NORTHERN ARIZONA UNIVERSITY

DISTRIBUTED WIND RESOURCE ASSESSMENT USING COMPUTATIONAL MODELING FOR OFF-GRID, KILOWATT-SIZE WIND TURBINES

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OUTLINE

- Background

- Objectives

- Met towers and wind turbines

- Meteodyn WT modeling software

- Modeling domain

- Results

- Conclusions

DISTRIBUTED WIND RESOURCE ASSESSMENT

- 2015 Distributed Wind Resource Assessment (DWRA) Workshop sponsored by the U.S. Department of Energy

- DWRA
  - Wind turbines that are "behind the meter," kW to multi-MW installations
  - Predict Annual Energy Output (AEP) of a distributed wind turbine

- The following challenges and barriers of DWRA were identified:
  - accuracy of the current approach is low and inconsistent
  - little verification of existing standards/rules of thumb
  - lack of available data to properly conduct the assessment

COST OF DISTRIBUTED WIND

- For small wind turbine installations, it is often not economically feasible to conduct a traditional wind resource assessment where a met mast is installed

Table 1: NRG Systems Complete Met Mast Costs

Met Mast Height	Complete Met Mast Cost ($)
$10\ m$	5,000-7,000
$34\ m$	9,000-10,000
$50\ m$	19,000-20,000

Table 2: National Renewable Energy Laboratory Wind Turbine Installed Costs

Wind Turbine Capacities	Mean Installed Cost ($/kW)	Installed Cost Std. Dev. (±$/kW)
$< 10\ kW$	$7,645	$2,431
$10\text{-}100\ kW$	$6,118	$2,101
$100-1000\ kW$	$3,751	$1,376
$1\text{-}10\ MW$	$2,346	$770

MAP OF ANNUAL ENERGY PRODUCTION

- Alternative to met mast measurements is numerical prediction
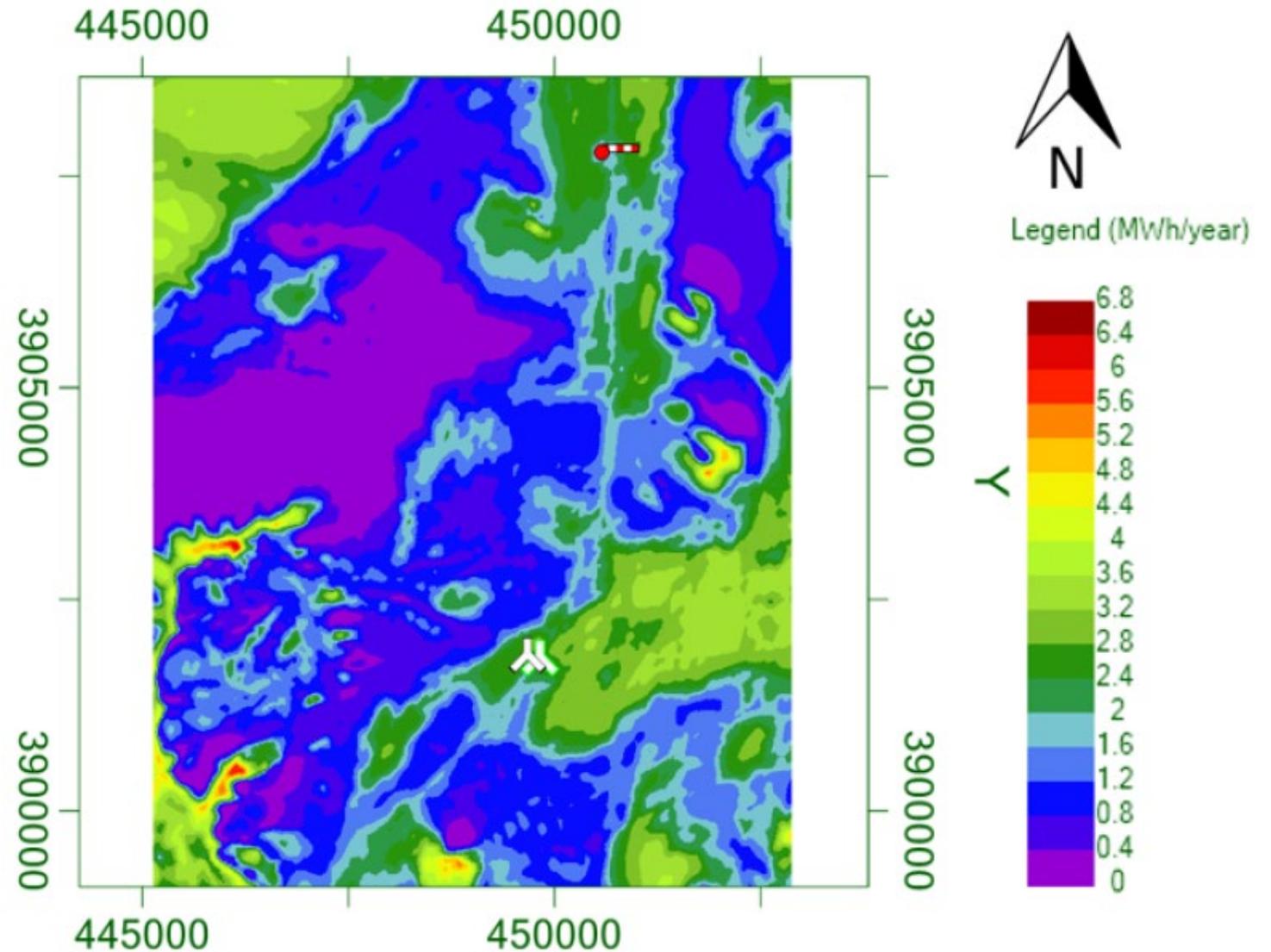
OBJECTIVES

- Investigate the accuracy in predicting wind speed and annual energy production (AEP) using numerical modeling software

  - Meteodyn WT

  - Multiple wind speed and wind turbine data sources available
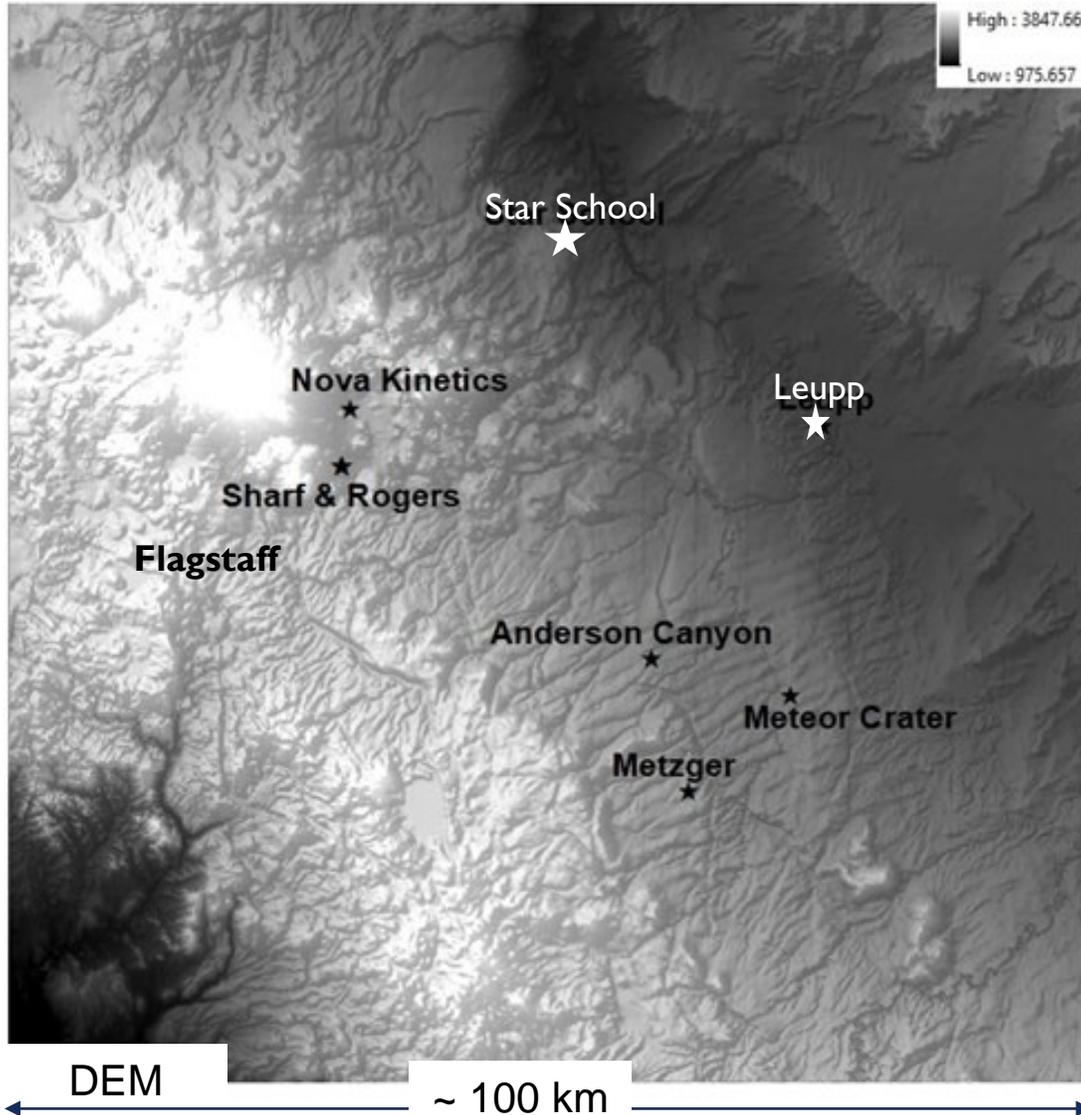
- Best practices

