100% Clean, Renewable Wind, Water, and Solar (WWS) Roadmaps for the 50 United States and 139 Countries of the World

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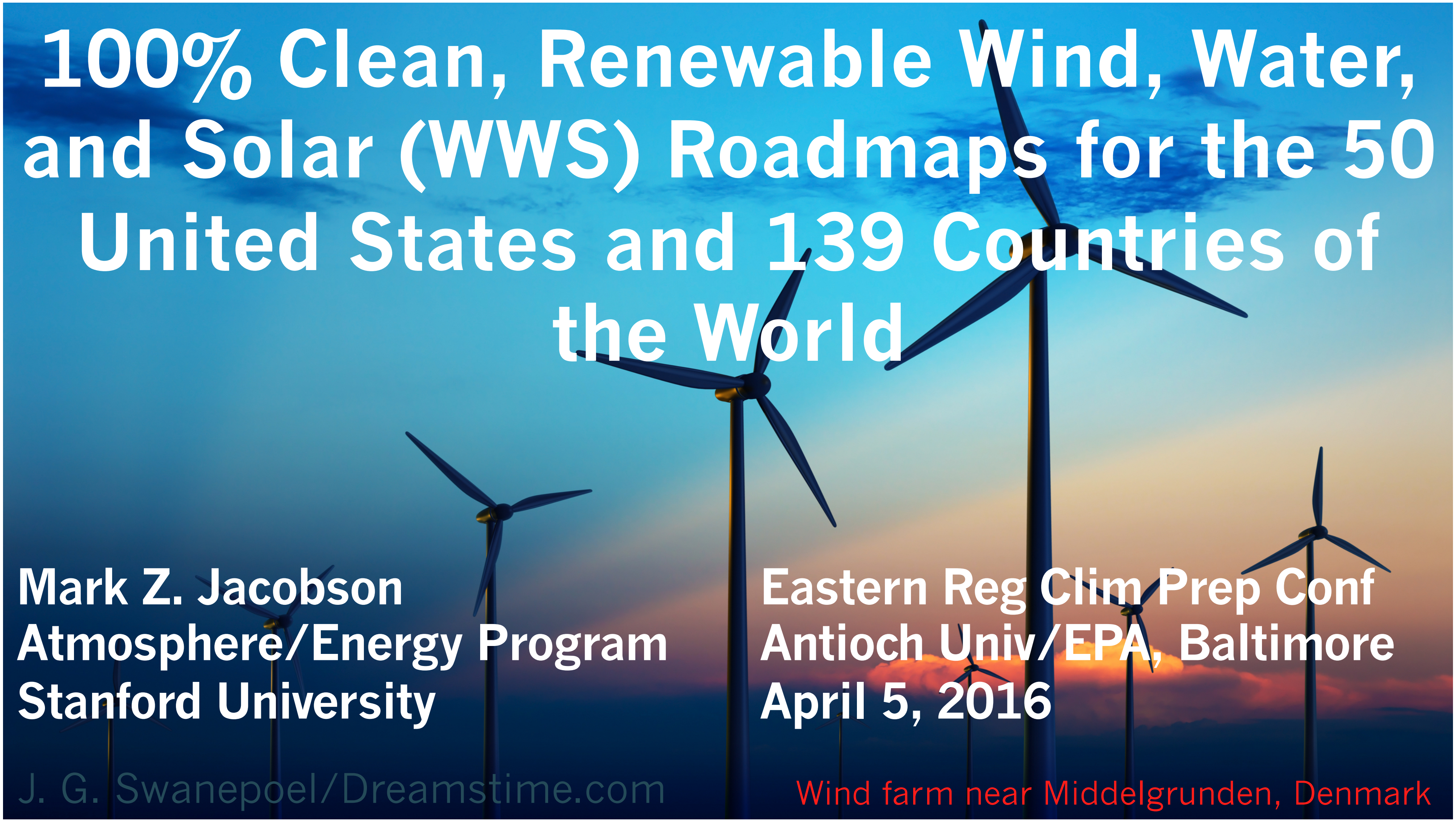
April 5, 2016



Wind farm near Middelgrunden, Denmark

What's the Problem? Why act Quickly?

Fossil-fuel + biofuel air pollution cause 4-7 mil. premature air pollution deaths/yr worldwide costing >3% of world GDP

Global warming due to world emissions will cost ~$16-20 trillion/year by 2050.

Increasing fossil energy use increases energy prices→ economic, social, political instability

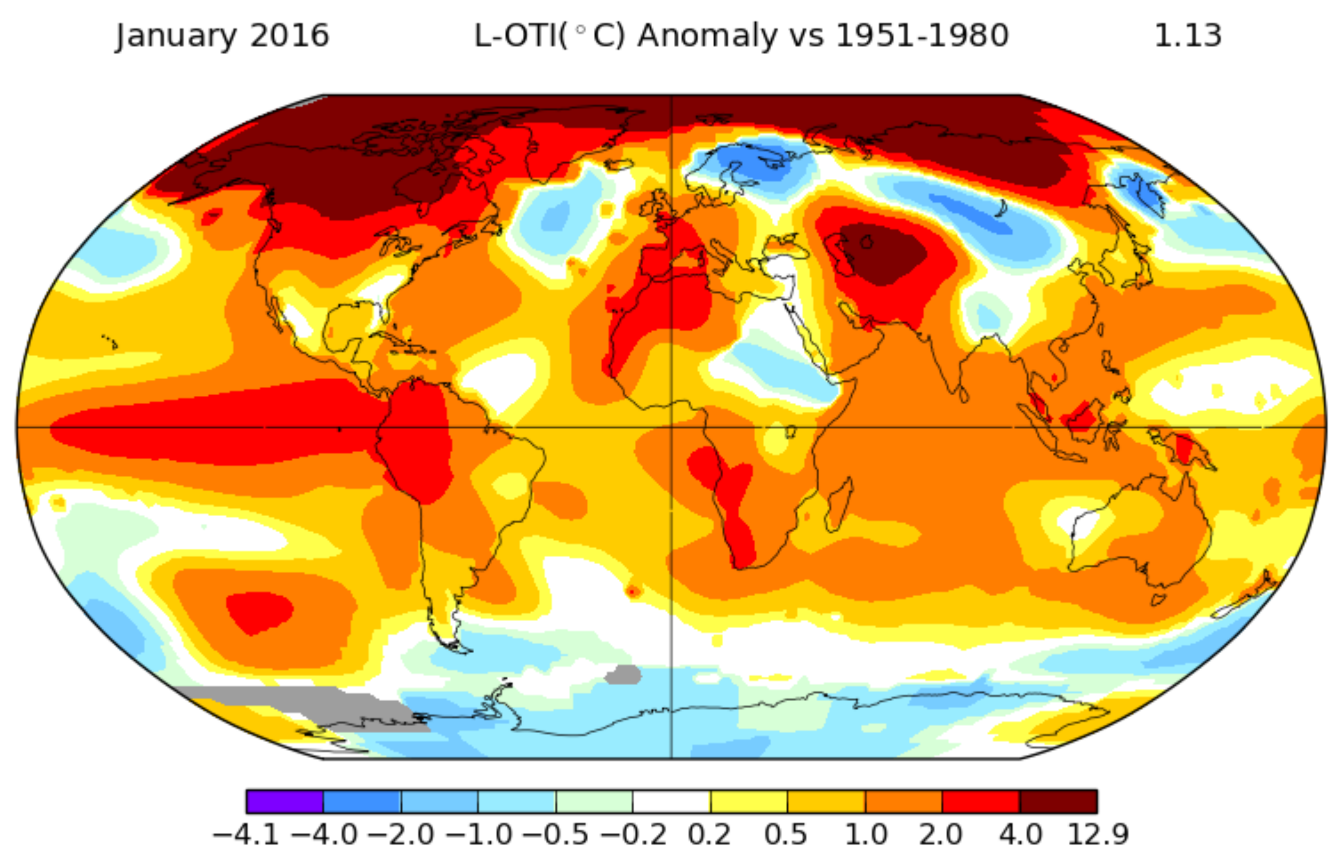
Drastic problems require immediate solutions.

Beijing, China, Jan 11-14, 2013

Lung of LA Teenage Nonsmoker in 1970s;

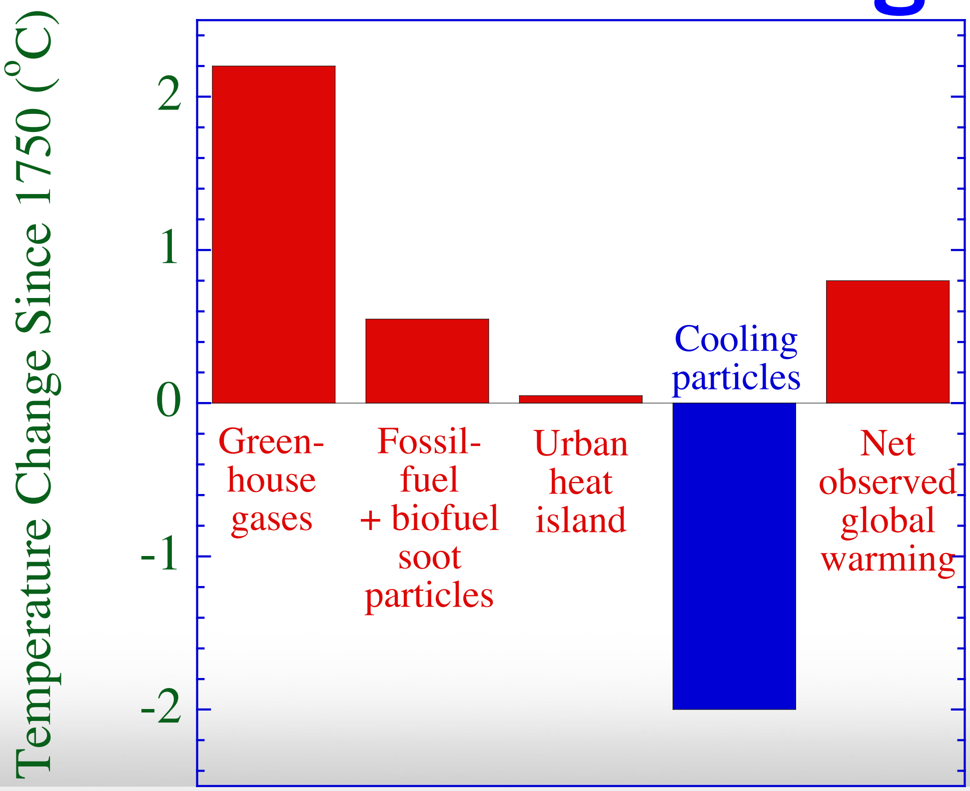
SCAQMD/CARB

Jan 2016 Global Warming 1.1 K=2 F



NASA GISS, 2014

Primary Contributors to Net Observed Global Warming



Wind, Water, Solar (WWS) All-Sector Solutions to Energy and Job Security, Air Pollution, Global Warming

ELECTRICITY	TRANSPORTATION	HEATING/COOLING	INDUSTRY
Wind	Battery-electric	Electric heat pumps	Electric resistance
Solar PV/CSP	Hydrogen fuel cell	Electric resistance	Electric arc furnaces
Geothermal	Cryogenic H_2	Solar water preheat	Induction furnaces
Hydro			Dielectric heating
Tidal/Wave			Hydrogen

Energy & Env. Sci, 2, 148 (2009)

Types of Storage for 100% WWS System

ELECTRICITY	HEATING/COOLING	OTHER
CSP with storage	Water	Hydrogen
Pumped hydro	Ice	Demand-response
Existing hydroelectric	Rocks in soil	

Why Not Natural Gas?

