Overview of Weather and Climate Risk in the Energy Industry

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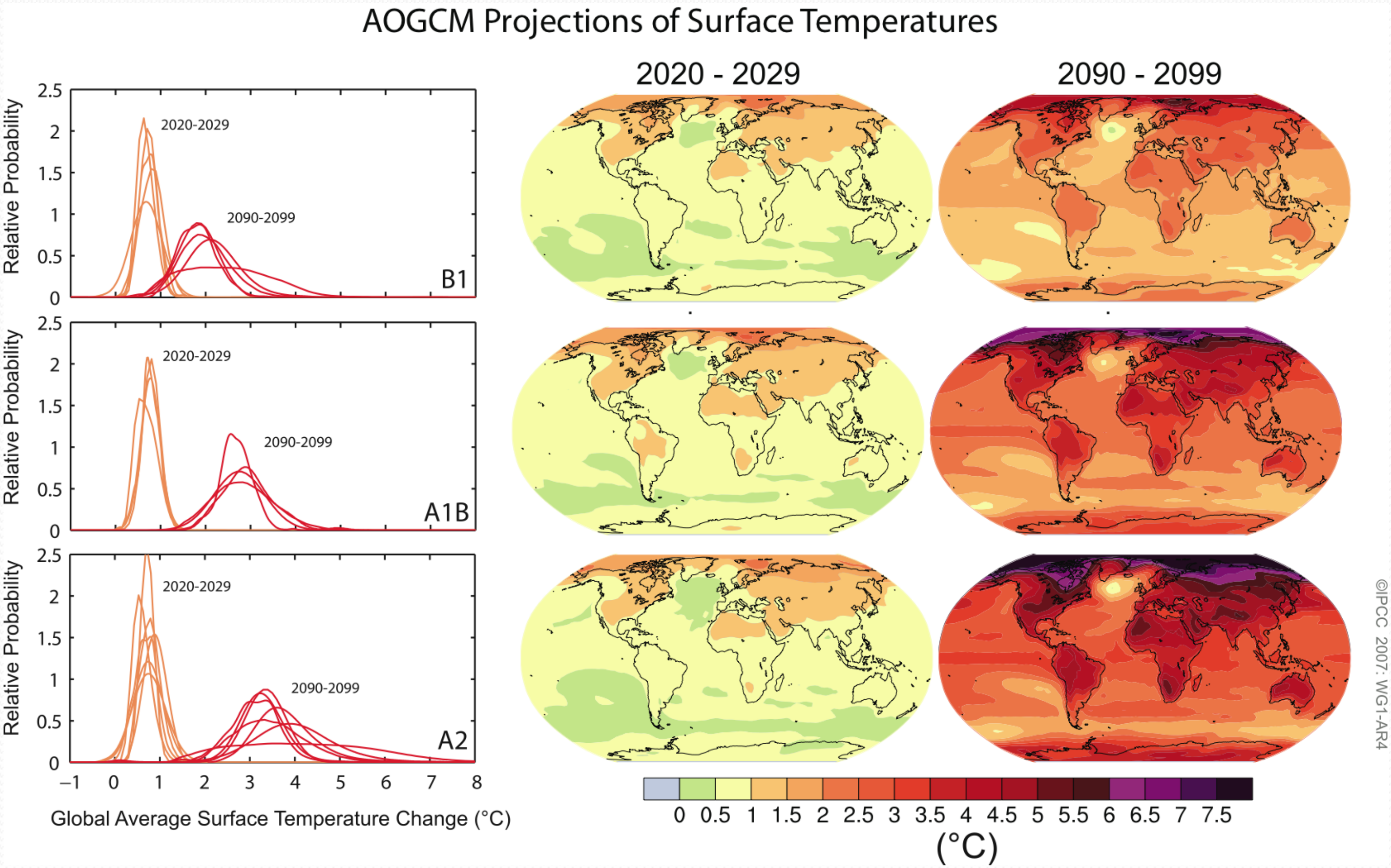
Alternative Climate Normals and Impacts to the Energy Industry Workshop
NCDC, Asheville, NC
April 24-25, 2012

Outline

- Climate Change Projections
- Impacts of Climate Change on Energy Services and Resources
- Climate Change Impacts on Wind Energy
- ENSO Impacts on Wind Energy
- Climate Change Impacts on Solar Energy
- Wind Forecast Improvement Project
- Local Climate Analysis Tool

Projections for three sample SRES scenarios



Energy services and resources will be increasingly affected by climate change

Hydro-met and/or climate change parameter	Select energy uses
Air temperature	Turbine production efficiency, air source generation potential and output, demand (cooling/hearting), demand simulation/ modeling, solar PV panel efficiency
Rainfall	Hydropower generation potential and efficiency, biomass production, demand, demand simulation/modeling
Wind speed and/or direction	Wind generation potential and efficiency, demand, demand simulation/modeling
Cloudiness	Solar generation potential, demand, demand simul/modeling
Snowfall and ice accretion	Power line maintenance, , demand, demand simul/modeling
Humidity	Demand, demand simulation/modeling

From "Climate Impacts on Energy Systems: Key issues for energy sector adaptation." The World Bank and Energy Sector Management Assistance Program.

Hydro-met and/or climate change parameter	Select energy uses
Short-wave radiation	Solar generation potential and output, output modeling, demand, demand simulation/modeling
River flow	Hydro-generation and potential, hydro-generation modeling (e.g., dam control), power station cooling water demands
Coastal wave height and frequency, and statistics	Wave generation potential and output, generation modeling, off-shore infrastructure protection and design
Flood statistics	Infrastructure protection and design, cooling water demands
Drought statistics	Hydro-generation output, demand
Storm statistics (e.g., strong winds, heavy rain, hail, lightning)	Infrastructure protection and design, demand surges
Sea level	Offshore operations

Energy Sector Vulnerability to Climate Change

Item	General Climate Impacts	Specific Climate Impacts	Additional Climate Impacts	Impacts on the Energy Sector
Climate Change Impacts on Resource Endowment				
Hydropower	Runoff	Quantity (+/-) Seasonal flows high & low flows, Extreme events	Erosion Siltation	Reduce firm energy Increased variability Increased uncertainty
Wind power	Wind field characteristics	Changes in density, wind speed, Increased wind variability	Changes in vegetation (might change roughness and available wind)	Increased uncertainty
Biofuels	Crop response to climate change	Crop yield, Agro-ecological zones shift	Pests, water demand, drought, frost, fires, storms	Increased uncertainty Increased frequency of extreme events
Solar power	Atmospheric transmissivity	Water content, cloudiness, cloud characteristics		Positive and negative impacts
Wave and tidal energy	Ocean climate	Wind field characteristics, no effect on tides	Strong non-linearity between wind speed and wave power	Increased uncertainty, Increased frequency of extreme events

From “Climate Impacts on Energy Systems: Key issues for energy sector adaptation.” The World Bank and Energy Sector Management Assistance Program.

Climate Change Impacts on Energy Supply

Hydropower	Water availability and seasonality	Water resource variability, Increased uncertainty of expected energy output	Impact on grid; might overload transmission capacity; extreme events	Increased uncertainty, Revision of system reliability, Revision of transmission needs
Wind power	Alteration of wind speed frequency distribution	Increased uncertainty of energy output	Short life span reduces risk associated with climate change; Extreme events	Increased uncertainty on energy output
Biofuels	Reduced transformation efficiency	High temperatures reduced thermal generation efficiency	Extreme events	Reduced energy generated, Increased uncertainty
Solar power	Reduced solar cell efficiency	Solar cell efficiency reduced by higher temperatures	Extreme events	Reduced energy generated, Increased uncertainty
Thermal power plants	Generation cycle efficiency, Cooling water availability	Reduced efficiency, Increased water needs, e.g., during heat waves	Extreme events	Reduced energy generated, Increased uncertainty
Oil and gas	Vulnerable to extreme events	Cyclones, floods, erosion and siltation (coastal areas, on land)	Extreme events	Reduced energy generated, Increased uncertainty