2.4 kW Skystream DWECS installed on the Scharf's property in Doney Park, AZ
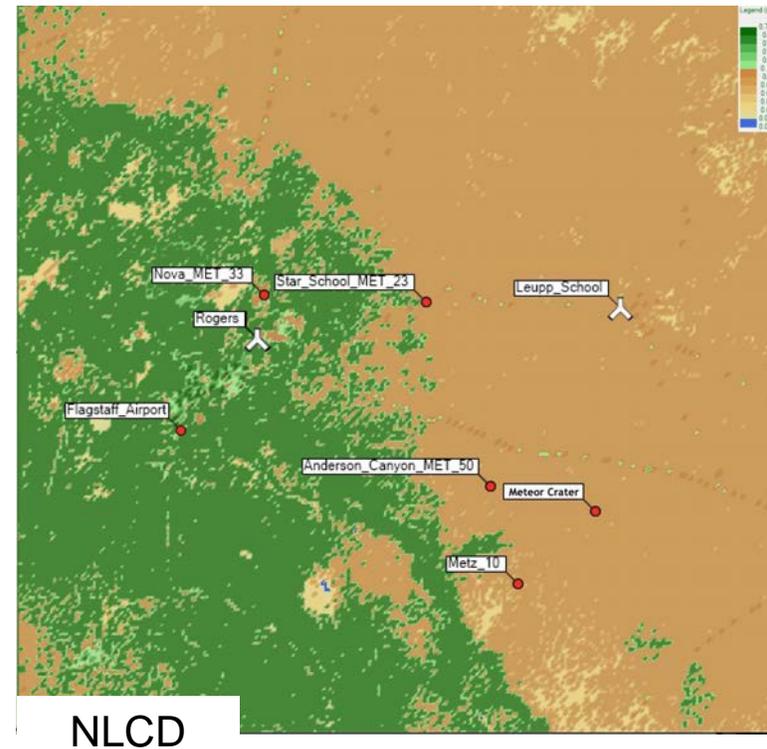
LOCATION IN ARIZONA, USA

United States - Annual Average Wind Speed at 30 m
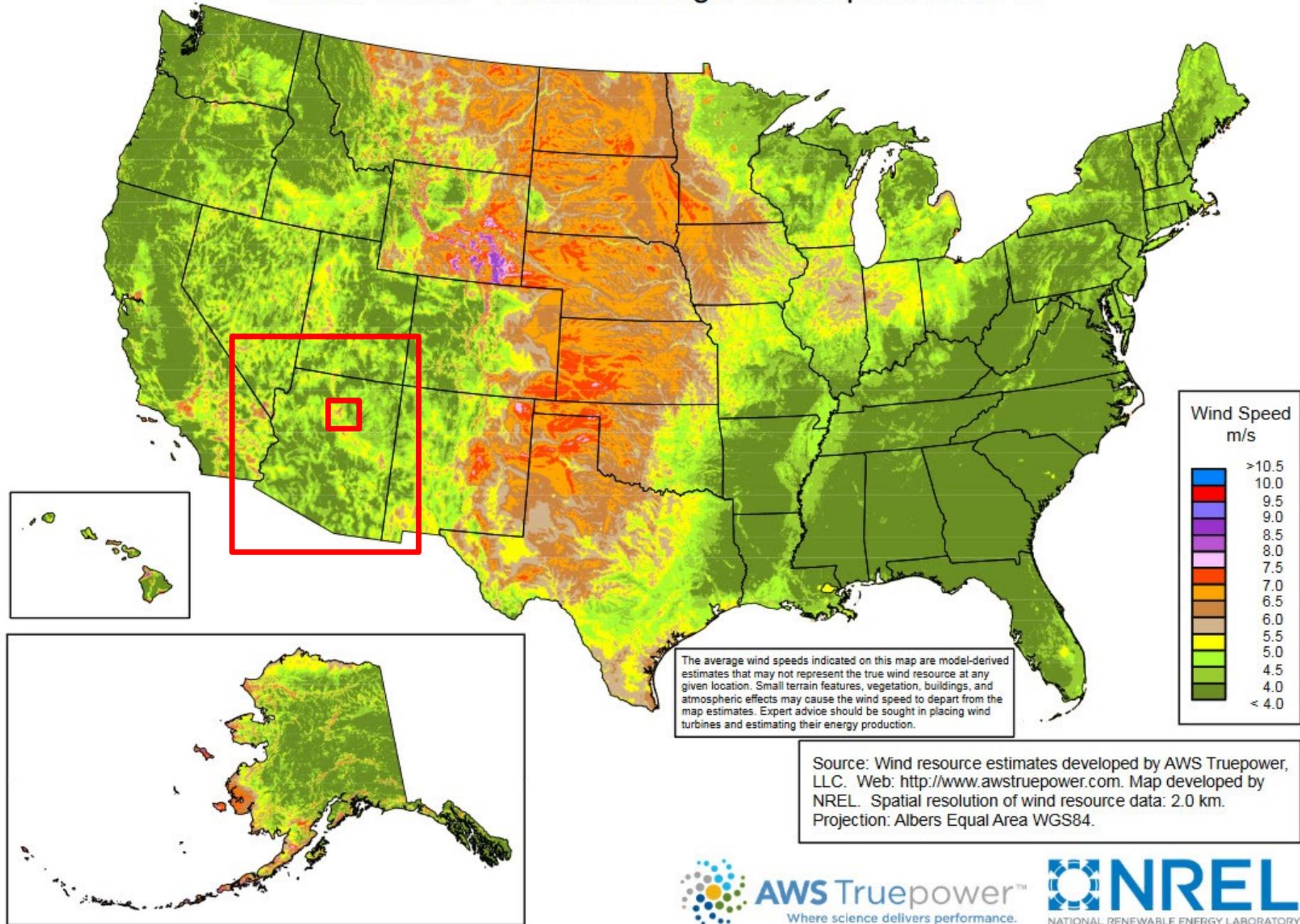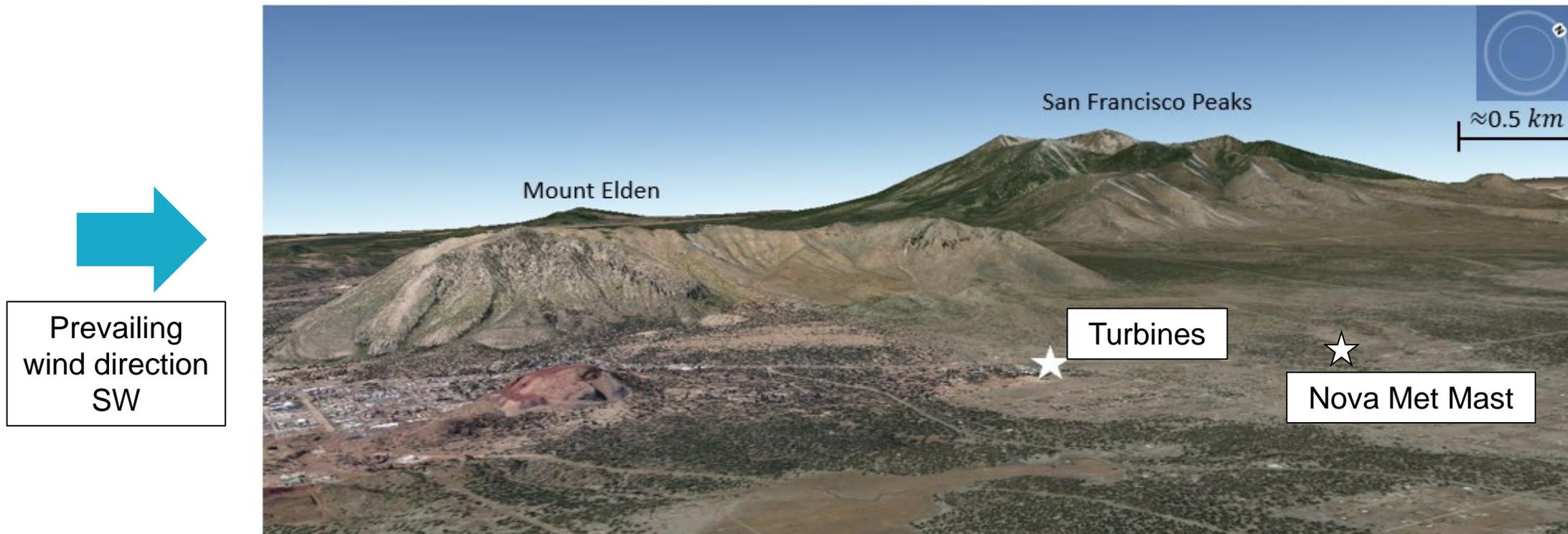
MODEL DOMAIN – TERRAIN, ROUGHNESS, DATA

USGS Data Sources:
National Digital Elevation Map (DEM, 10m)
National Land Surface Database (NLCD roughness)