Gas wells in Upper Green River Valley, WY: Ecoflight.org

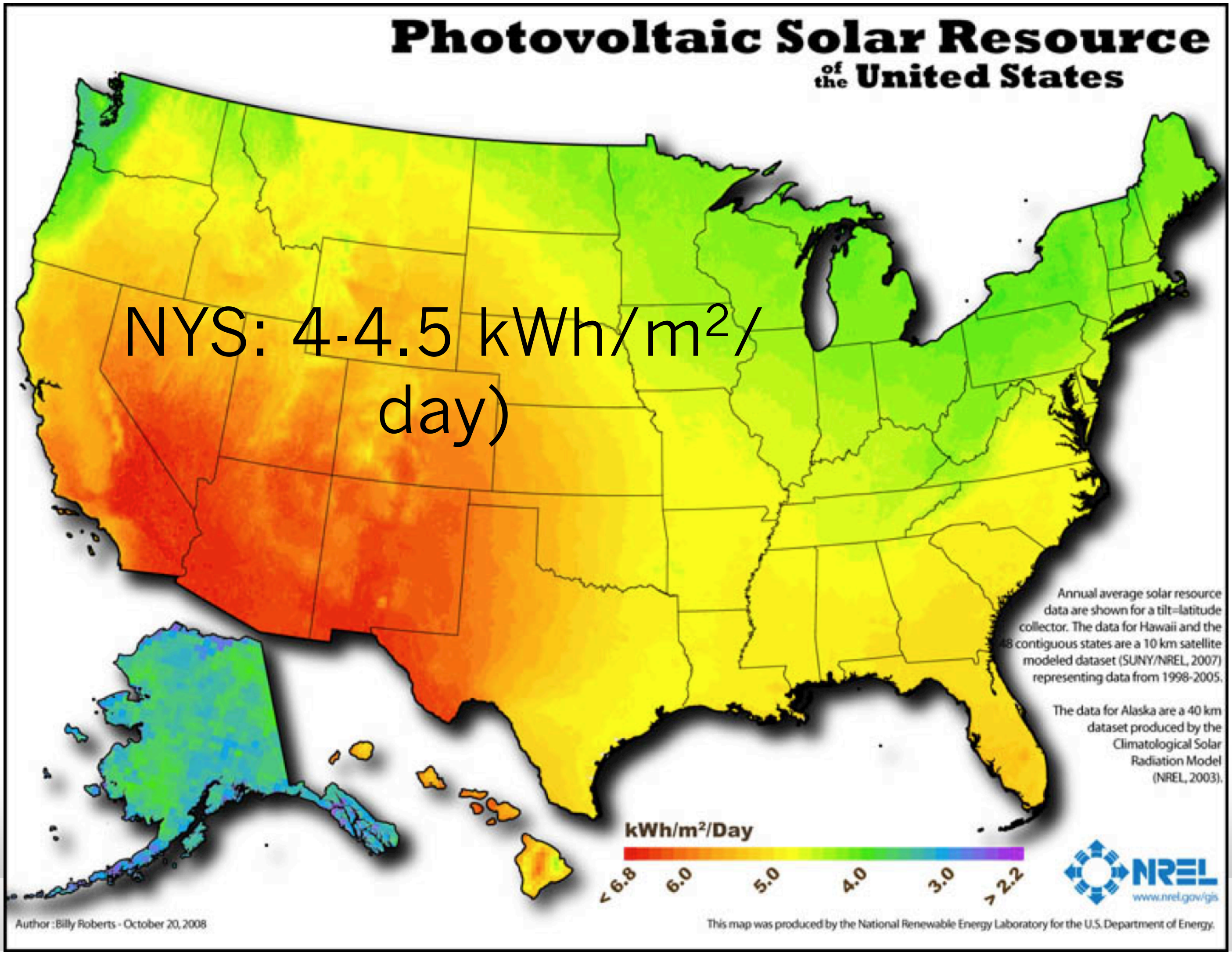
50-70 times more CO_2 and air pollution per kWh than wind

Methane from natural gas a main contributor to Arctic ice loss.

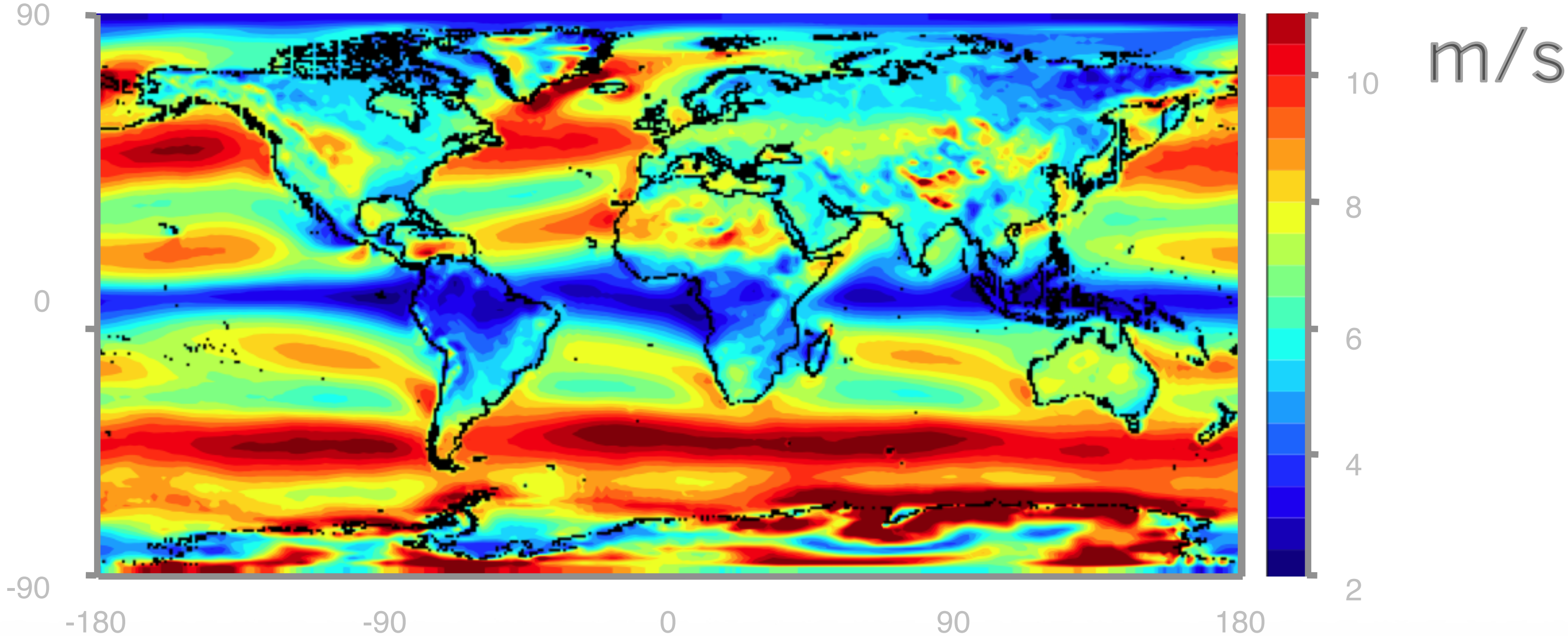
Natural gas mining, transport, and use causes 5000 premature mortalities/year in the U.S.

Hydrofracking causes land and water supply degradation and enhanced methane leaks.