Impacts on Transmission, distribution and transfers				
Transmission, distribution and transfers	Increased frequency of extreme events, Sea level rise	Wind and ice, Land slides and flooding, Coastal erosion, sea level rise	Erosion and siltation, Weather conditions that prevent transport	Increased vulnerability of existing assets
Impacts on Design and Operations				
Siting infrastructure	Sea level rise, Increased extreme events	Flooding from sea level rising, coastal erosion, Increased frequency of extreme events	Water availability, Permafrost melting, Geomorphodynamic equilibrium	Increased vulnerability of existing assets, Increased demand for new good siting locations
Down time and system bottlenecks	Extreme weather events	Impacts on isolated infrastructure, Compound impacts on multiple assets in the energy system	Energy system not fully operational when community required it the most	Increased vulnerabilty, Reduced viability, Incrases social pressure for better performance
Energy Trade	Increased vulnerability to extreme events	Cold spells and heat waves	Increased stress on transmission, distribution and transfer infrastructure	Increased uncertainty, Increased peak demand on energy system

Impacts on Energy Demand				
Energy Use	Increased demand for indoor cooling	Reduced growth in demand for heating, Increased energy use for indoor cooling	Associated efficiency reduction with increased temperature	Increased demand and peak demand taxing transmission and distribution systems
Other Impacts				
Cross-Sector Impacts	Competition for water resources, competition for adequate siting locations	Conflicts in water allocation during stressed weather conditions, Competition for good siting locations	Potential competition between energy and non-energy crops for land and water resources	Increased vulnerability and uncertainty, Increased costs

Climate Change Impacts on Wind Energy

- Wind power is proportional to the cube of the wind speed. Thus, a change in hub-height wind speed from 5.0 to 5.5 m/s yields an increase in energy density of 30%.
- Current literature indicates it is unlikely that mean wind speeds and energy density will change by more than the current inter-annual variability (+/- 15%) over most of Europe and North America during this century.
- Pryor and Barthelmie, *Climate change impacts on wind energy: A review*. Renewable and Sustainable Energy Reviews, 14 (2010), 430-437.]

$$E = \frac{1}{2}\rho U^3$$

where

E = energy density ($W\ m^{-2}$),
ρ = air density ($kg\ m^{-3}$),
U = wind speed at hub-height ($m\ s^{-1}$)

U.S. Wind Resource in next 50 years

- Pryor and Barthelmie (PNAS, 2011) analyze simulations from the current generation of regional climate models and show, at least for the next 50 years, the wind resource in the regions of greatest wind energy penetration will *not* move beyond the historical envelope of variability. Thus this work suggests that the wind energy industry can, and will, continue to make a contribution to electricity provision in these regions for at least the next several decades.

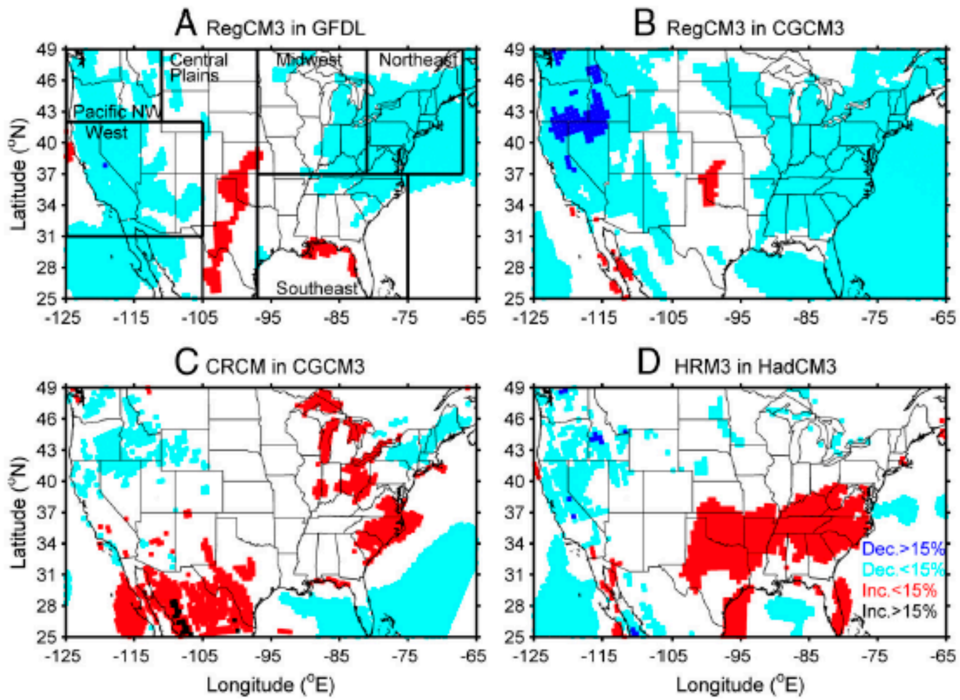
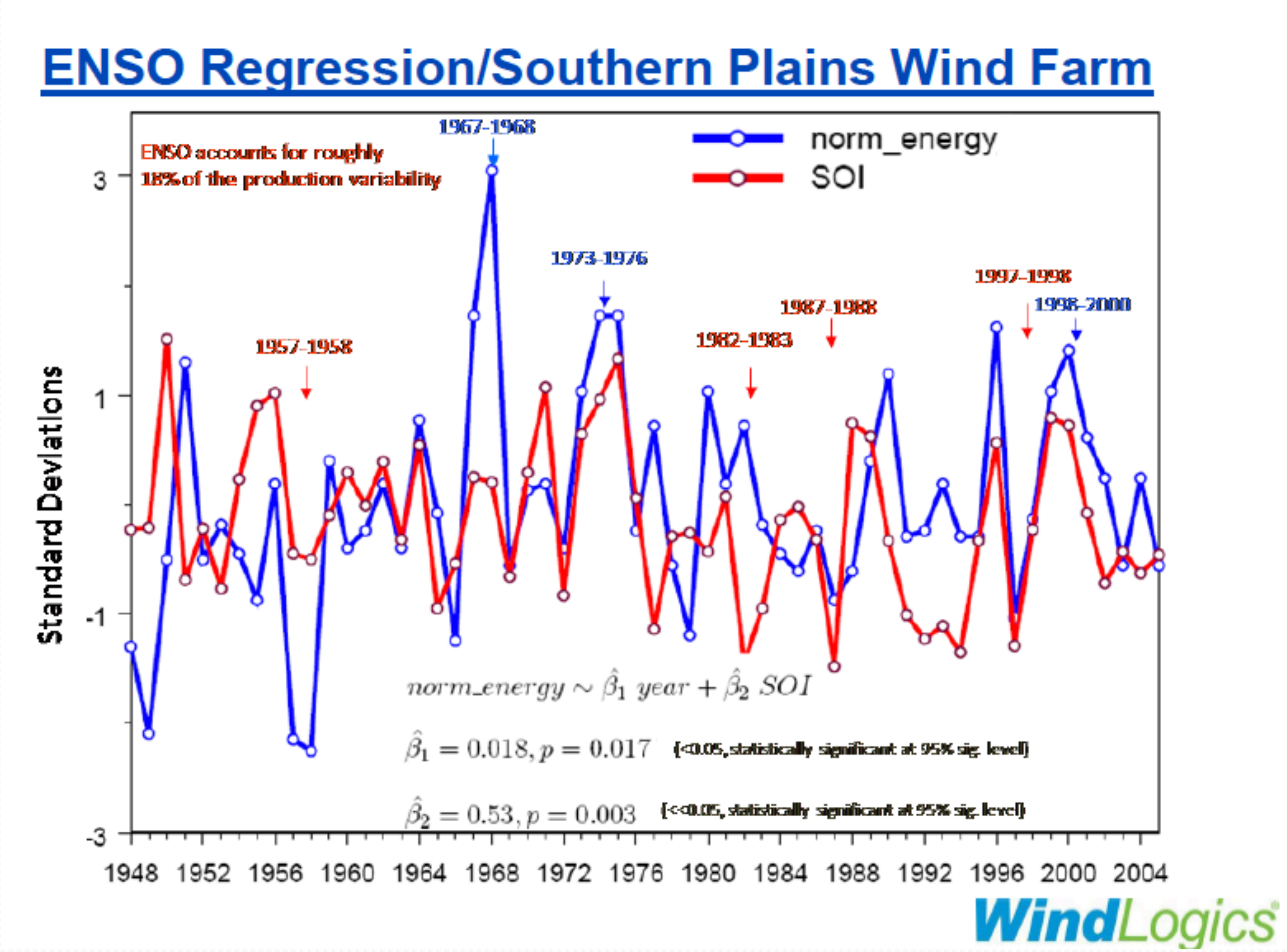


Fig. 3. Difference in the mean wind energy density (in %) for 2041–2062 vs. 1979–2000. *A–D* show the different AOGCM–RCM combinations. The sign and magnitude of change is only shown for grid cells where the value for the future period beyond the 95% confidence intervals on the mean value during 1979–2000. The colors depict both the sign and magnitude of the difference using the legend in *D*. The climate regions as derived from the National Assessment and used in Fig. 4 are denoted in *A*.