DEM

~ 100 km

NLCD

PERSPECTIVE VIEW OF DOMAIN

- The domain is centered near Doney Park, a small community northeast of Flagstaff, AZ.
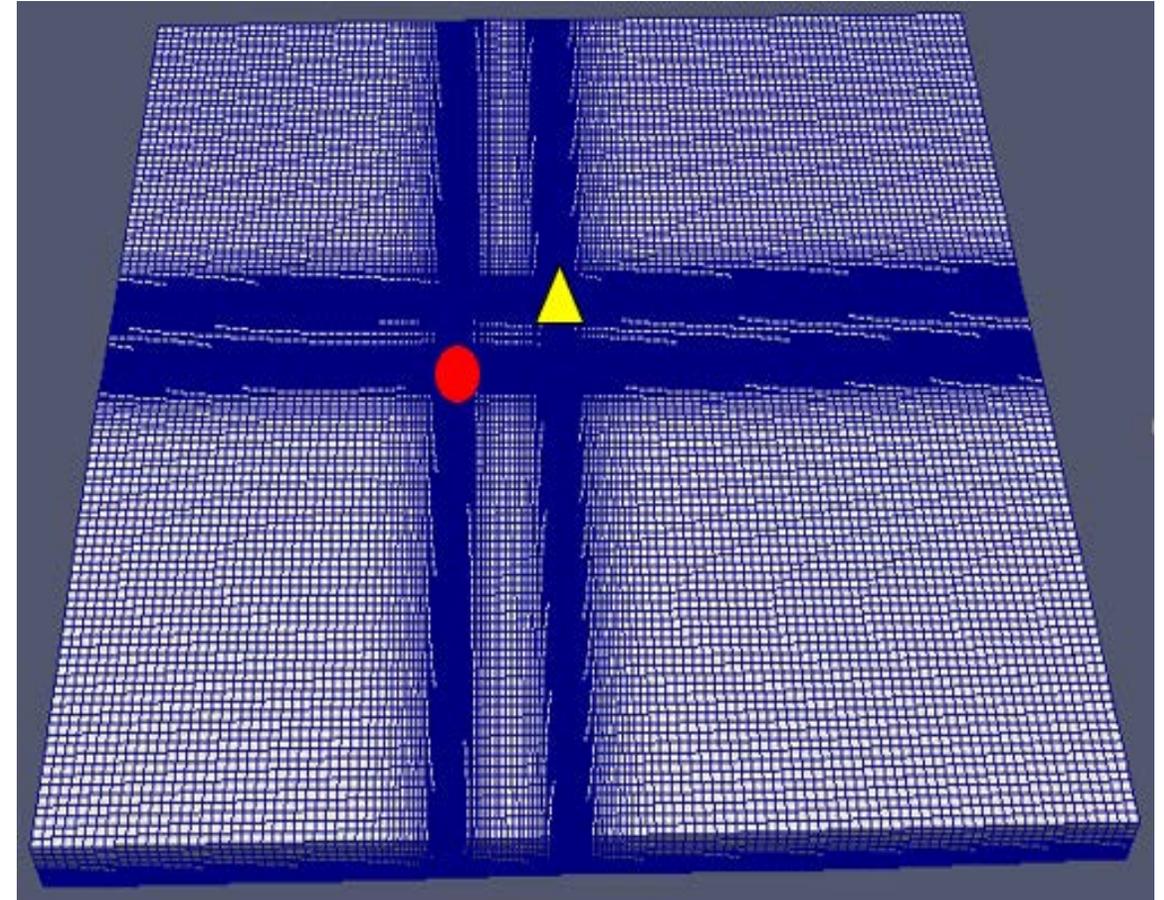
  - Elevation approximately $2,100\ m$

Google Earth Pro image of the surrounding terrain in east Flagstaff and Doney Park
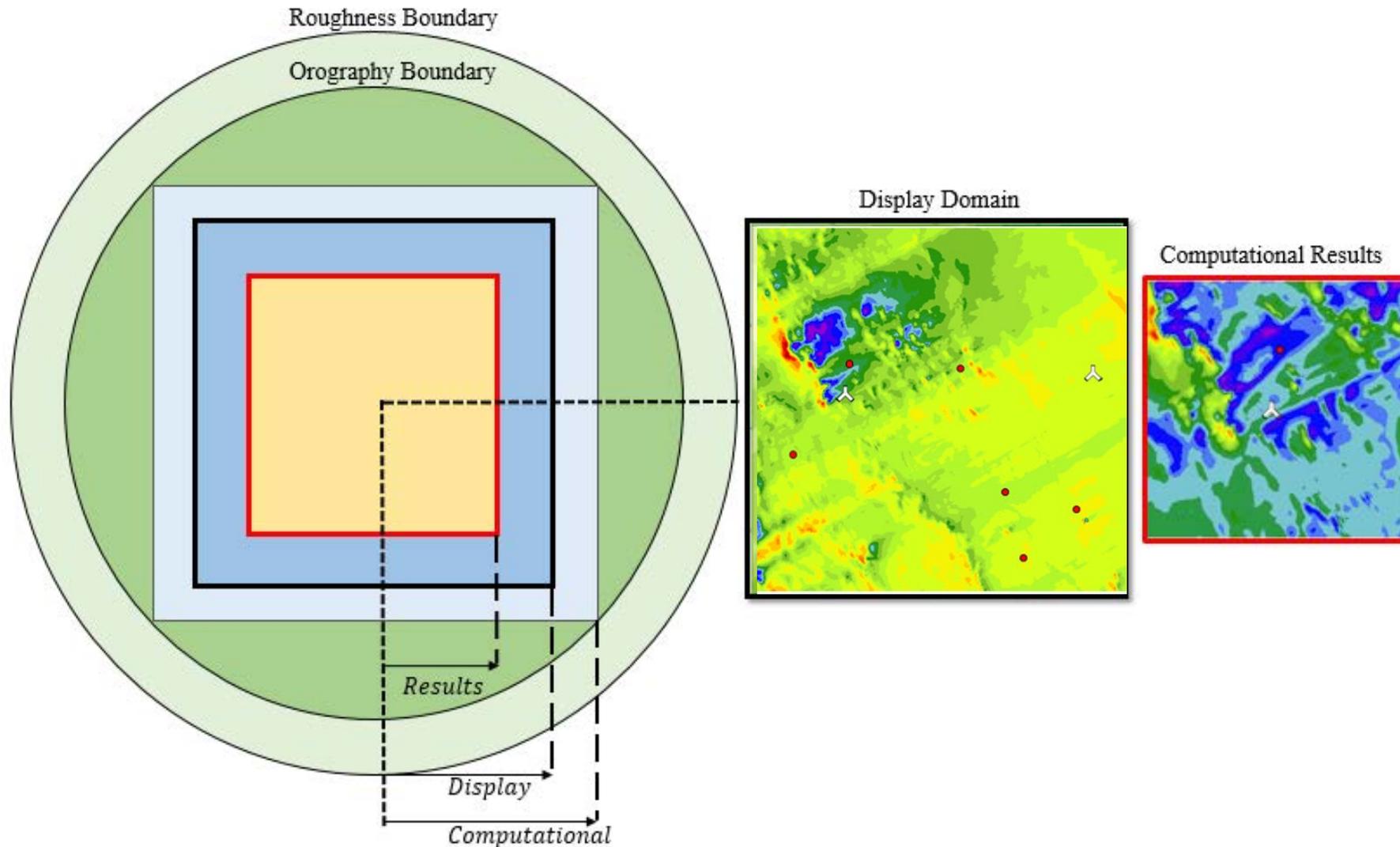
OROGRAPHY AND MESH GENERATION

- Boundary Conditions

  - Orography

  - Roughness

  - Forest density

  - Thermal stability…
    defines inlet boundary
    wind speed profile

- Refinement points and
  mesh generation

Meteodyn WT

COMPUTATIONAL DOMAIN

Roughness Boundary

Orography Boundary

Results

Display

Computational

Display Domain

Computational Results

METEODYN WT SOLUTION METHOD

- Meteodyn WT solves the Reynolds-Averaged Navier Stokes (RANS) equations

  - steady state, nonlinear, incompressible, isothermal, non-dimensional

- Computes speed-up ratios

$$\Delta S = \frac{\Delta U}{U_0} = \frac{(U_{RANS} - U_0)}{U_0}$$

- Performs "Directional Calculations"

- "Synthesize" output wind speeds or wind power predictions by dimensiolizating the speed-up ratios using wind speed data