NYS: 4-4.5 kWh/m^2/ day)

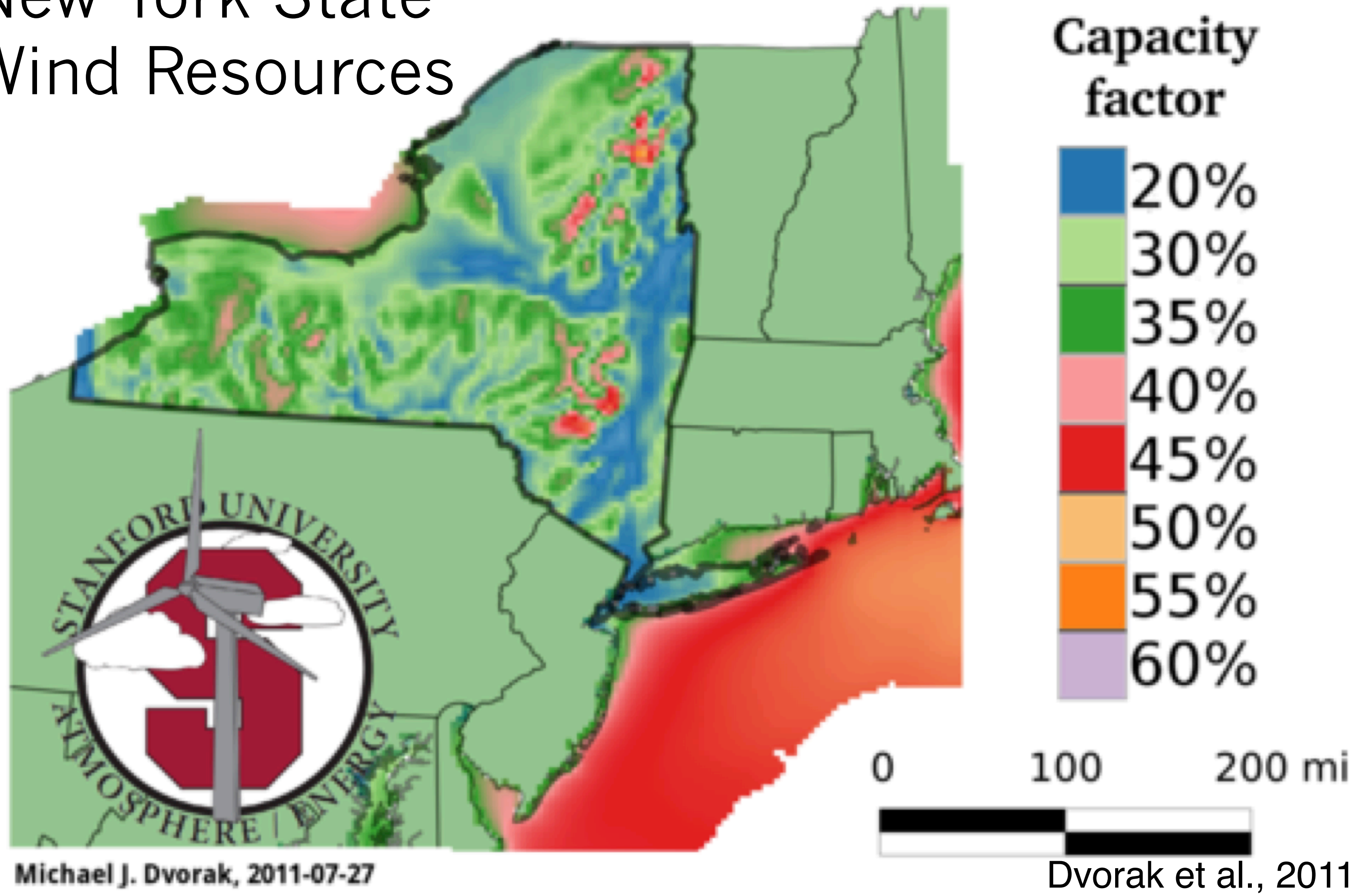


World Wind Speeds at 100m



All wind over land in high-wind areas outside Antarctica ~70-80 TW
= ~5-6 times world end-use WWS power demand 2050 of 13.4 TW

New York State Wind Resources

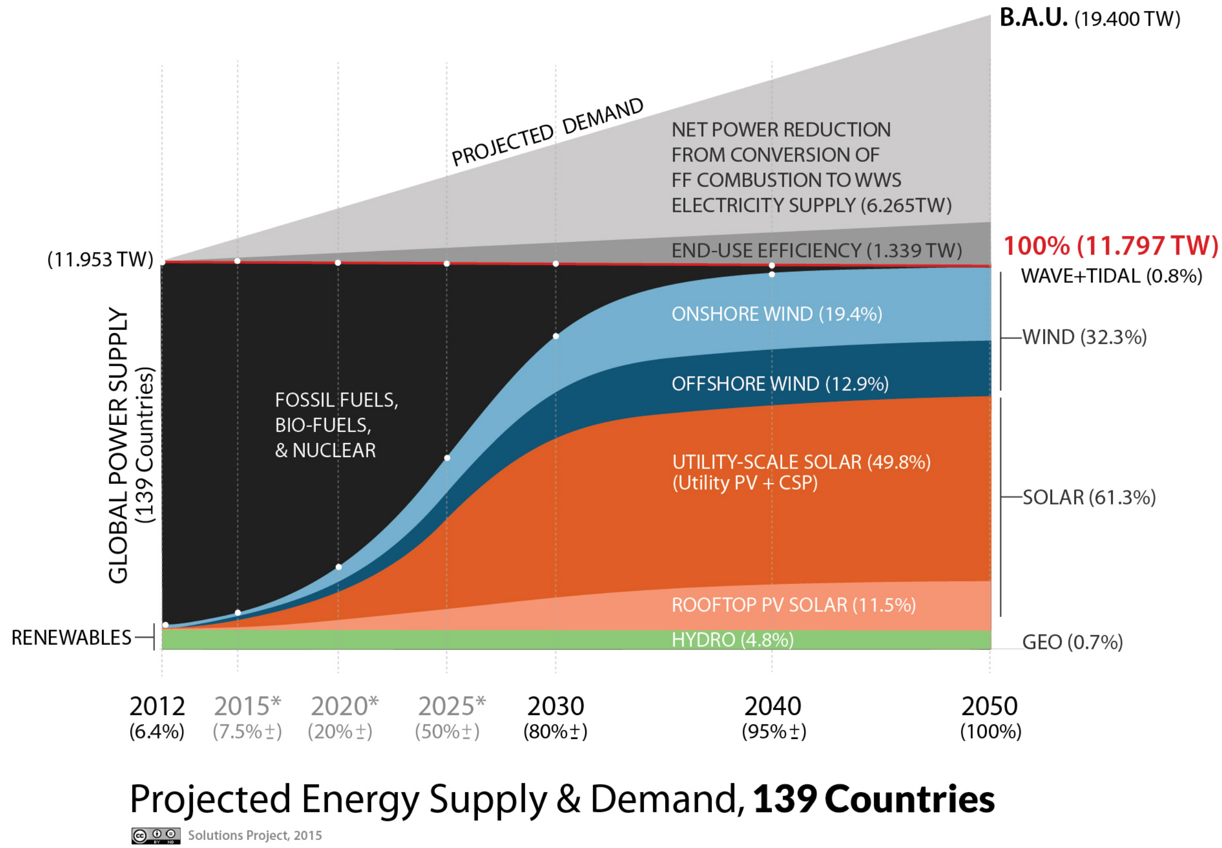


Dvorak et al., 2011

End-Use Power Demand For All Energy Purposes

Year and Fuel Type	139-Countries	Maryland
2012 (TW)	12.0	0.032
2050 with current fuels (TW)	19.4	0.035
2050 WWS (TW)	11.8	0.020
2050 Reduction w/ WWS (%)	39	42.3

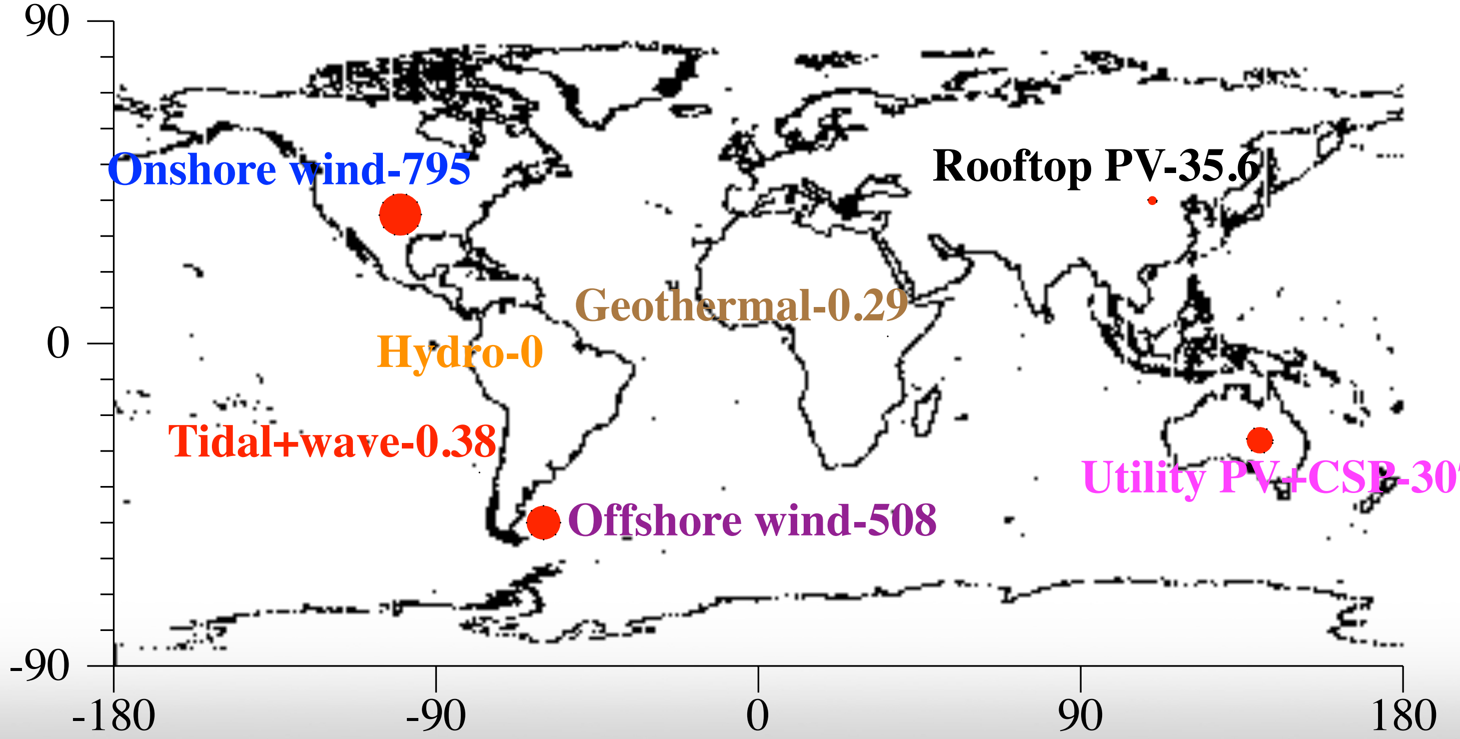
Timeline for 139-Country Transition to WWS



Number of New Plants to Power 139 Countries All Purposes

TECHNOLOGY	PCT SUPPLY 2050	NUMBER
5-MW onshore wind turbines	19.8%	1,192,000
5-MW offshore wind turbines	12.9	762,000
5-kW Res. roof PV systems	5.55	653 million
100-kW com/gov roof PV systems	5.97	35.3 million
50-MW Solar PV plants	42.3	497,000
100-MW CSP plants	7.67	15,500
100-MW geothermal plants	0.74	840
1300-MW hydro plants	4.38	0
1-MW tidal turbines	0.07	32,000
0.75-MW wave devices	0.72	496,000
	100%	