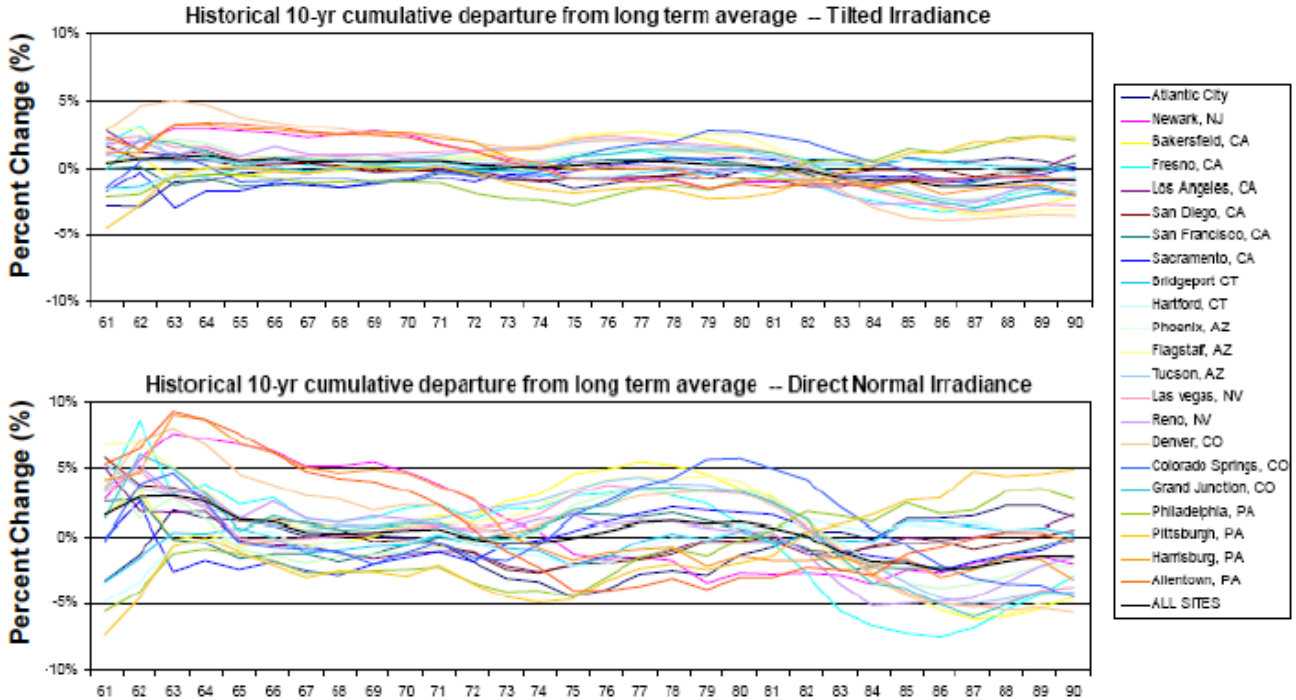
El Nino-La Nino Effects on Wind



Slide courtesy of Cathy Finley, WindLogics.

Climate and Solar Energy

Climate cycles also have significant impact on solar resource

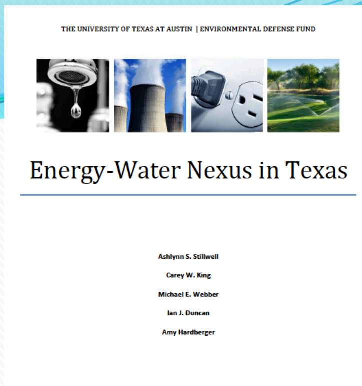


Major influences on long term solar resource variability include interannual variability (El Niño, La Niña) and multi-decadal oscillations (PDO)

WindLogics

Slide courtesy of Cathy Finley, WindLogics

Energy and Water Consumption


THE UNIVERSITY OF TEXAS AT AUSTIN | ENVIRONMENTAL DEFENSE FUND

Energy-Water Nexus in Texas

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Carey W. King
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Ian J. Duncan
Amy Hardberger

Table 1.2. Water consumption reported volumes for different fuels and cooling technologies. Air-cooling requires negligible water and is compatible with all of the technologies listed [17, 25-27]

			Cooling Technologies – Water Consumption (gal/MWh)				
			Open-Loop	Closed-Loop Reservoir	Closed-Loop Cooling Tower	Hybrid Cooling	Air-Cooling
Fuel Technology	Thermal	Coal	300	385 (±115)	480	between	60 (±10)
		Nuclear	400	625 (±225)	720	between	60 (±10)
		Natural Gas Combustion Turbine	negligible	negligible	negligible	negligible	negligible
		Natural Gas Combined-Cycle	100	130† (±20)	180	between	60† (±10)
		Integrated Gasification Combined-Cycle	not used	not used	350† (±100)	between	60† (±10)
		Concentrated Solar Power	not used	not used	840 (±80)	between	80† (±10)
	Non-Thermal	Wind	none	none	none	none	none
		Photovoltaic Solar	none	none	none	none	none

†Estimated based on withdrawal and consumption ratios

Energy and Water Withdrawal

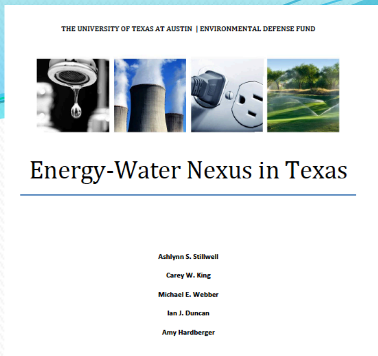


Table 1.1. Water withdrawal reported volumes for different fuels and cooling technologies. Air-cooling . negligible water and is compatible with all of the technologies listed. [17, 25-27]

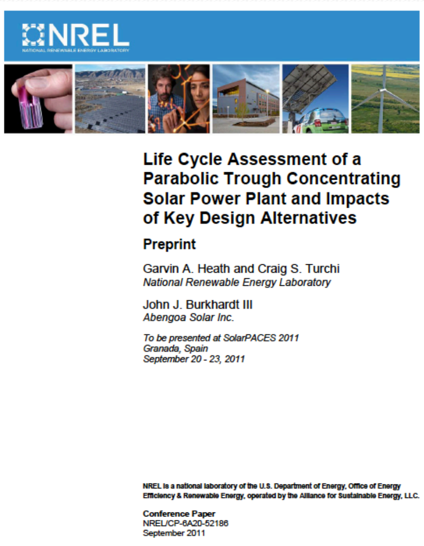
			Cooling Technologies – Water Withdrawal (gal/MWh)				
			Open-Loop	Closed-Loop Reservoir	Closed-Loop Cooling Tower	Hybrid Cooling	Air-Cooling
Fuel Technology	Thermal	Coal	35,000 (±15,000)	450 (±150)	550 (±50)	between	<100
		Nuclear	42,500 (±17,500)	800 (±300)	950 (±150)	between	<100
		Natural Gas Combustion Turbine	negligible	negligible	negligible	negligible	negligible
		Natural Gas Combined-Cycle	13,750 (±6,250)	155† (±25)	230	between	<100†
		Integrated Gasification Combined-Cycle	not used	not used	400† (±110)	between	<100†
		Concentrated Solar Power	not used	not used	840† (±80)	between	<100†
	Non-Thermal	Wind	none	none	none	none	none
		Photovoltaic Solar	none	none	none	none	none