$$\Delta S + \text{MET MAST} \Rightarrow \text{RESULTS}$$
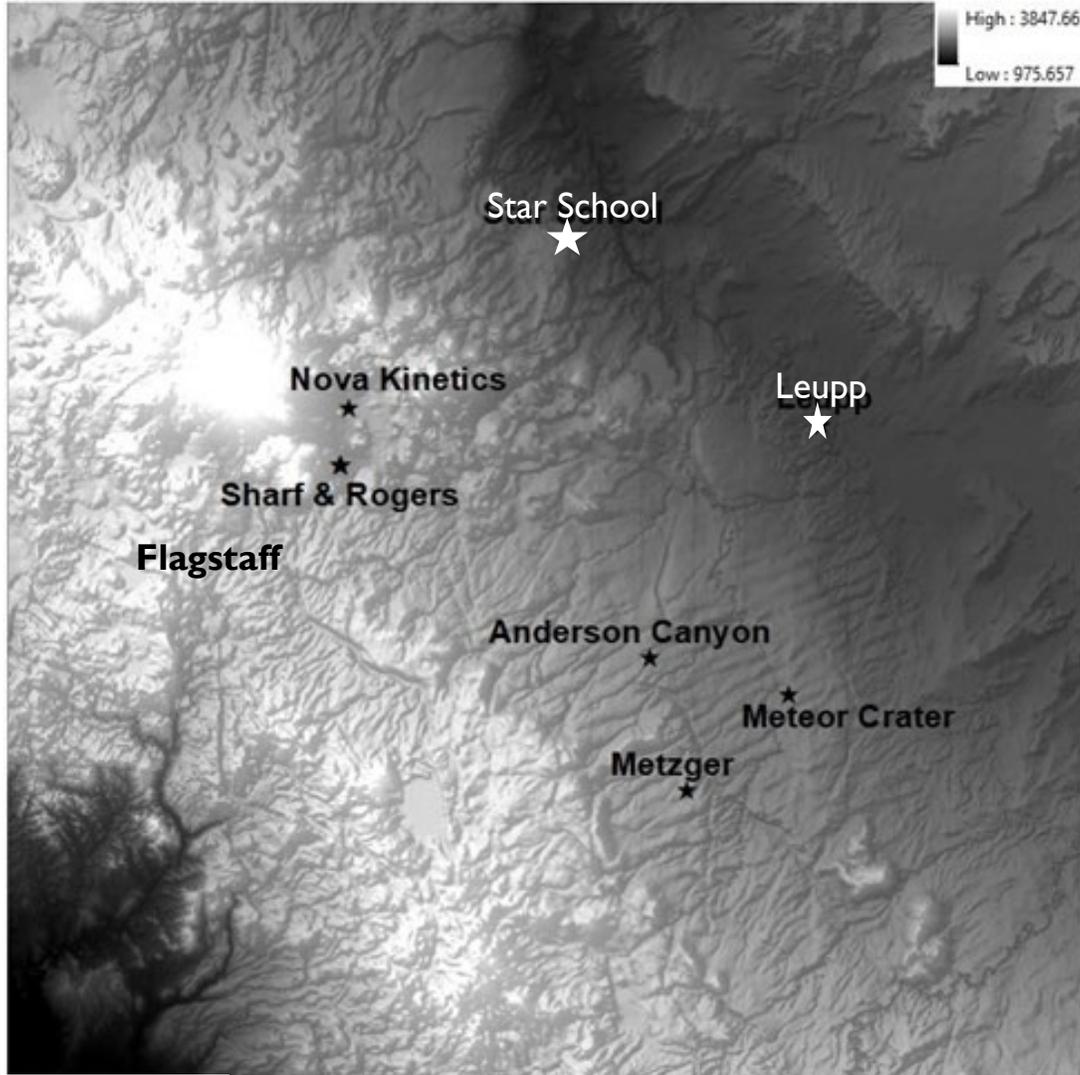
DATA SOURCES

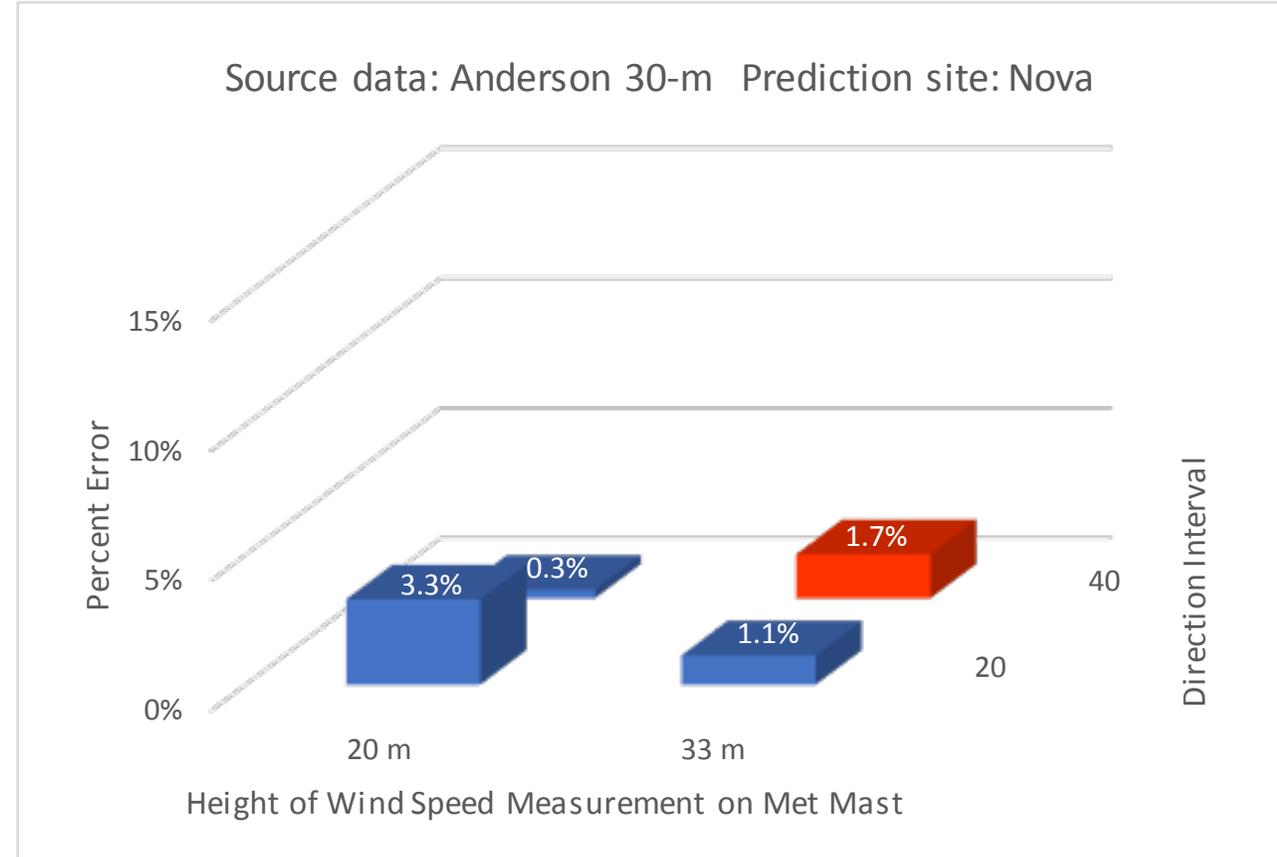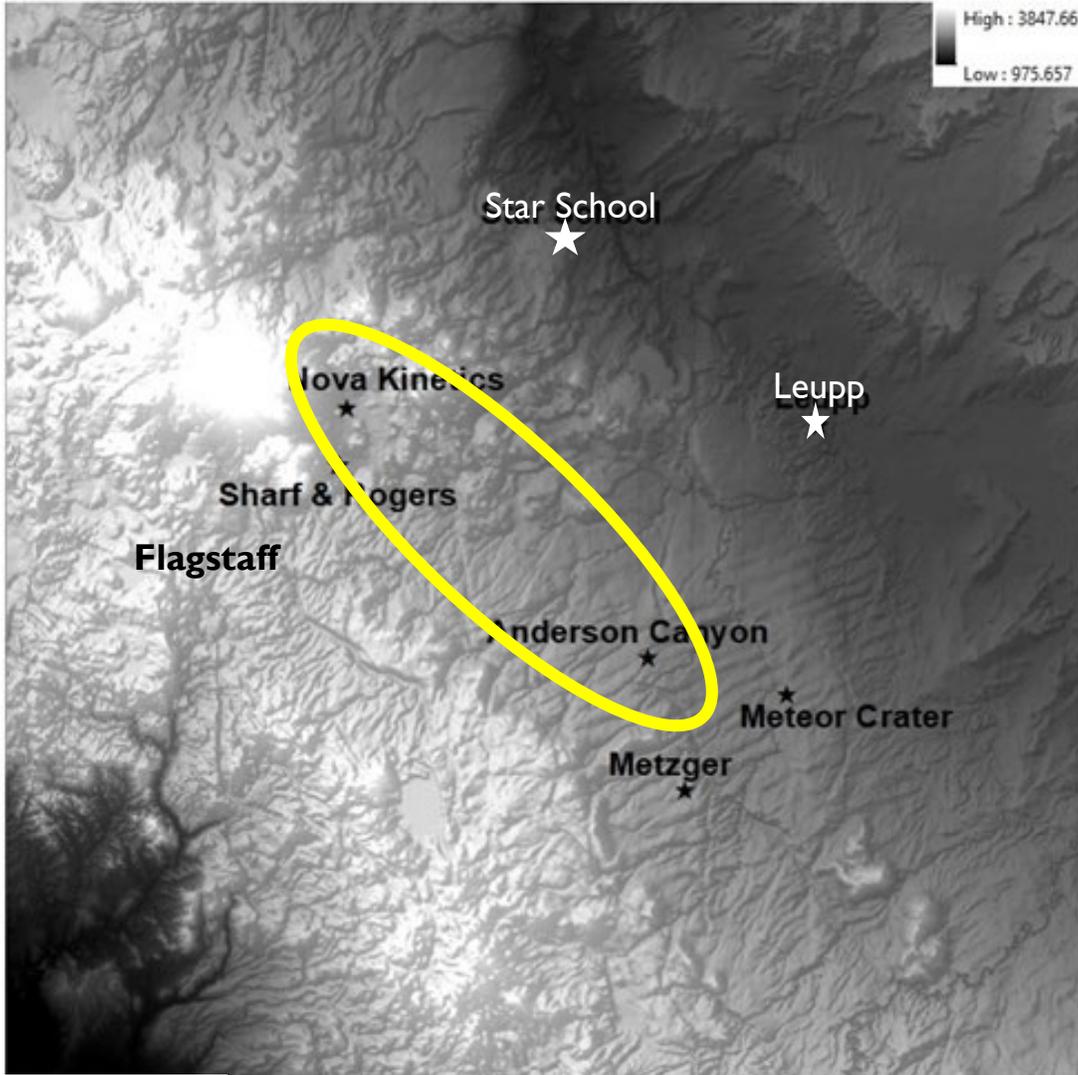| Location	Description of Data Source
Anderson	Met tower with measurements at 30-m and 10-m; 10-min ave.
Metz	Met tower with measurements at 30-m and 10-m; 10-min ave.
Meteor	Met tower with measurements at 30-m and 9-m; 10-min ave.
Nova	Met tower with measurements at 30-m and 20-m; 10-min ave.
Sharf	2.4 kW Skystream 3.7 turbine; 10-m hub height; hourly energy
Rogers	2.4 kW Skystream 3.7 turbine; 10-m hub height; hourly energy
Leupp	Three 2.4 kW Skystream 3.7 turbine; 21.3-m hub; hourly energy