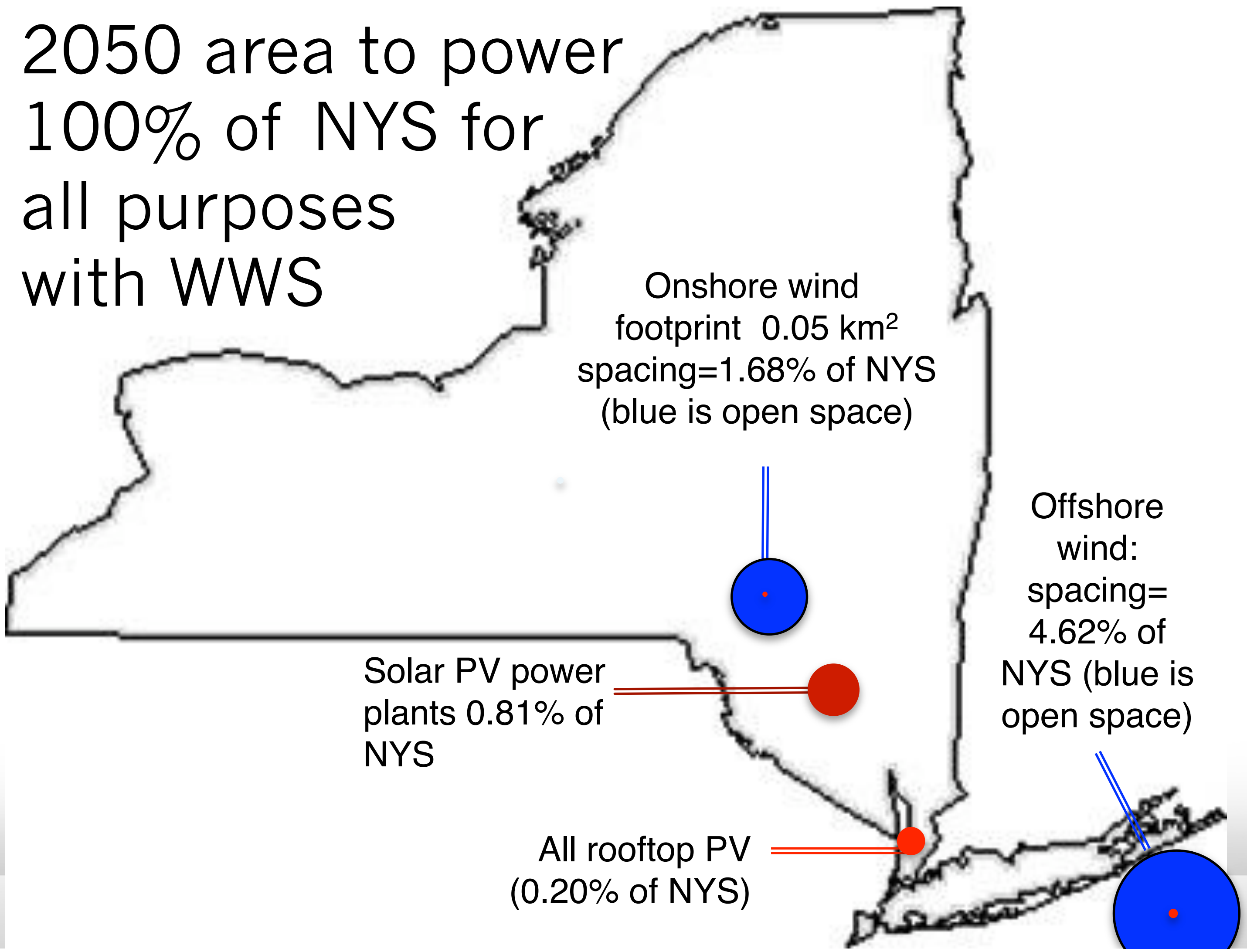
Area (Thousands of km²) Beyond 2014 Installations to Power 100% of 139 Countries for all Purposes w/ WWS in 2050



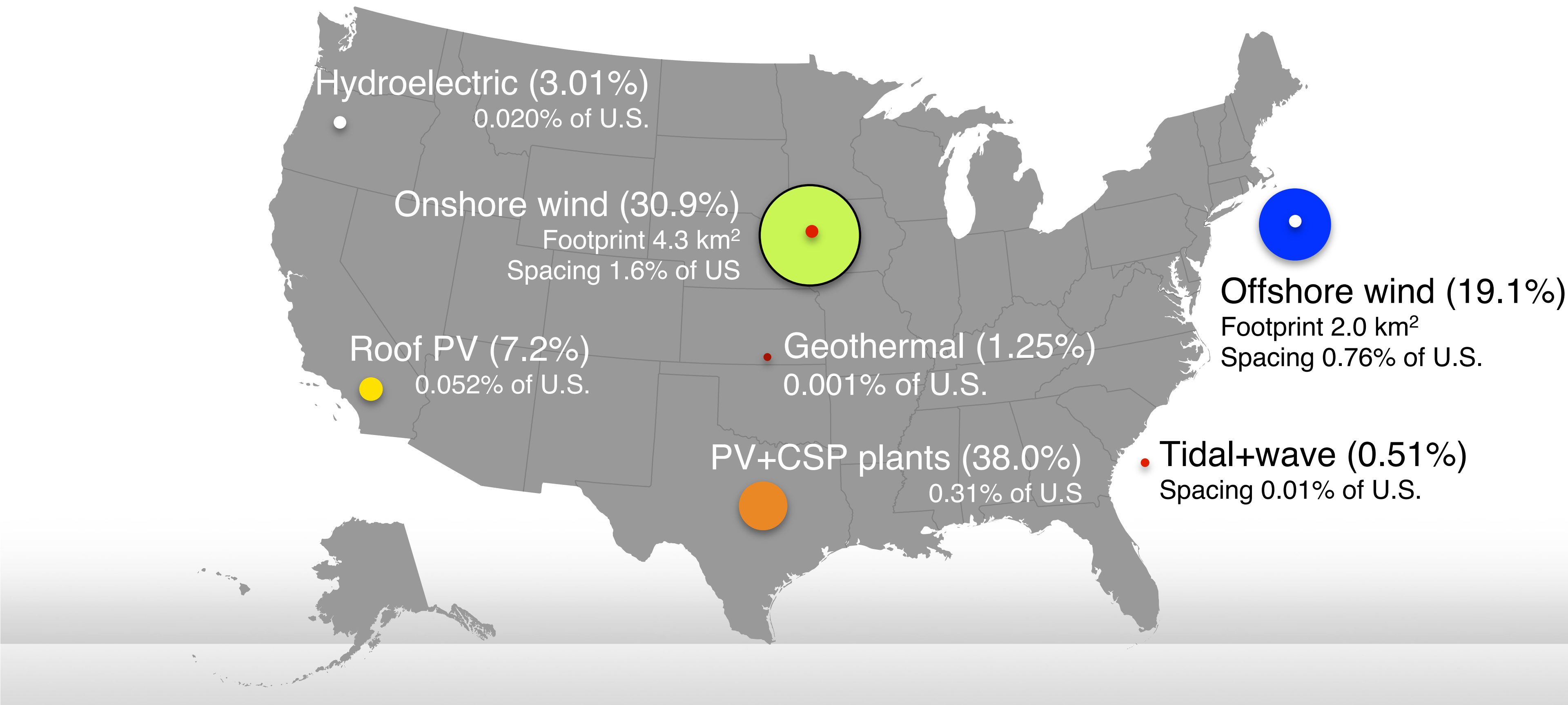
Number of New Plants to Power Maryland for All Purposes

TECHNOLOGY	PCT SUPPLY 2050	NUMBER
5-MW onshore wind turbines	5%	670
5-MW offshore wind turbines	60.0	6,200
5-kW Res. roof PV systems	5.4	1.4 million
100-kW com/gov roof PV systems	4.8	56,000
50-MW Solar PV plants	22.2	469
100-MW CSP plants	0	0
100-MW geothermal plants	0	0
1300-MW hydro plants	1.5	0
1-MW tidal turbines	0.03	25
0.75-MW wave devices	1.0	1,240
	100%	

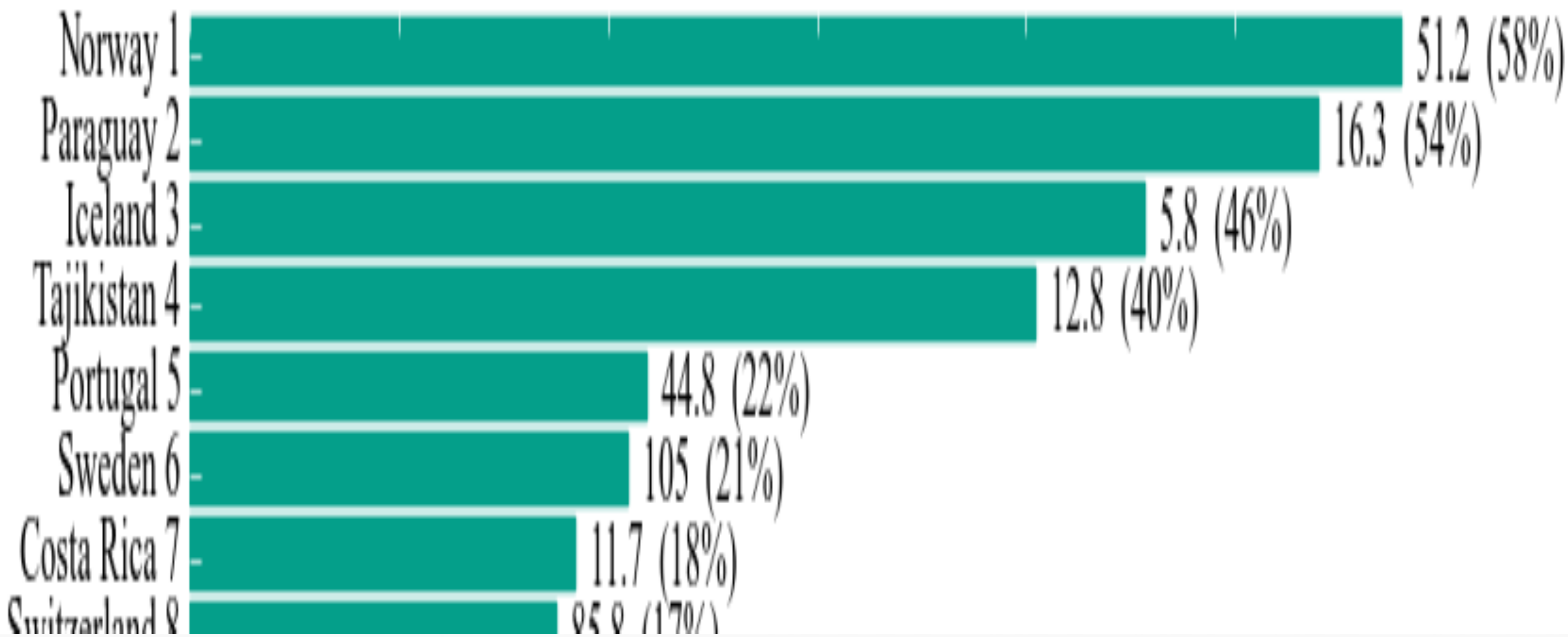
2050 area to power 100% of NYS for all purposes with WWS