†Estimated based on withdrawal and consumption ratios

Dry cooling and Concentrated Solar Power

	Wet	Dry	Units
Gross Capacity	118	120.5	MW
Parasitics (at design point)	15	17.6	MW
Net Capacity	103	103	MW
Rankine Cycle Efficiency	37.4	35.4	%
Annual Generation	426,700	438,800	MWh
Capacity Factor	0.47	0.49	
Grid Electricity Consumption	3,700	3,990	MWh/yr
Natural Gas Consumption	8,900	15,600	MMBtu/yr
Solar Field Aperture Area	987,500	1,063,000	m^2
HTF Mass	4,270	4,600	metric ton
TES Storage Capacity	1,990	2,140	MWh_{th}
Total Plant Fenceline Area	4,100,000	4,140,000	m^2

Table 1. Specifications of Wet- (Reference Plant) and Dry-Cooled Designs [5]



Life Cycle Phase	Plant System	GHG [g CO2eq / kWh]		WATER [L / kWh]		CED [MJeq / kWh]	
		Wet	Dry	Wet	Dry	Wet	Dry
Manufacturing	HTF	2.5	2.6	0.10	0.10	0.051	0.053
	Power Plant	1.9	2.4	0.076	0.085	0.033	0.037
	Solar Field	4.6	4.8	0.15	0.16	0.071	0.074
	TES	2.7	2.8	0.15	0.15	0.037	0.038
Construction	HTF	0.14	0.15	0.0012	0.0012	0.0018	0.0018
	Power Plant	0.19	0.21	0.0041	0.0030	0.0032	0.0034
	Solar Field	0.77	0.81	0.022	0.023	0.012	0.013
	TES	0.64	0.67	0.0054	0.0057	0.010	0.011
Operation	HTF	2.2	2.3	0.081	0.085	0.039	0.041
	Power Plant	6.2	6.9	4.0	0.29	0.10	0.12
	Solar Field	0.61	0.64	0.14	0.14	0.010	0.011
	TES	0.99	1.03	0.029	0.030	0.016	0.017
Dismantling	HTF	0.018	0.018	0.000079	0.000077	0.00027	0.00027
	Power Plant	0.014	0.014	0.000062	0.000061	0.00021	0.00021
	Solar Field	0.090	0.088	0.00039	0.00038	0.0013	0.0013
	TES	0.0019	0.0018	0.0000080	0.0000079	0.000028	0.000028
Disposal	HTF	0.50	0.52	0.00087	0.00090	0.00025	0.00025
	Power Plant	0.14	0.08	0.00021	0.00022	0.00010	0.00012
	Solar Field	0.77	0.81	0.0013	0.0013	0.00063	0.00066
	TES	0.68	0.71	0.0048	0.0050	0.0088	0.0093
Life Cycle Phase Subtotals		**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
Manufacturing		12	13	0.47	0.50	0.19	0.20
Construction		1.7	1.8	0.033	0.033	0.028	0.029
Operation		10	11	4.2	0.55	0.17	0.19
Dismantling		0.12	0.12	0.00053	0.00053	0.0019	0.0018
Disposal		2.1	2.1	0.0071	0.0074	0.0098	0.010
Grand Total		**26**	**28**	**4.7**	**1.1**	**0.40**	**0.43**

Table 2. Life Cycle Impact Metrics Disaggregated by Phase and System for Wet- (Reference Plant) and Dry-Cooled Designs

Energy Sector Needs Improved Observations, Weather Models & Forecasts

Improved forecasts of turbine-height winds, clouds, rain (for balancing by hydropower dams), icing conditions are needed.

Improved understanding of:

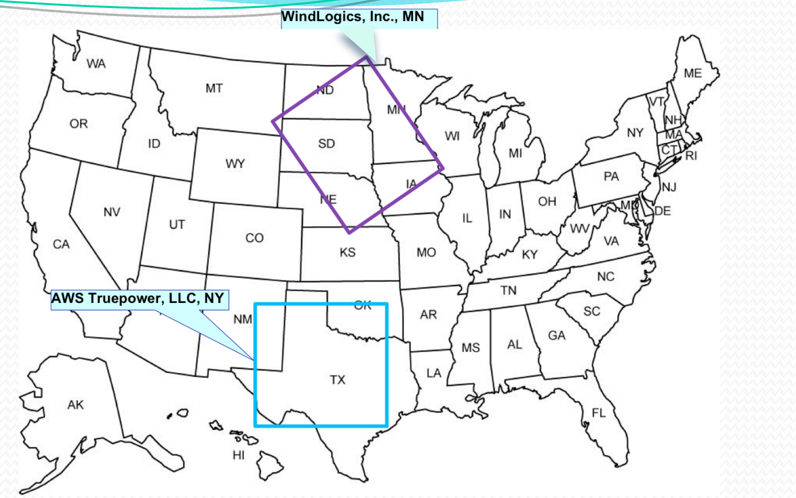
- Boundary layer processes
- Mesoscale processes
- Terrain effects
- Upwind turbine effects
- Extreme wind events
- Turbulence
- Shear
- Low-level jet
- Ramp events
- Clouds
- Aerosols

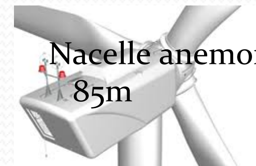
Sea smoke. Photo courtesy of Uni-Fly A/S

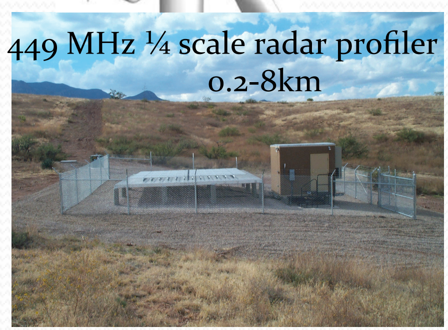
Wind Forecast Improvement Project

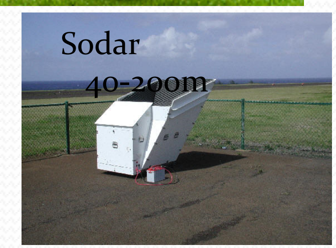
- Improve short-range forecasts (0-6 h) of wind speed, direction, and turbulence at wind turbine hub-height.
  - Deploy a regional network of upper-air remote sensing observations
  - Combine this network with industry provided tall-tower and wind turbine nacelle meteorological observations
  - Assimilate this data into NOAA's developmental High Resolution Rapid Refresh (HRRR) NWP model

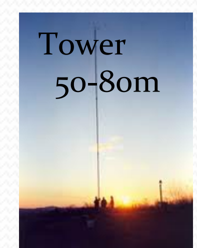
- Demonstrate that the improved forecasts can reduce the cost of wind energy and make renewable energy profitable











What is the Local Climate Analysis Tool (LCAT)?

- Online interactive tool
- For regional and local climate studies
- State-of-the-art station and reanalysis gridded data
- Best practices for climate analysis

Field Office Need for LCAT

- Easy access to standardized, scientifically sound methodologies for local climate analysis to meet growing needs of users
- Staff need to be able to
  - Access, manipulate, and interpret local climate data
  - Facilitate development of forecasts making weather-climate linkage
  - Characterize climate variability and change impacts on water and weather elements

All LCAT slides are courtesy of Marina Timofeyeva, NOAA/NWS

What is the Local Climate Analysis Tool (LCAT)?

Priority Topics

Priority Topic	Question
Drought Analysis and Impacts	How severe is this year drought in my area?
Climate Change Impacts	What is the rate of climate change in my town?
Climate Variability Impacts	How does El Nino change our chances for sunny days?
Water Resources Applications	What is climate variability impact on our water resources?
Attribution of Extreme Events	Is the flood we have due to climate change?

How does LCAT work?