	Anderson (km)	Metz (km)	Meteor (km)	Nova (km)	Sharf (km)	Rogers (km)	Leupp (km)
Anderson	-	14.1	14.7	40.3	37.5	37.6	29.7
Metz	14.1	-	14.4	52.6	48.8	48.9	40.1
Meteor	14.7	14.4	-	54.1	51.8	51.9	28.0
Nova	40.3	52.6	54.1	-	6.0	6.0	48.6
Sharf	37.5	48.8	51.8	6.0	-	0.14	49.6
Rogers	37.6	48.9	51.9	6.0	0.14	-	49.7
Leupp	29.7	40.1	28.0	48.6	49.6	49.7	-

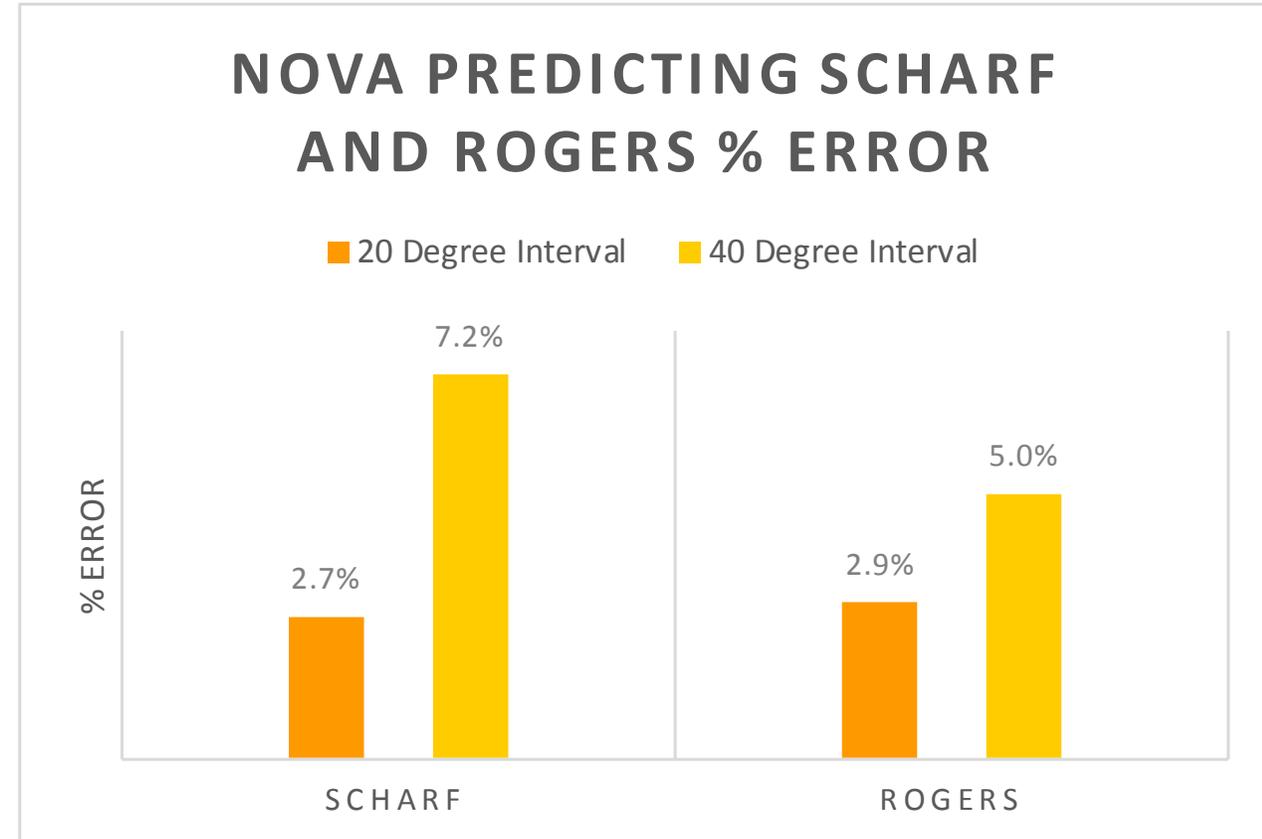# PREDICT MEAN W.S. AT ANDERSON WITH METZ
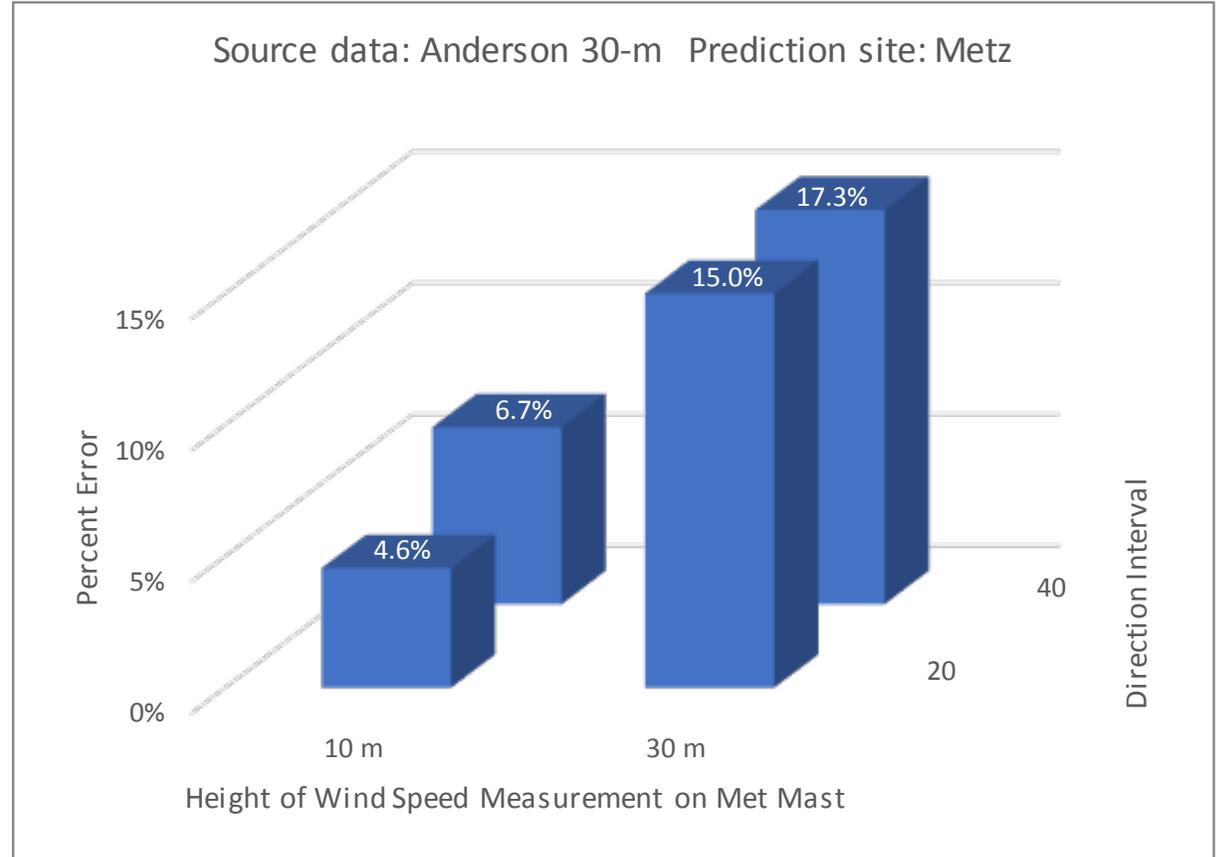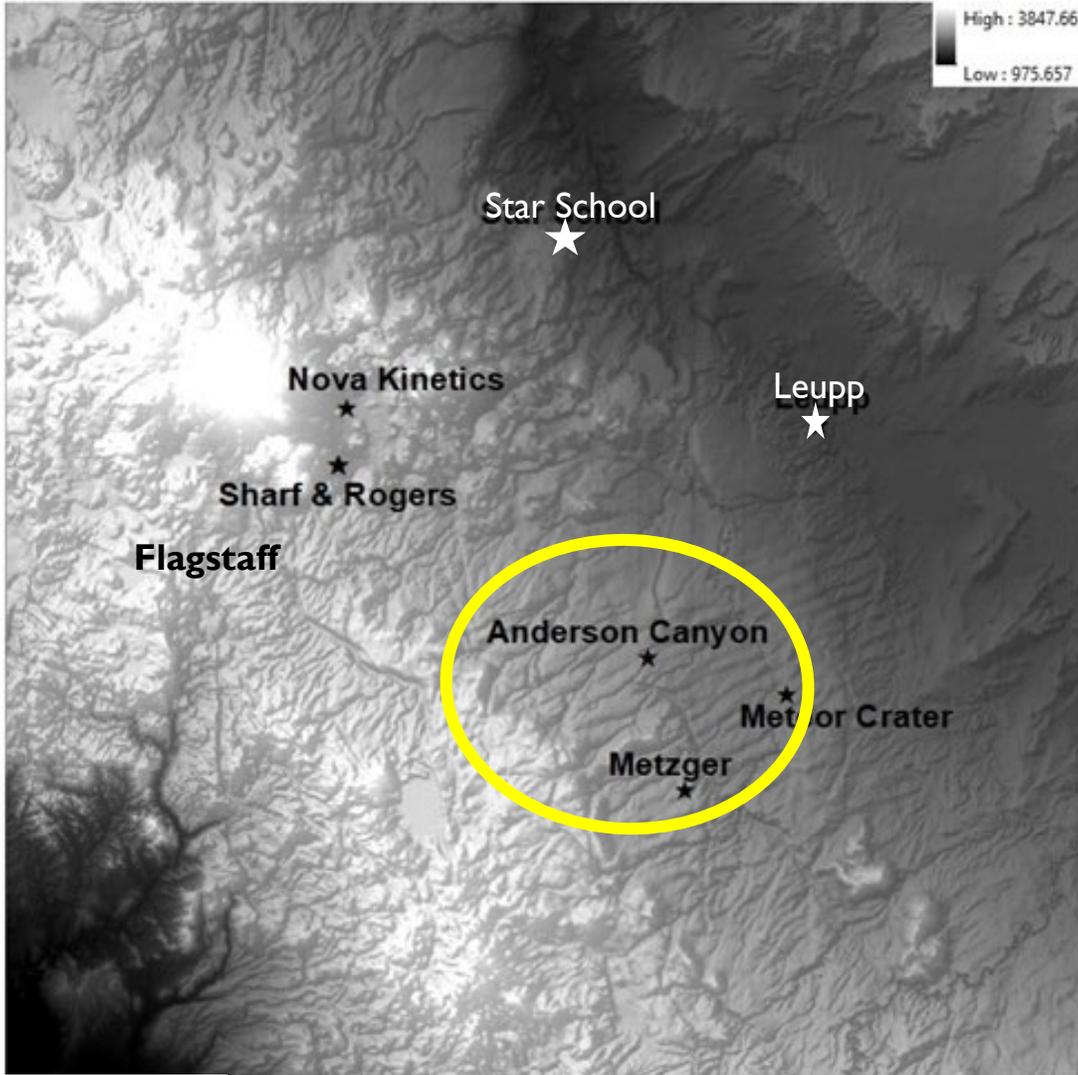
- ~ 5% to 15% error with 20° interval
- 14 km separation