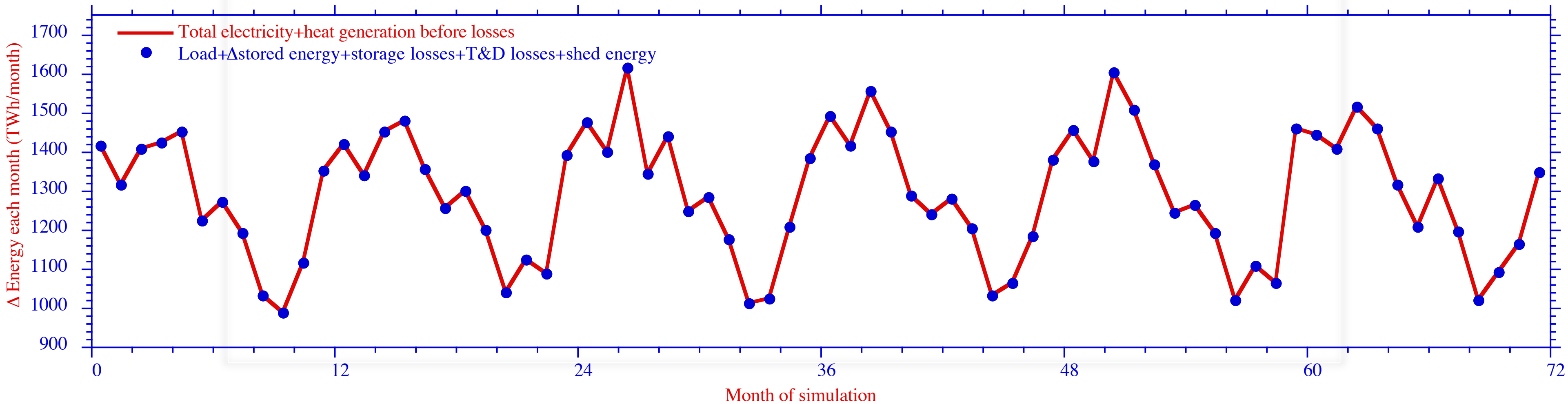
Additional Area Needed to Power 100% of 50 States for all Purposes With Wind, Water, & Solar in 2050



% of 2050 All-Sector WWS Already Installed



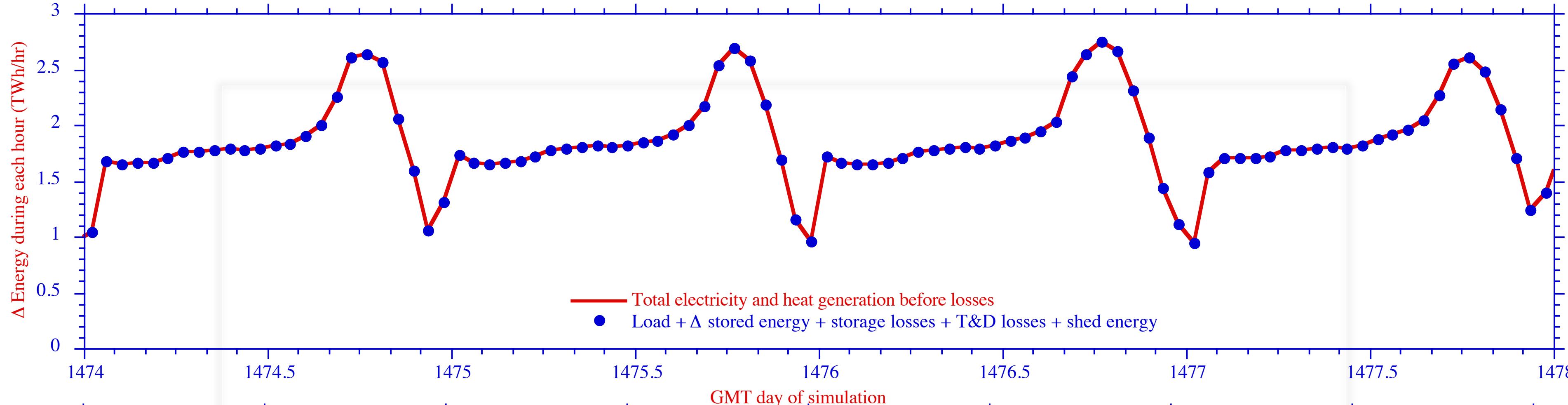
Matching 100% 2050-2055 U.S. Load With WWS for 6 Years

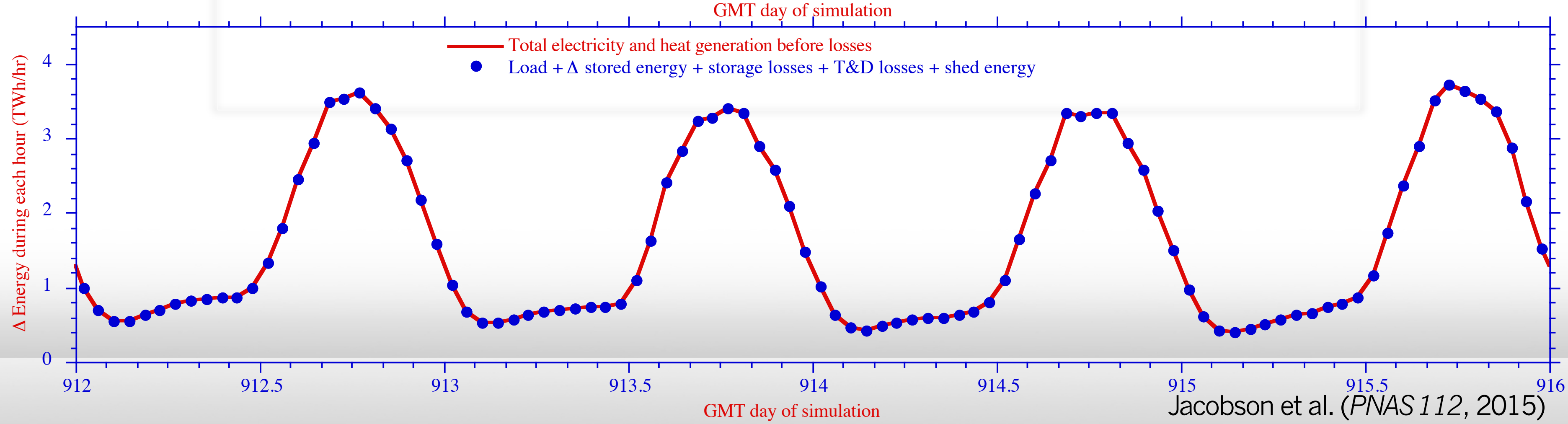


Red = Energy supply
Blue = Energy demand + change of storage + losses

Jacobson et al. (*PNAS 112*, 2015)

Matching 100% U.S. Load With WWS on Two Sets of Four Days





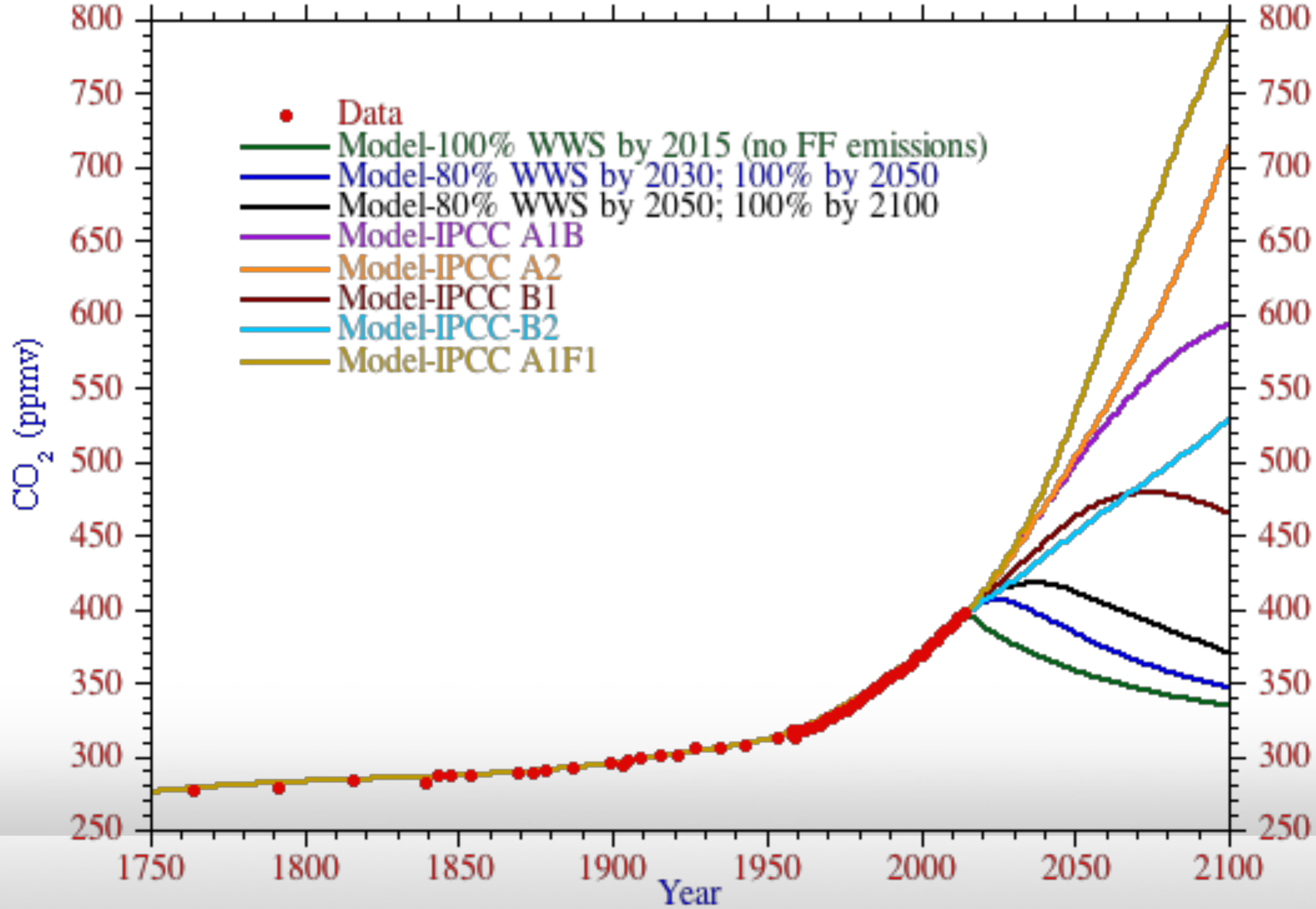
Jacobson et al. (*PNAS 112*, 2015)

