td>Assisting in deployment, lead in analysis</td>
</tr>
<tr>
<td>10-30</td>
<td>K-12 students</td>
<td>2 days</td>
<td>Tour of field site plus classroom activity on wind energy</td>
</tr>
</tbody>
</table>
**Instruments on each mast**
Based on instrumentation we have used in the 2010 field campaign and instruments available for 2011, we request four surface flux stations each with the following instruments:

1. CO2/H2O Open path gas analyzer and sonic anemometer system
2. Micrologger unit
2. Air temperature and relative humidity
2. Radiation shield for T and RH
2. Cup anemometers (ISS uses prop-vane: we can discuss pros and cons)
1. Wind direction

We invite discussion from the NCAR ISS team on selection of instruments and deployment locations we have chosen.

**Summary**
We request an NCAR educational deployment of four surface flux stations to complement stations and lidars we will be deploying in a wind farm co-located with agricultural fields. We will use this opportunity to teach students at a variety of levels about the science and engineering of wind energy. Activities using the data will be designed for a variety of levels of learners. The experience of standing in a wind farm surrounded by intensely managed agricultural fields where crops are grown for both food, feed, and fuel (bioenergy crops) will provide a teachable moment for discussing the societal challenges of meeting competing national needs for energy and food while protecting valuable environmental resources.