PREDICT MEAN W.S. AT ANDERSON WITH METZ

Source data: Anderson 30-m   Prediction site: Nova

- ■ ~ 1% to 3% error with 20° interval
- ■ 40 km separation

PREDICT AEP AT SCHARF & ROGERS WITH NOVA

NOVA PREDICTING SCHARF AND ROGERS % ERROR

- 20 Degree Interval
- 40 Degree Interval

SCHARF: 2.7% (20 Degree), 7.2% (40 Degree)

ROGERS: 2.9% (20 Degree), 5.0% (40 Degree)
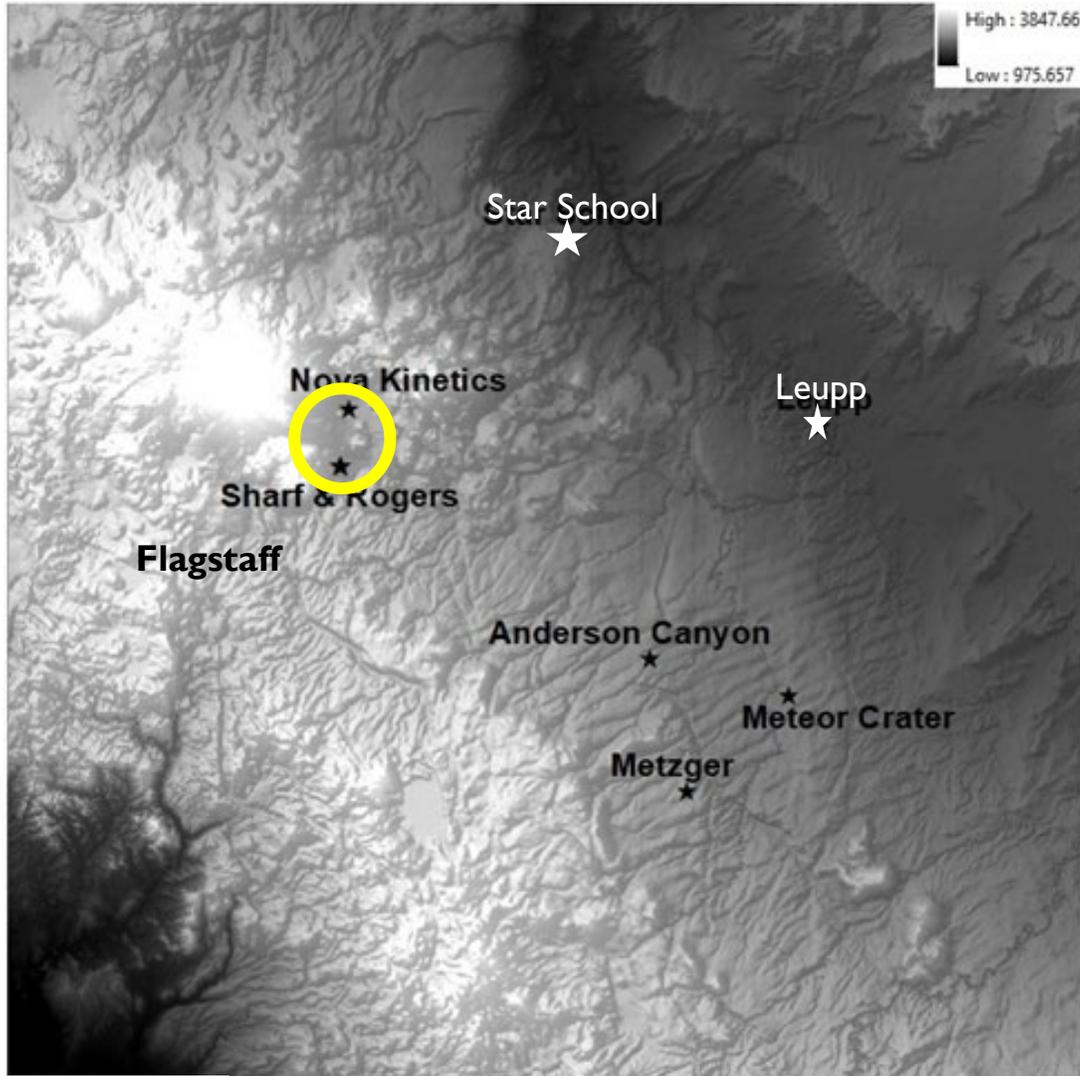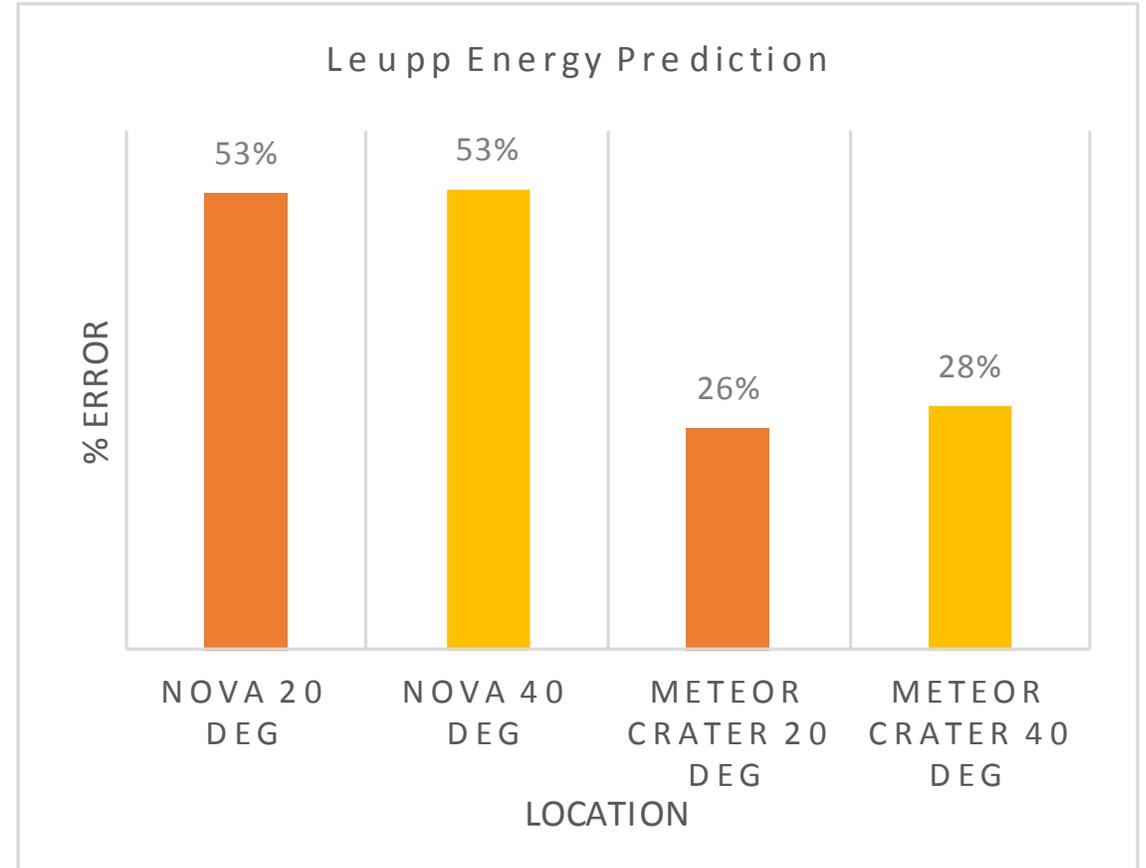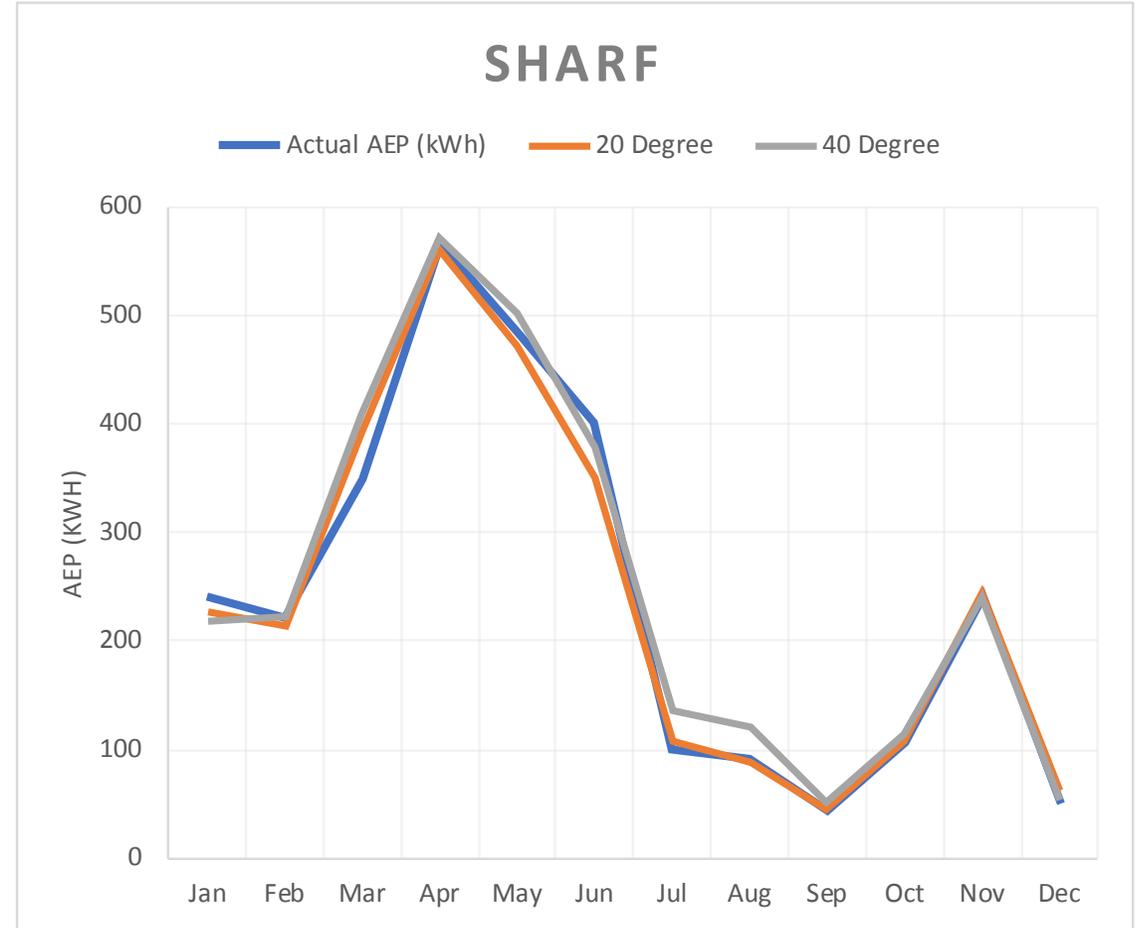
- ~ 3% error with 20° interval
- 6 km separation