2015 U.S. Unsubsidized Costs of Energy (¢/kWh)

Wind onshore	3.2	to 7.7
Wind offshore	11	to 19.4
Geothermal	8.2	to 11.7
Hydroelectric	4	to 6
CSP with 18 hr storage	11.9	to 18.1
Utility-scale solar PV	5.0	to 7.0
Community rooftop PV	7.8	to 13.6
Residential rooftop PV	18.4	to 30.0
Gas combined cycle	5.2	to 7.8
Gas peaking	16.5	to 21.8
Advanced pulverized coal	6.5	to 15.0
Nuclear	9.7	to 13.6

Lazard (2015)

CO2 From Siple Ice Core (1750-1953) / Mauna Loa (1959-2014) vs. CO2 From GATOR-GCMOM Model (1750-2100), Including WWS and IPCC Scenarios After 2014



Summary–Converting 139 Countries to 100% WWS

→Reduces 2050 139-country BAU power demand by ~39%

→ Eliminates ~4-7 million premature air pollution deaths per year (saving ~$25 trillion/yr ~7.9% of world GDP)

→Eliminates up to ~$17 trillion/yr global climate costs 2050

→Each person saves $170/yr fuel costs; $4800/yr health+climate costs

→WWS w/storage+DRM gives 100% reliability @ ~11-12 ¢/kWh in US

→Creates 22 million more jobs than are lost

→Requires only 0.29% of land for footprint; 0.66% for spacing

→Makes countries energy independent, reducing international conflict

→Creates distributed power, reducing terrorism/catastrophic risk

→Reduces energy poverty of up to 4 billion people worldwide

Barriers : up-front costs, transmission needs, lobbying, politics.

Materials are not limits

Papers / Graphics

Articles and data

web.stanford.edu/group/efmh/jacobson/Articles/I/
WWS-50-USState-plans.html

Infographic maps

www.thesolutionsproject.org
100.org

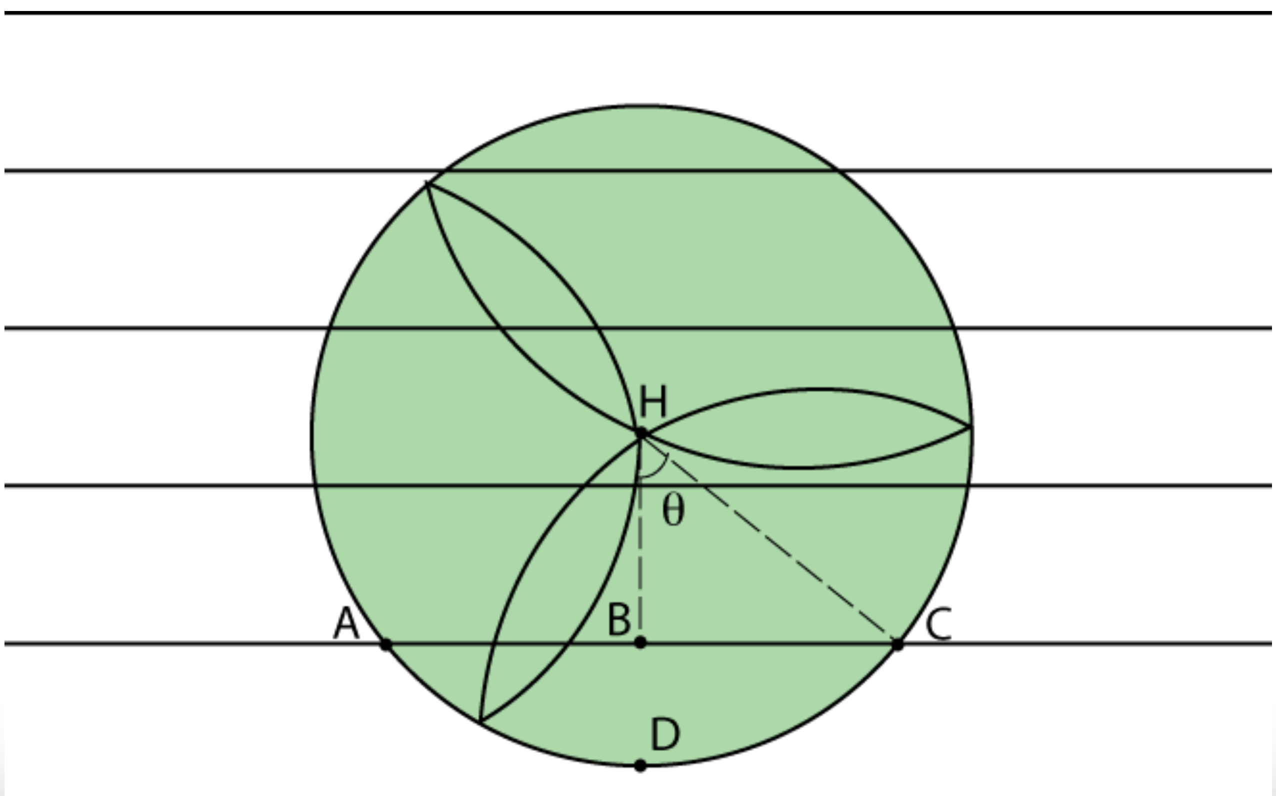
Can Walls of Offshore Wind Turbines Dissipate Hurricanes?

Simulations of Hurricanes Katrina, Isaac, and Sandy were run with a 3-D global-regional nested model to examine impacts of arrays of offshore turbines on hurricane winds and storm surge.

Simulations were run with and without 7.58-MW Enercon E-126 turbines spaced one every 0.45 km^2 within 100 km of the coast in specified areas.

The turbine extracted energy according to its power curve up to either 34 m/s (cutout) or 50 m/s (destruction) speed.

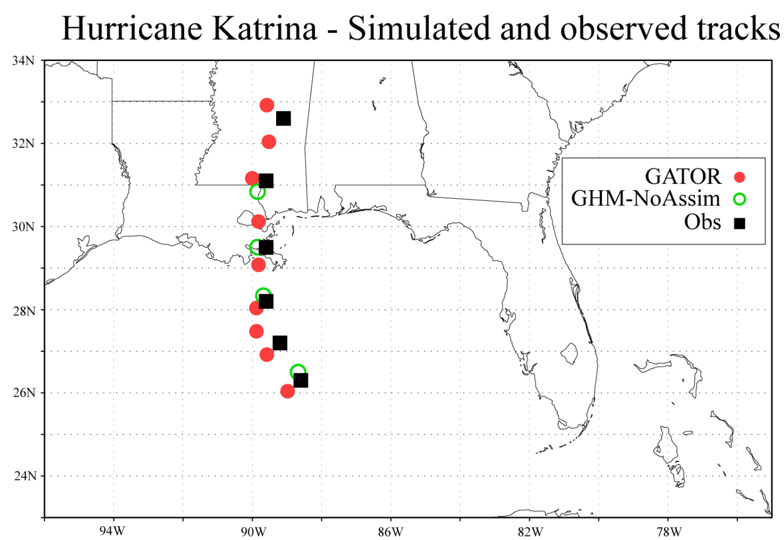
Representation of a vertically-resolved wind turbine in model



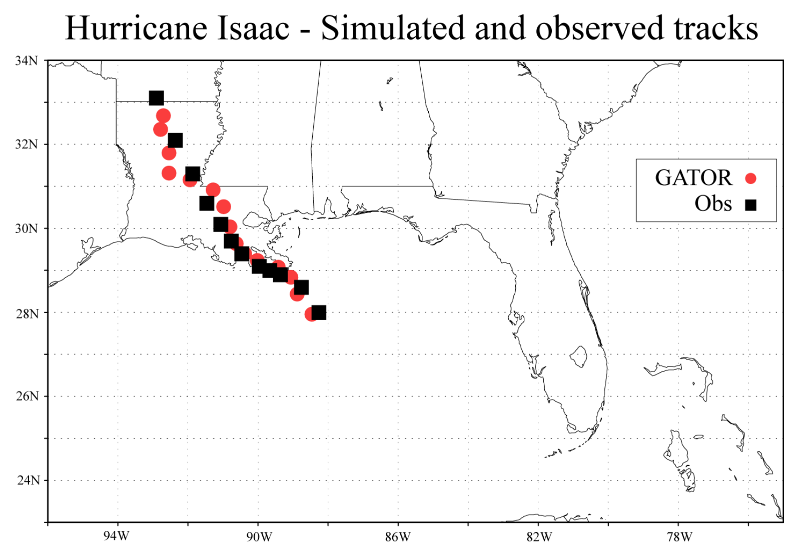
Lines are model layers

Jacobson and Archer (2012)