LCAT uses principles of Artificial Intelligence in connecting human and computer perceptions on application of data and scientific techniques in multiprocessing simultaneous users' tasks

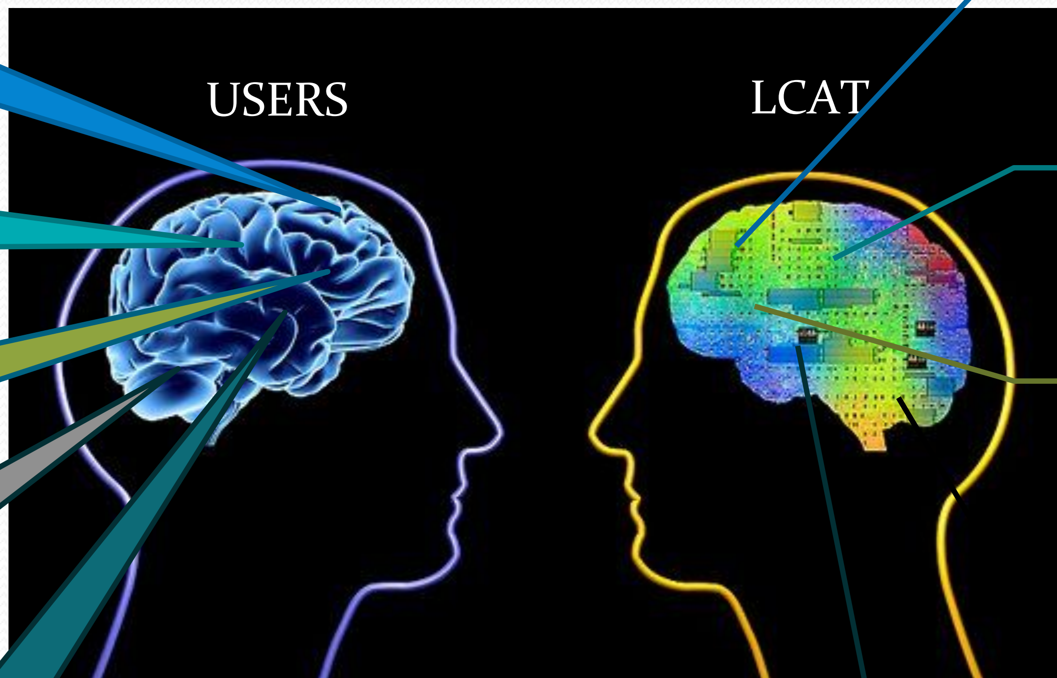
How is the temperature in my town changing?

Should we expect floods during La Nina events?

How severe is the drought in my region this year?

Which climate model performs best in my region?

What are the projections for climate in my region?



Data: Homogenized station maximum temperature
Analysis: best practices for trend; rate of change
Output: statistics, plots, metadata

Data: Homogenized precipitation and river flow
Analysis: composites, risk assessment
Output: statistics, plots, metadata

Data: Drought indices
Analysis: time series analysis
Output: statistics, plots, metadata

Data: Reanalysis and GCM fields
Analysis: downscaling, sensitivity tests
Output: statistics, plots, metadata

Data: GCM outputs
Analysis: downscaling
Output: statistics, plots, metadata

LCAT Output

Climate Change Impacts

Trend Performance

Root Mean Square Error

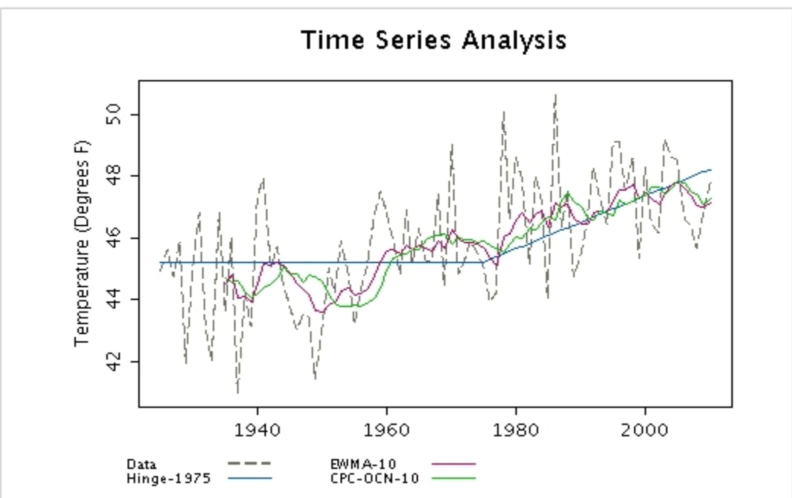
Hinge with anchor at 1975:	1.74
Exponentially Weighted Moving Average (Alpha=10):	1.39
CPC Optimal Climate Normal (10-Year Moving Average):	1.71

Ensemble Performance

Ensemble Standard Deviation 0.40

Rate of Change

Annual Rate of Change	0.047 Degrees F per year
Decadal Rate of Change	0.47 Degrees F per decade
Climatological Rate of Change	1.41 Degrees F per 30-year period



Climate Variability Impacts

Data Statistics

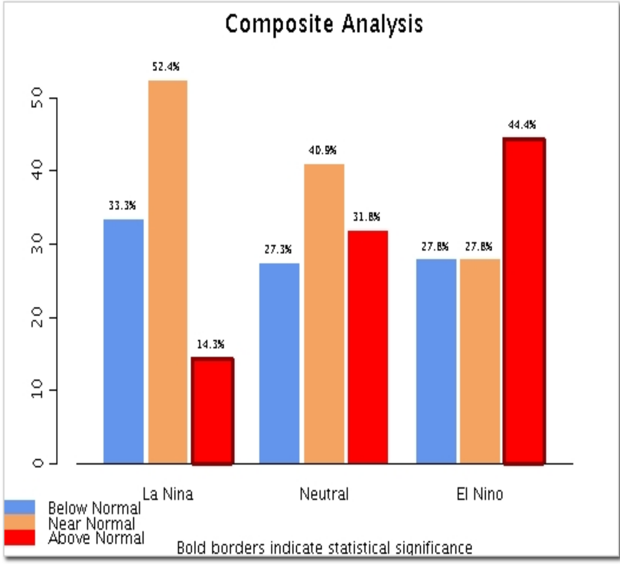
Mean:	45.90 Degrees F
Median:	45.7 Degrees F
Mode:	43.6 Degrees F
Standard Deviation:	1.654
Climatological Mean:	46.02 Degrees F
Tercile Low:	44.75 Degrees F
Tercile High:	47.2 Degrees F
Below Events:	21
Neutral Events:	22
Above Events:	18
Total Events:	61

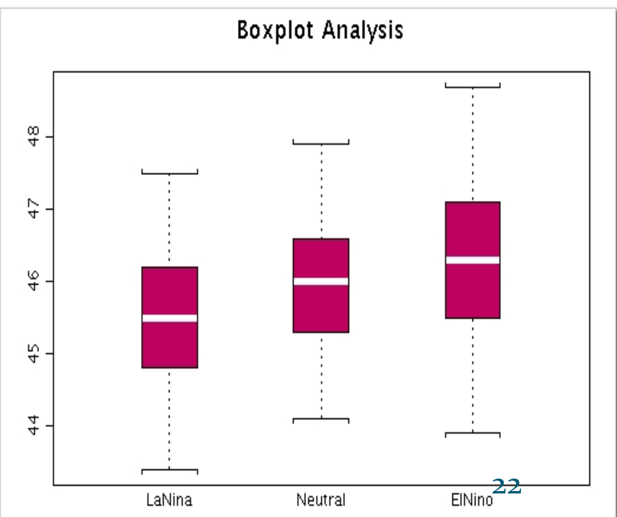
Anomaly

Lower Category Anomaly:	-0.55 Degrees_F
Middle Category Anomaly:	-0.05 Degrees_F
Upper Category Anomaly:	0.29 Degrees_F