PREDICT AEP AT LEUPP WITH METEOR
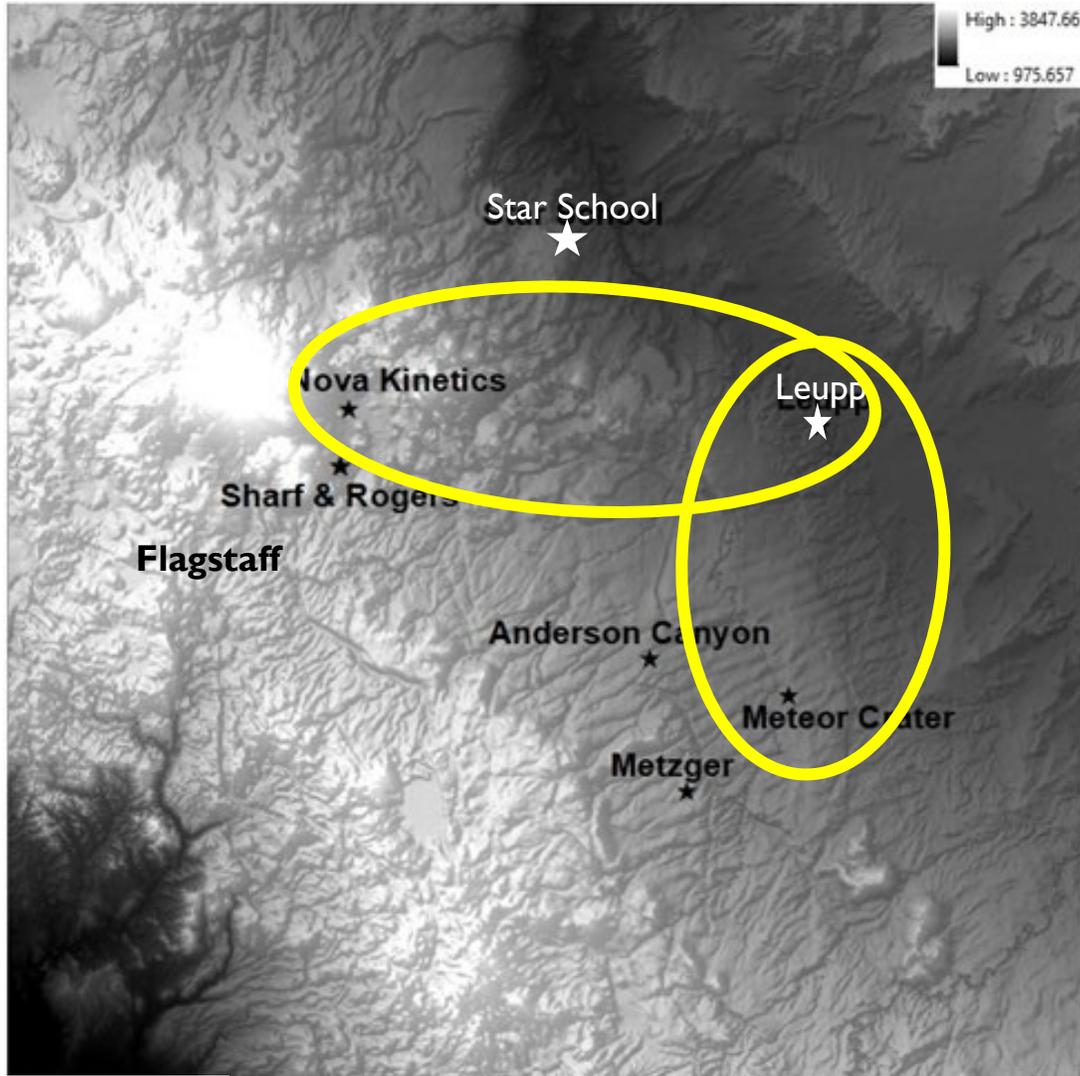
- ■ ~ 25% error with 20° interval