Modeled (GATOR-black and GFDL) vs. Observed Tracks of Katrina and Isaac



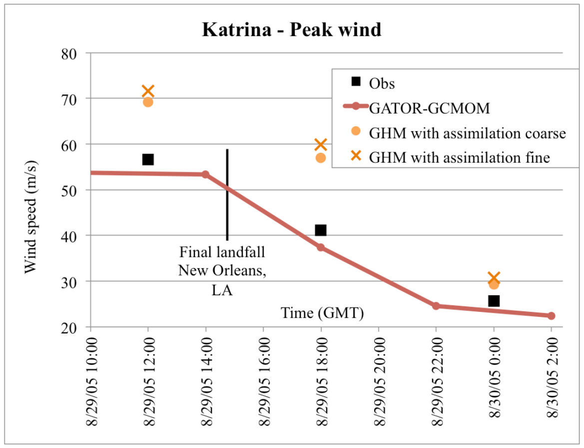
Katrina



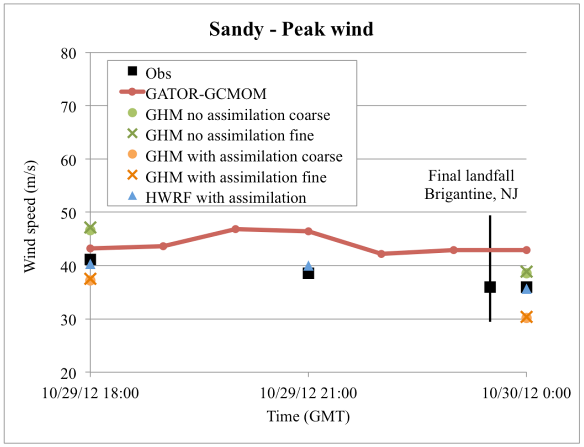
Isaac

Data from Central Florida Hurricane Center

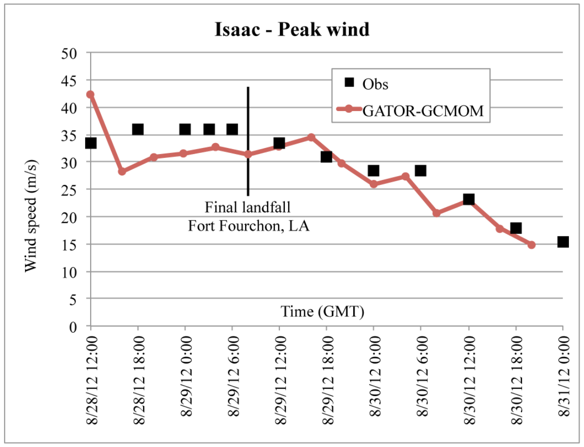
Modeled (GATOR-black, GFDL, HWRF) vs. Observed Peak Winds of Katrina, Sandy, Isaac