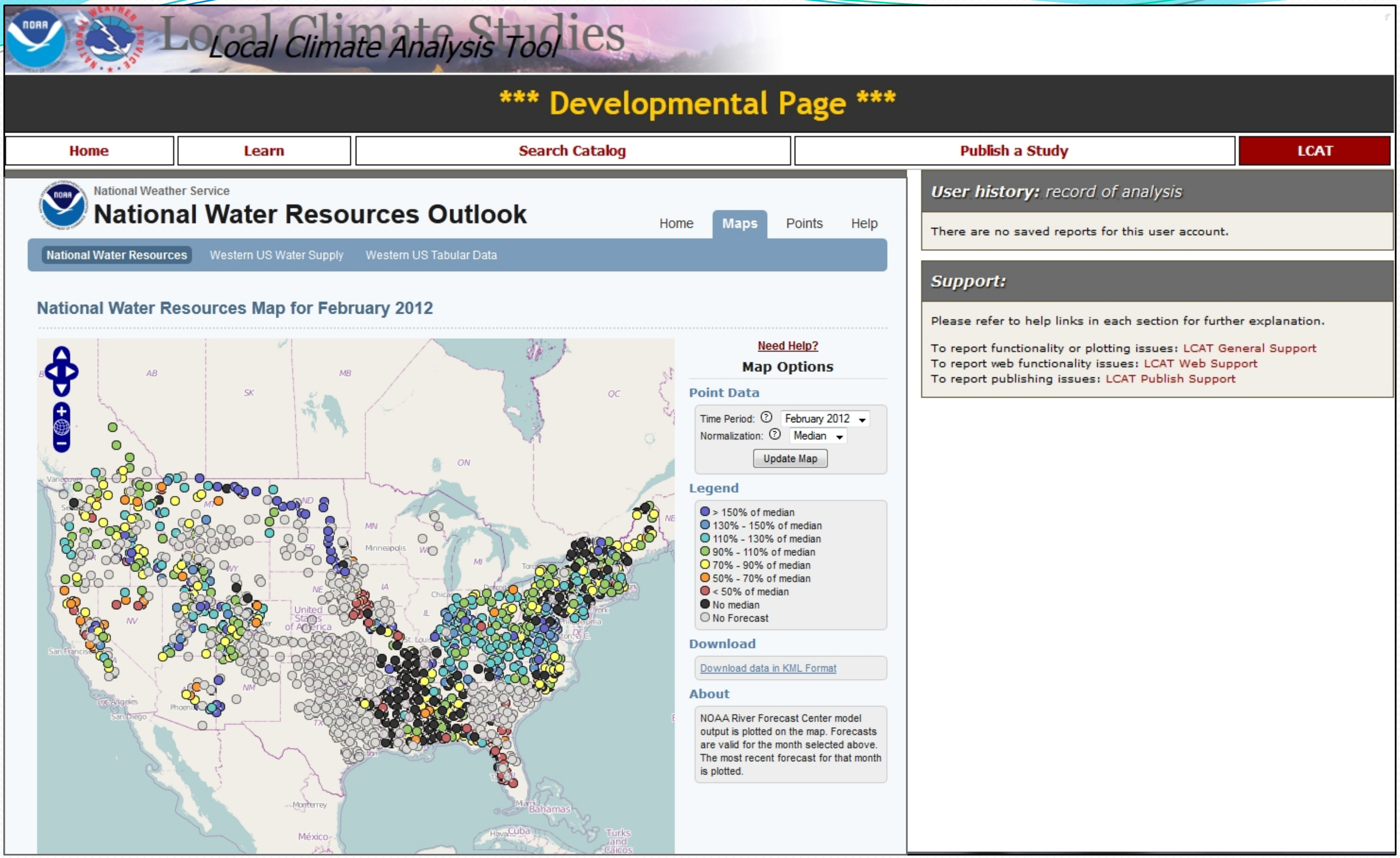
Trend Performance

No trends selected by user.



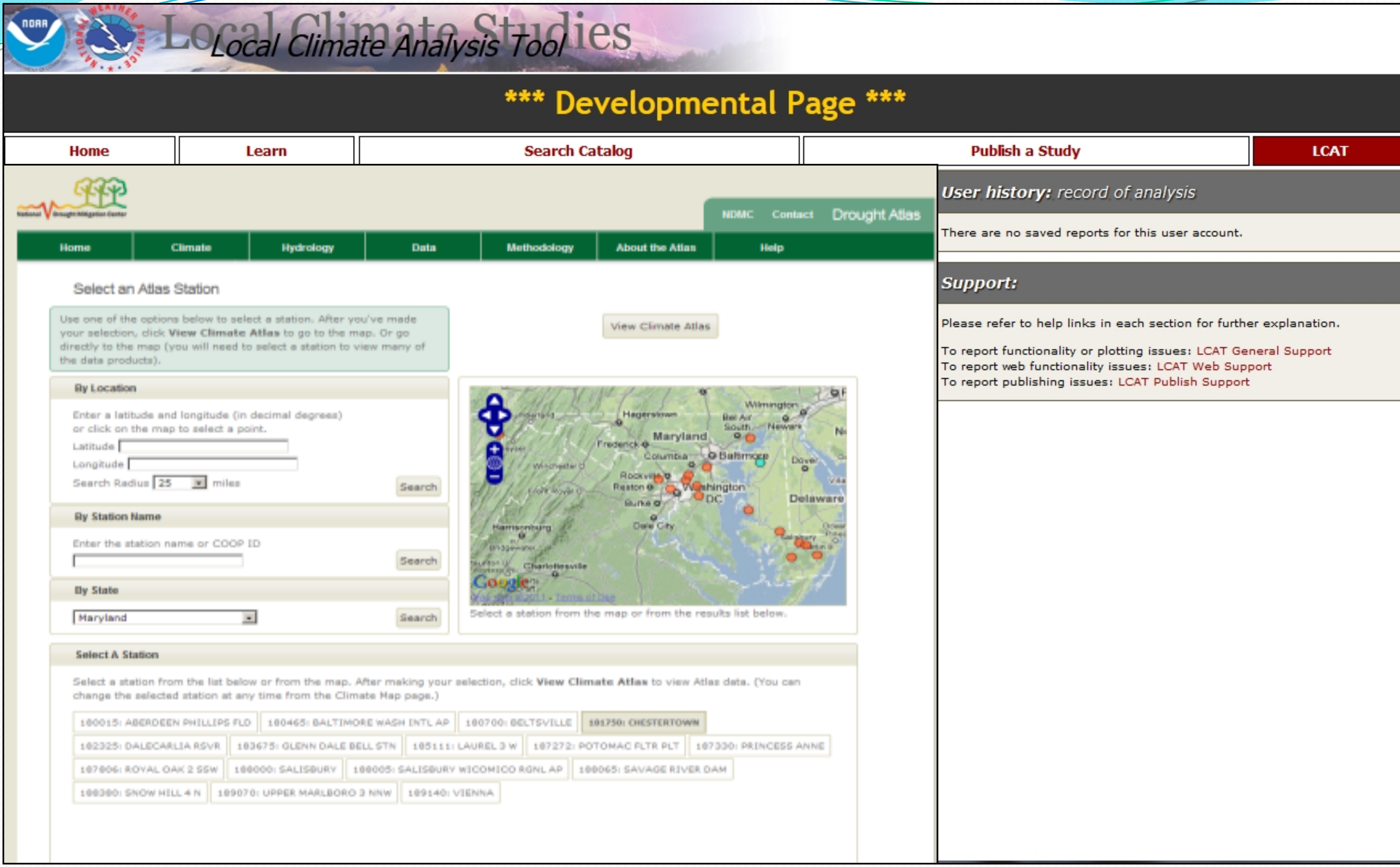


Water Resources Applications



LCAT will include links to relevant external climate analysis tools such as the National Water Resource Outlook webpage

Drought Analysis and Impacts



LCAT will include links to relevant external climate analysis tools such as the Drought Atlas (coming soon)

Currently Under Development

By September 2012:

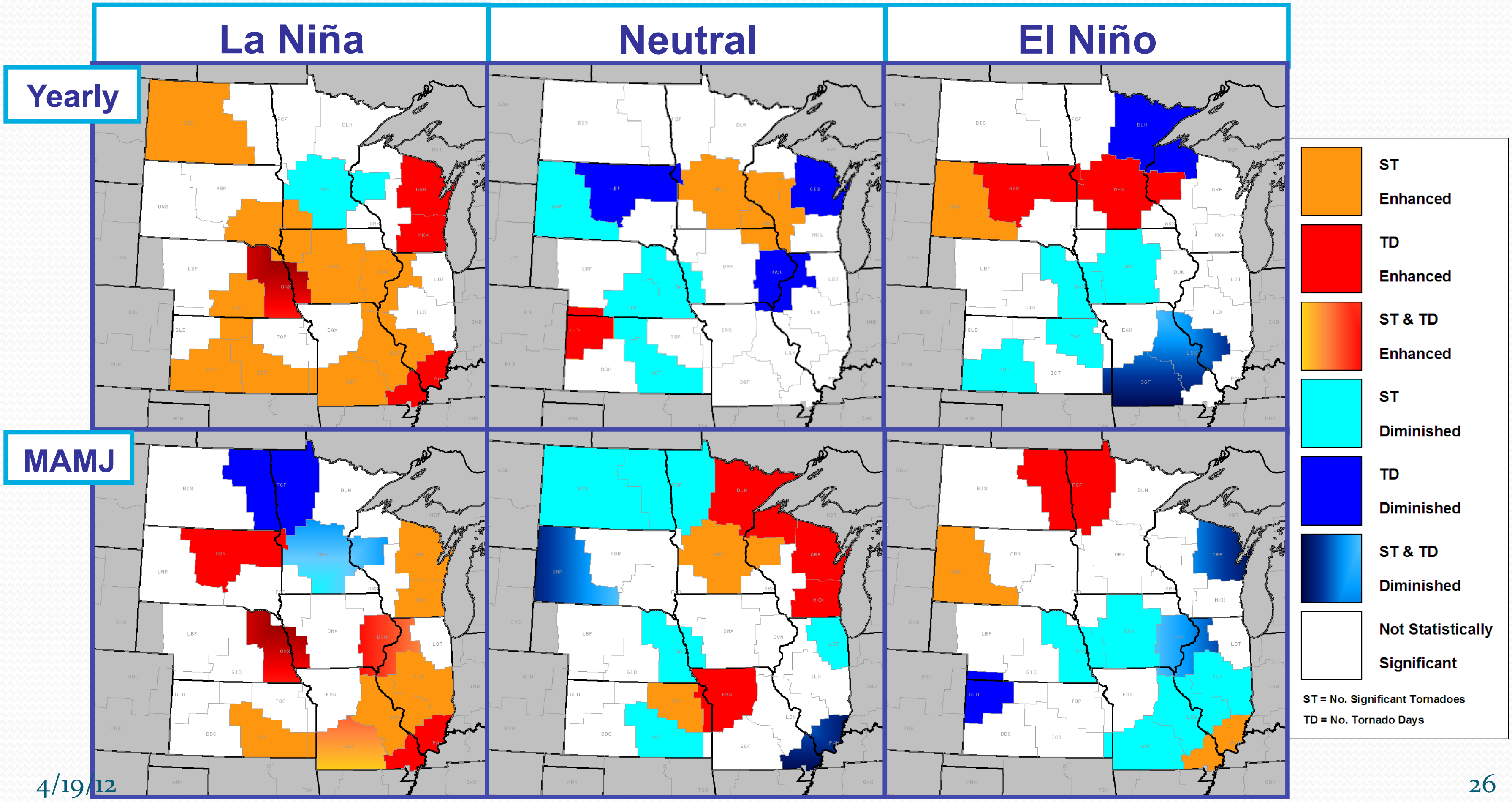
- Trend communication between Climate Change & Climate Variability sections
- Additional output statistics displayed
- Enhancements to help buttons and references
- Personalized report labeling for easier reference
- Reference maps for Climate Divisions, County Warning Areas, and station locations
- Additional output formats available (comma-, space- or tab- delimited, XML, PDF and Excel)
- Analog signal years displayed (e.g., years that were La Niña or El Niño)
- Additional data sets:
  - Alaska and Hawaii stations
  - NCDC Climate Division Data

LCAT FY13 plans:

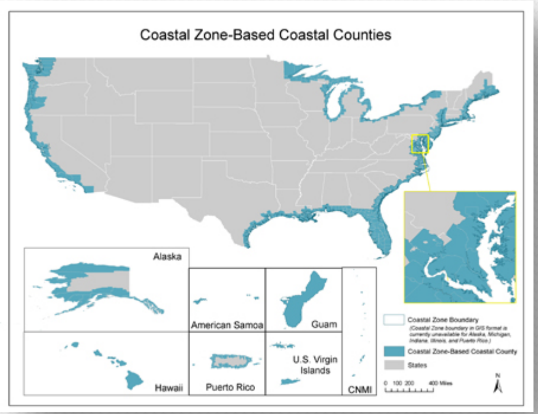
- Tuning ONI index capability
- Addition of Climate Variability Indexes (NAO, SOI, MEI)
- Functional link between xmACIS data and LCAT
- Additional statistical analysis options (e.g., Multiple linear regression, logistic regression, PCA, etc.)
- User defined variable seasons (e.g. 2- , 4-month or 6-month periods)
- Increase of spatial options (e.g.:, county or state wide)
- Additional options for definition of climate variable (e.g., critical value)
- Multiple signal option combinations (e.g., Negative ONI with Positive AO)
- Drought studies (incorporation of drought data)
- Trouble Ticketing system implemented
- Functionality improvements
- Publication process available
- Additional data sets:
  - Pacific Island Data sets
  - Reanalysis data

LCAT Future

- **Incorporation of special data sets (tornado, snowfall, number of days with extremes, extreme time series, etc.) will enhance IDSS capabilities by providing integrated environmental services**

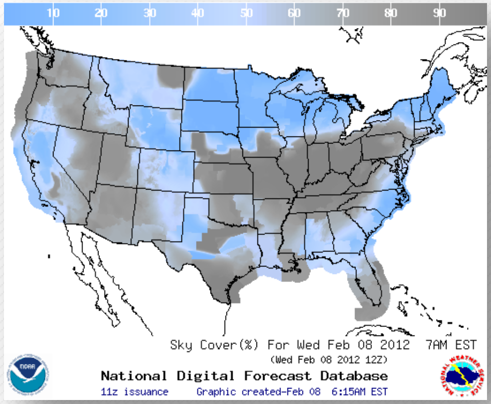


LCAT Future



- **Water level (tides, etc.) and climate signals for coastal regions**
  - What are water level extremes during El Niño or La Niña events?
  - Are there seasonal extremes?
  - Does the AO affect water levels on the NE coast?

- **Wind and solar data (aerosols, cloud cover, cloud thickness, etc.) for energy industry**
  - What has been the maximum wind speed over the past 30 years?
  - How does this compare to the past 80 years?
  - What is the average daily cloud cover in a region during an El Niño winter?

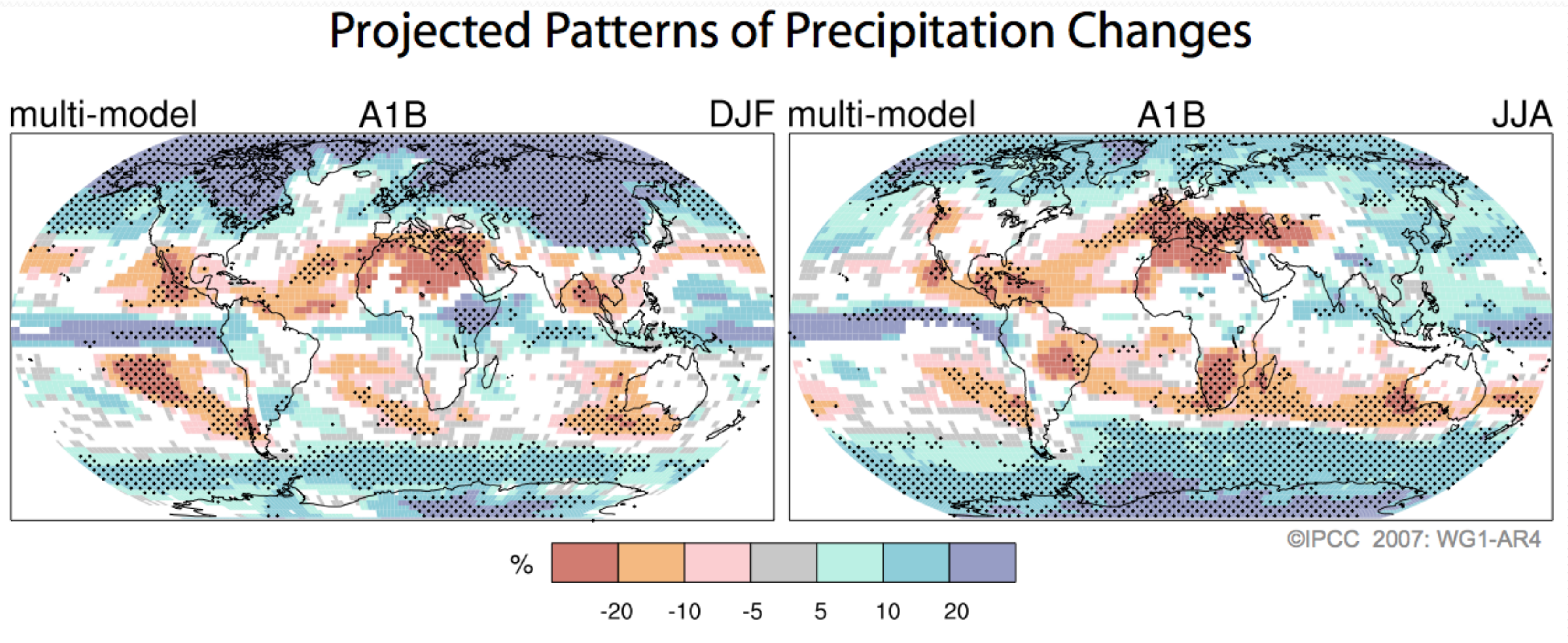


Summary

- Energy services and resources will be increasingly affected by climate change.
- Energy production from wind and solar (and future ocean energy) are directly dependent on weather and climate.
- Further research in all the areas mentioned is needed.