- ■ 28 km separation

DIURNAL AND ANNUAL PROFILES
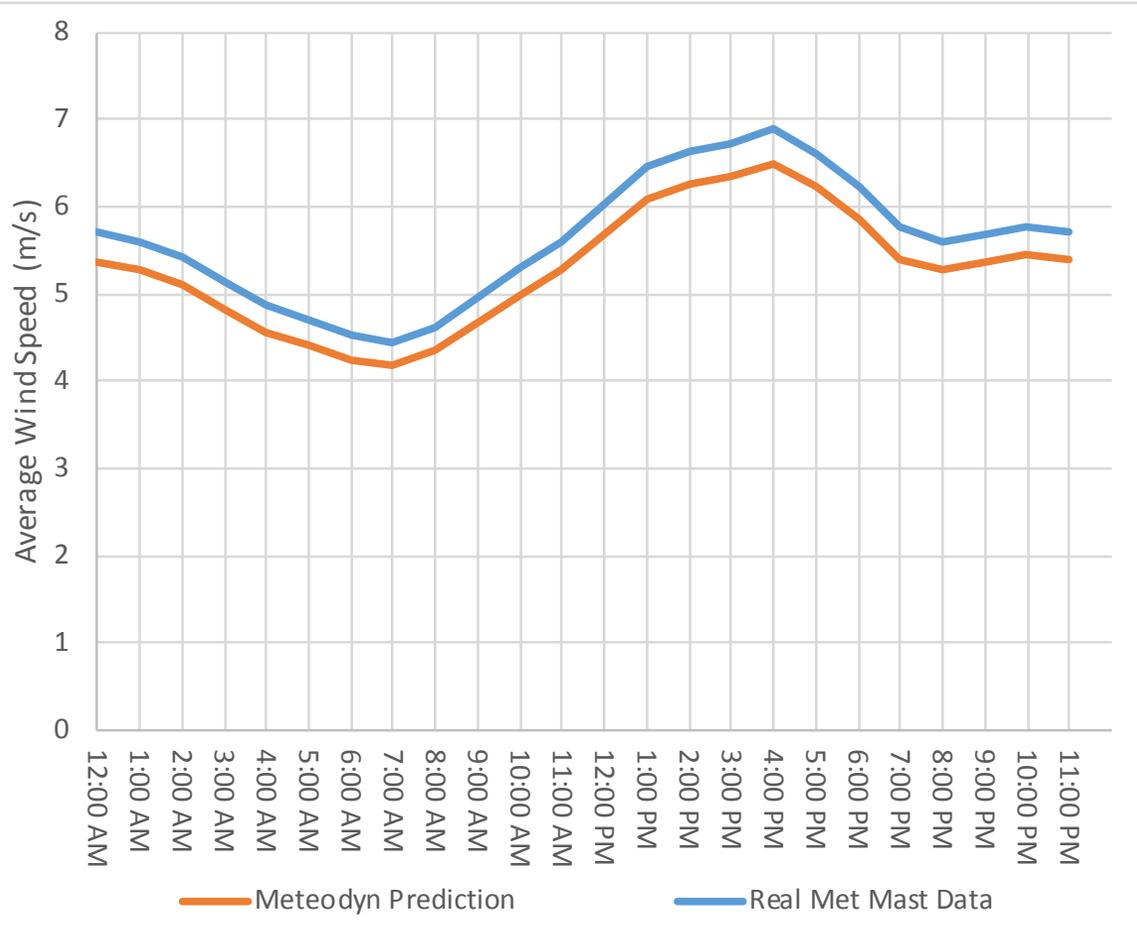
CONCLUSIONS

- Meteodyn accuracy good but varies depending on data and location
  - Wind Speed errors 1% to 23%
  - AEP errors 3% to 25%
  - Time correlation very good
- 20° direction interval generally better than 40°
- Solver settings
  - 10-m Digital Elevation Data
  - USGS NLCD roughness data
  - Normal forest density
  - Neutral stability

QUESTIONS?

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DIRECTIONAL MESHES
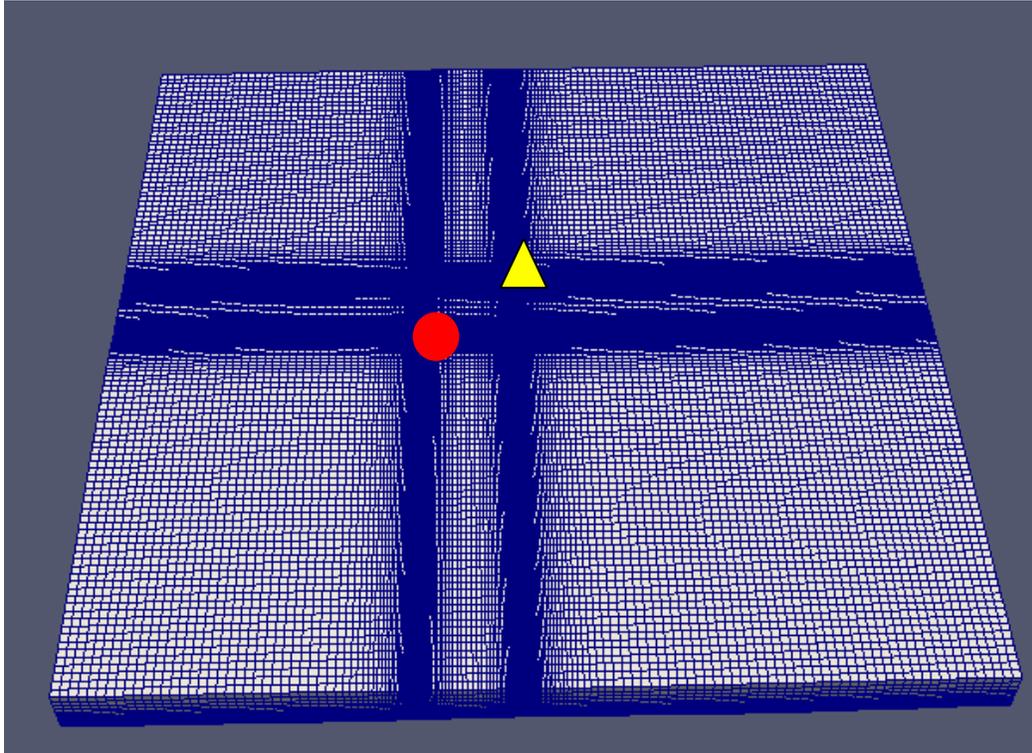

240° mesh
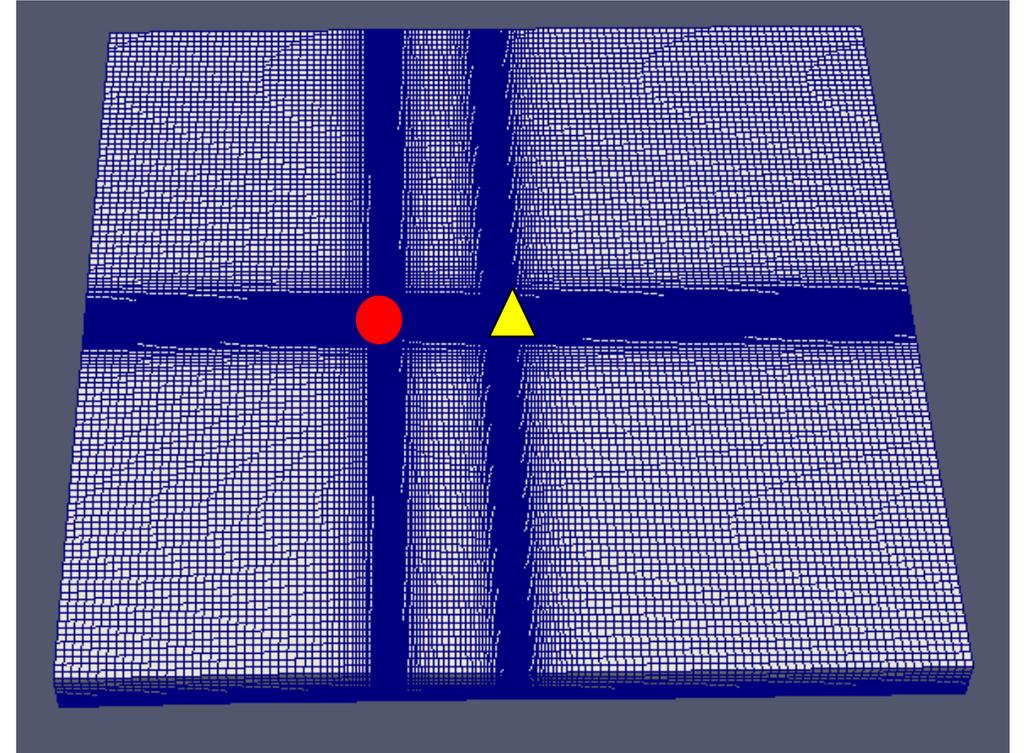
270° mesh

COMPUTATIONS AND RESULTS SYNTHESIS

- The Directional Computations (DCs)

    - generate a surface grid from the orography file

    - bind roughness lengths, z_0, to the surface grid cells

    - canopy heights are defined as $d = 20z_0$

    - one mesh for each directional sector, adding up to 360°

    - solve the RANS equations

$$\Delta S + \text{MET MAST} \Rightarrow \text{RESULTS}$$

DATA SOURCES AND MEAN VALUES

Location	Mean Wind Speed	Description
Anderson at 10-m	4.57 m/s	3 years of wind speed data; 2006-2008
Anderson at 30-m	5.34 m/s	3 years of wind speed data; 2006-2008
Metz at 10-m	5.05 m/s	3 years of wind speed data; 2006-2008
Metz at 30-m	5.65 m/s	3 years of wind speed data; 2006-2008
Nova at 20-m	3.05 m/s	2-mo. wind speed data: Aug-July 2013
Nova at 33-m	3.54 m/s	2-mo. wind speed data: Aug-July 2014
Location	AEP	Description
Sharf	2.895 MWh	1 year production
Rogers	2.942 MWh	1 year production
Leupp	2.537 MWh	4-year average production

DATA SOURCES AND ERROR RANGE

Source Data	Prediction	Distance	Error Range	Description
Anderson at 10-m	**Metz at 10- and 30-m**	14.1 km	10% to 23%	3 years of wind speed data; 2006-2008
Anderson at 30-m	**Metz at 10- and 30-m**	14.1 km	4% to 17%	3 years of wind speed data; 2006-2008
Metz at 10-m	**Anderson at 10- and 30-m**	14.1 km	1% to 10%	3 years of wind speed data; 2006-2008
Metz at 30-m	**Anderson at 10- and 30-m**	14.1 km	10% to 17%	3 years of wind speed data; 2006-2008
Anderson at 10-m	**Nova at 20-m and 33-m**	40.3 km	7% to 12%	2-mo. wind speed data: Aug-July 2011
Anderson at 30-m	**Nova at 20-m and 33-m**	40.3 km	0% to 3%	2-mo. wind speed data: Aug-July 2012
Nova at 20-m	**Anderson at 10-and 30-m**	40.3 km	1% to 5%	2-mo. wind speed data: Aug-July 2013
Nova at 33-m	**Anderson at 10-and 30-m**	40.3 km	2% to 4%	2-mo. wind speed data: Aug-July 2014
Nova at 20-m	**Sharf & Rogers**	6 km	3% to 7%	1-year coincident wind and power data
Nova at 20-m	**Leupp**	48.6 km	53%	No coincident wind and power data
Meteor at 9-m	**Leupp**	28 km	26% to 28%	2-year coincident wind and power data