Backup Slides

Projections of Future Changes in Climate



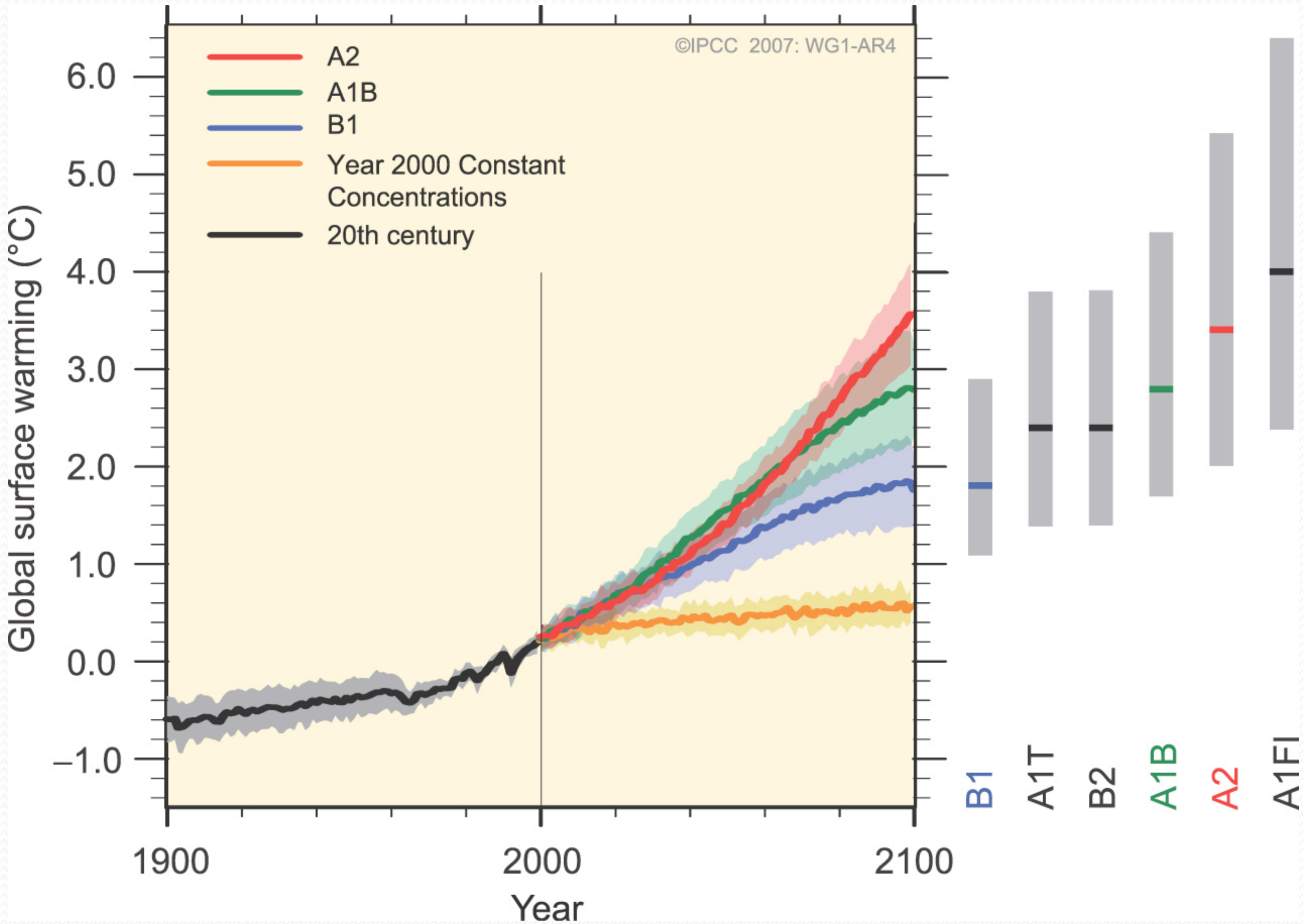
Drying in much of the subtropics, more rain in higher latitudes, continuing the broad pattern of rainfall changes already observed.

Projections of Future Changes in Climate

Multi-Model Averages and Assessed Ranges for Surface Warming

In 2100:
600 ppmv CO2 equiv (B1) Best estimate is +1.8°C by 2100; likely range 1.1-2.9°C

Or 1550 ppmv (A1FI) Best estimate is 4°C by 2100; likely range 2.4-6.4°C



Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints.

Pounds CO2 per Btu

- Coal 208,000 (21% total energy in U.S.; 48% of U.S. electricity)
- Oil 164,000 (35% total energy in U.S.)
- Gas 117,000 (25% of total energy in U.S.; 19% electricity prod.)

If all electricity production currently using coal new were switched to gas, total U.S. GHG emissions would be ~ 10% less.

Climate Change Impacts on Wind Energy

Wind power is proportional to the cube of the wind speed. Thus, a change in hub-height wind speed from 5.0 to 5.5 m/s yields an increase in energy density of 30%.

For at least this century, natural variability exceeds the climate change signal in wind energy resource and extreme wind speeds. [Pryor and Barthelmie, Climate change impacts on wind energy: A review. Renewable and Sustainable Energy Reviews, 14 (2010), 430-437.]

Impact of climate change on wind resource

<u>Wind resource magnitude</u>

- Change geographic distribution or inter- and intra-annual variability
- Downscaling by either dynamical or statistical methods
- Europe: By 2100, possible increase in winter annual mean wind speeds and wind energy density in north, and decrease in south
- U.S.: By ~ 2060, possible (<3%) decrease, and by 2100 <5% decrease, in mean wind speed

Northwest U.S. (Idaho, Montana, Oregon, Washington, Wyoming), SRES A1B and A2, summertime wind speeds could decrease by 5-10%, yielding 40% reduction in energy density; wintertime wind speeds little change. [Sailor, Smith, and Hart, Climate change implications for wind power resources in the Northwest United States. Renewable Energy, 33 (2008) 393-2406.]

Climate Change Impacts on Wind Energy

Variability of Wind Resource

- Historical inter-annual variability across much of Europe, measured as standard deviation of annual wind indices, is ~ +/- 10-15%, and inter-decadal variability ~+/- 30 %.
- Inter-annual variability in mean wind speeds in Minnesota ~+/- 5%.
- Little research has been done to determine if climate change will yield change in inter-annual or –decadal variability of wind speeds or energy density

Impact on operation and maintenance of wind farms and turbine design

- Changes in extreme loads that frequently arise from high wind speeds may result from increased storm intensity and changed tracking
- Turbines are designed based on hub-height mean annual wind speeds, reference extreme wind speed, and characteristic turbulence (turbulence not expected to be significantly affected by climate change)
- Extreme wind speeds and gusts
  - Some studies indicate increased magnitude of wind speed extremes in northern and central Europe.
    - Caution: It is difficult to quantify occurrence of events that are rare by definition.
- Icing
  - Reduced icing frequency in Scandinavia, making some sites previously deemed unsuitable for wind power more suitable
- Air density: At mean sea level, an increase in temp from 5 ° C to 10 ° C leads to a decrease in air density of 1-2%, with a commensurate decline in energy density.

Conclusion

Current literature indicates it is unlikely that mean wind speeds and energy density will change by more than the current inter-annual variability (+/- 15%) over most of Europe and North America during this century.

[Pryor and Barthelmie, Climate change impacts on wind energy: A review. Renewable and Sustainable Energy Reviews, 14 (2010), 430-437.]