Katrina



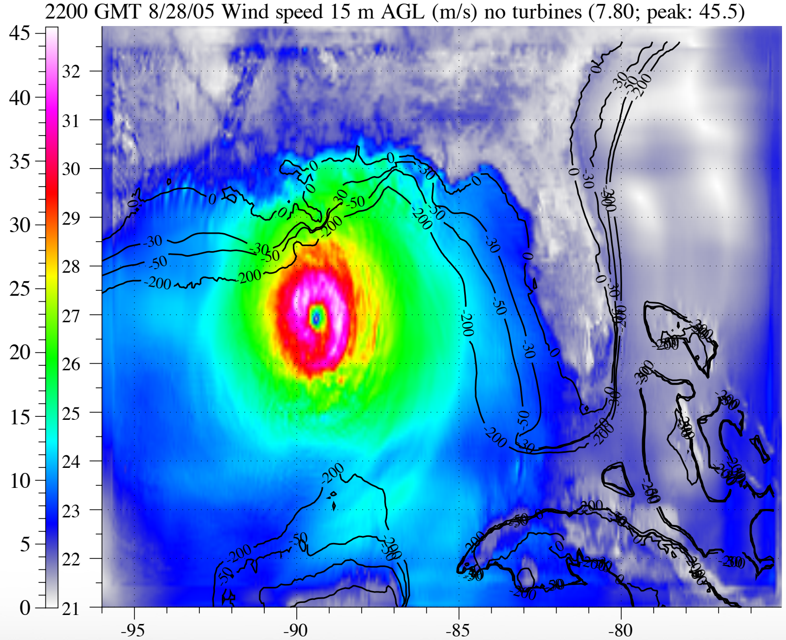
Sandy



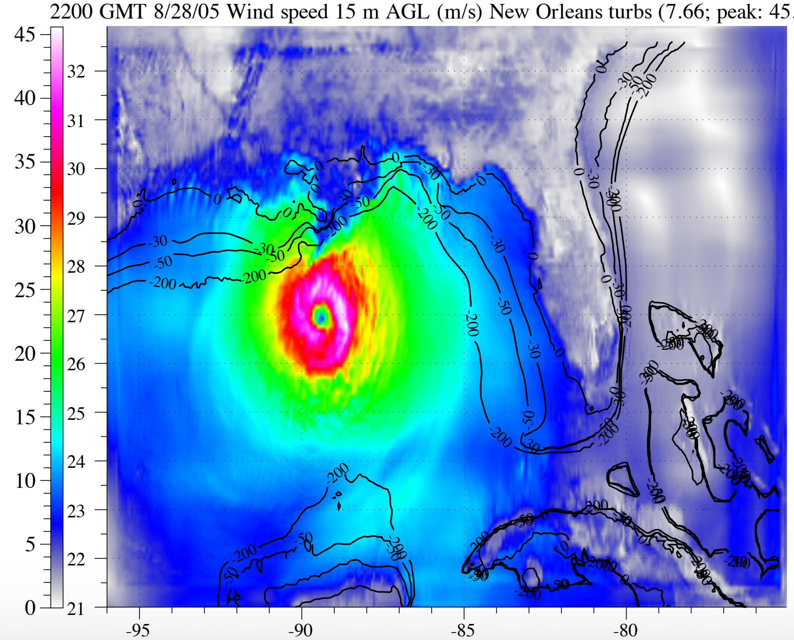
Isaac

Data from Central Florida Hurricane Center

Hurricane Katrina Surface Winds
August 28, 22:00 GMT

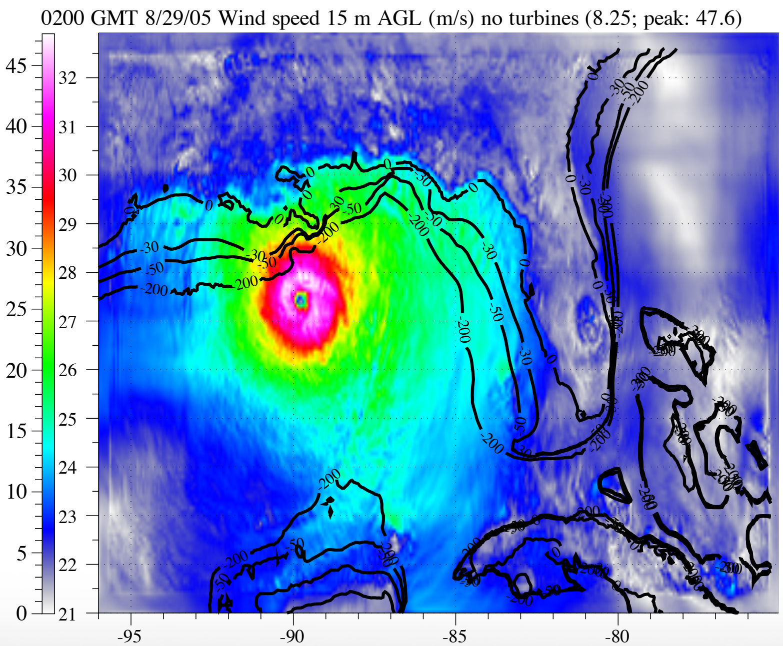


No turbines

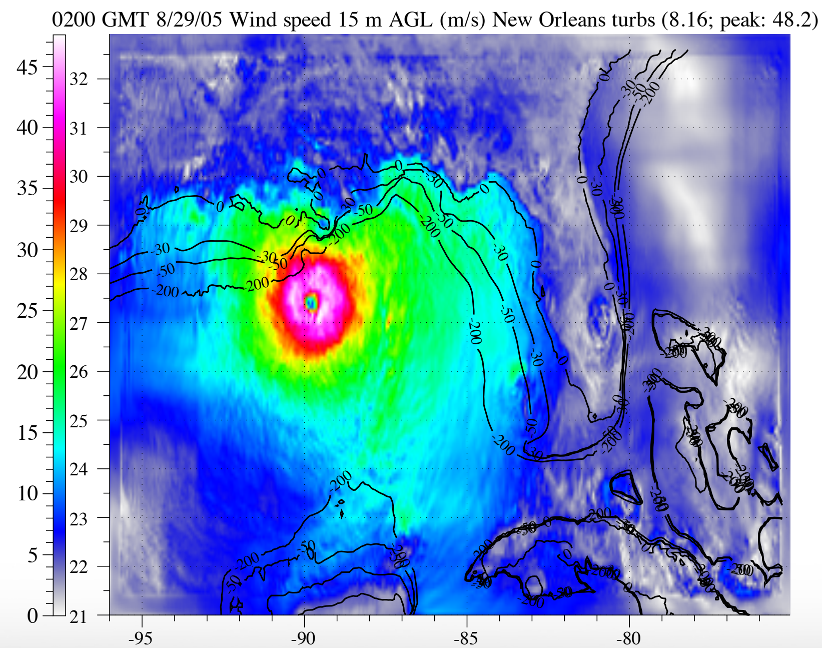


With turbines

Hurricane Katrina Surface Winds
August 29, 02:00 GMT

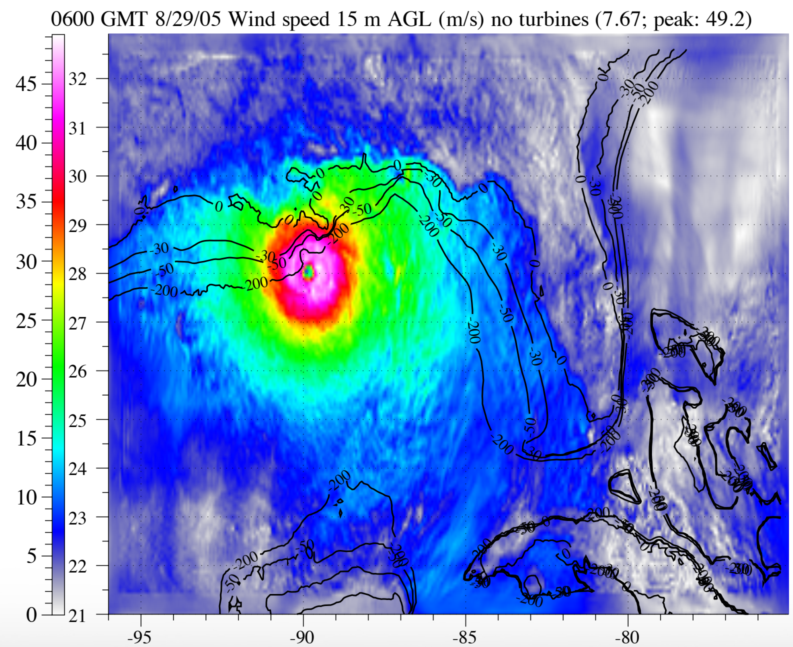


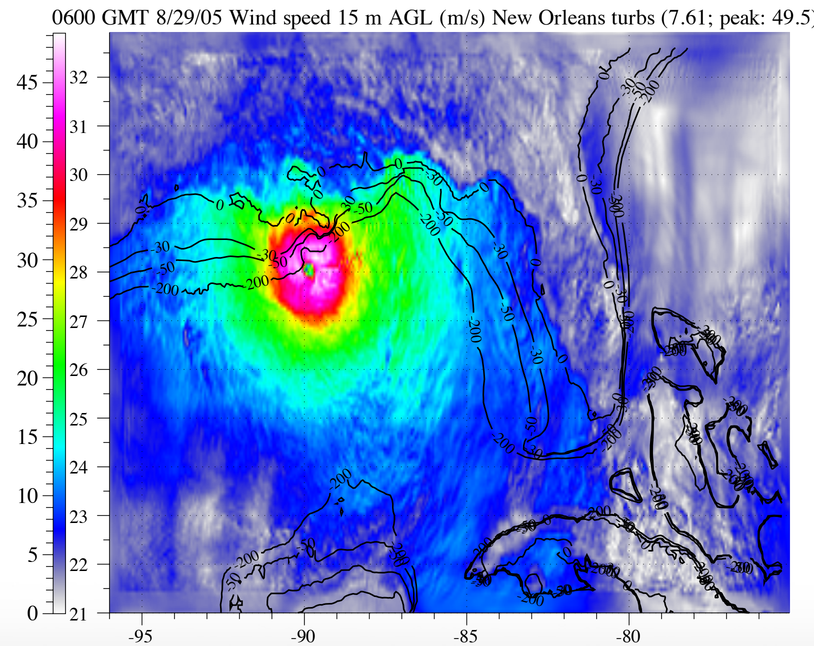
No turbines



With turbines

Hurricane Katrina Surface Winds
August 29, 06:00 GMT

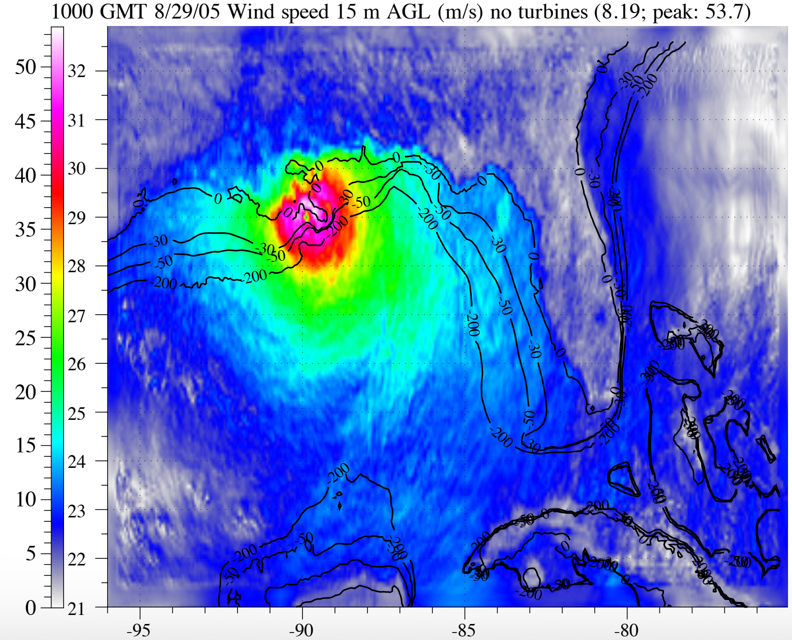




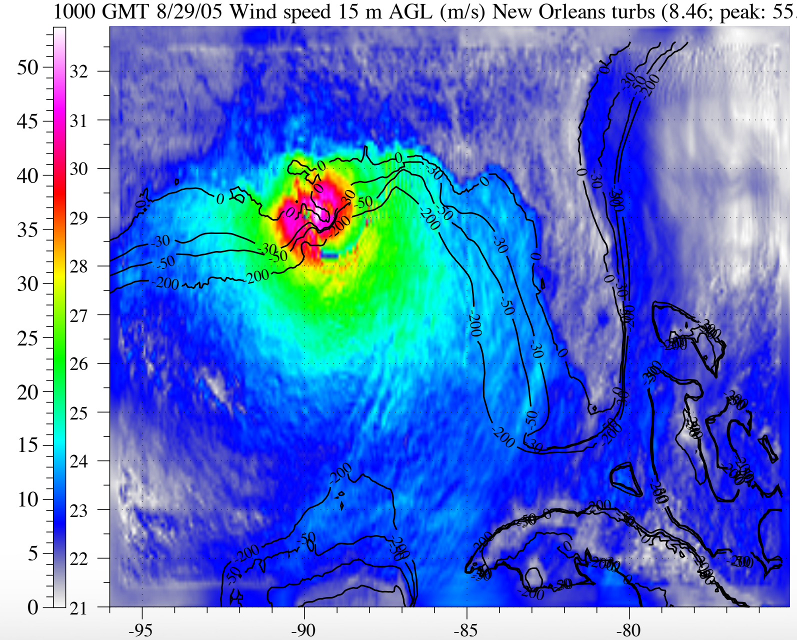
No turbines

With turbines

Hurricane Katrina Surface Winds
August 29, 10:00 GMT

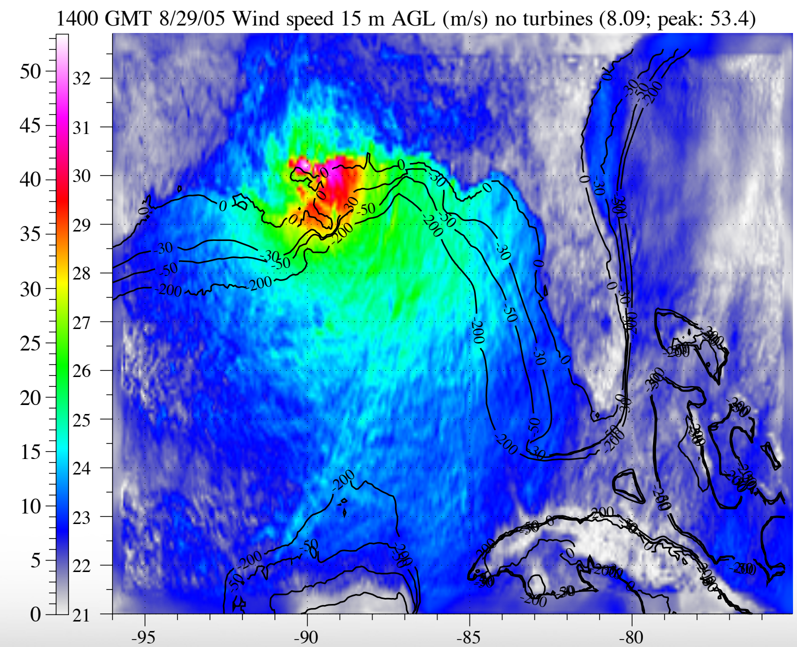


No turbines

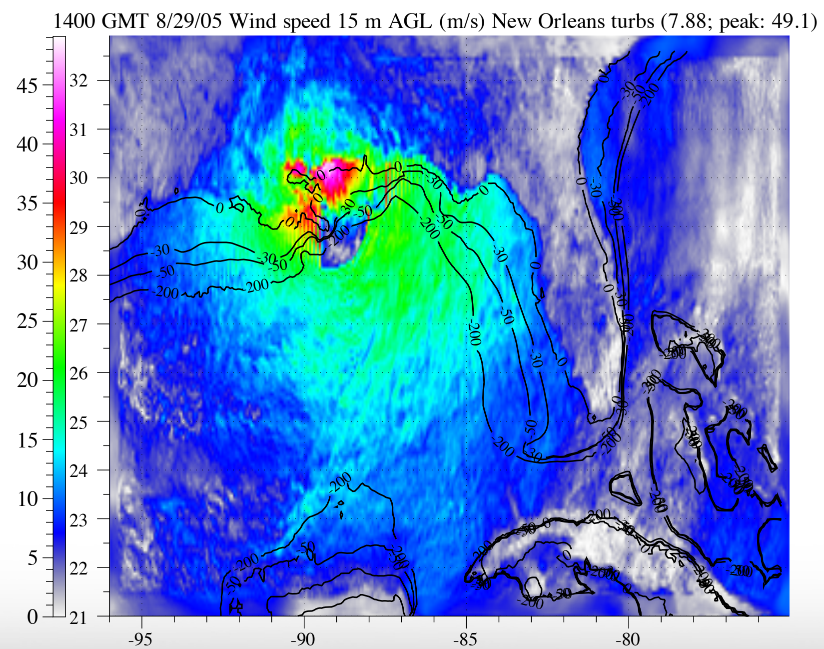


With turbines

Hurricane Katrina Surface Winds
August 29, 14:00 GMT

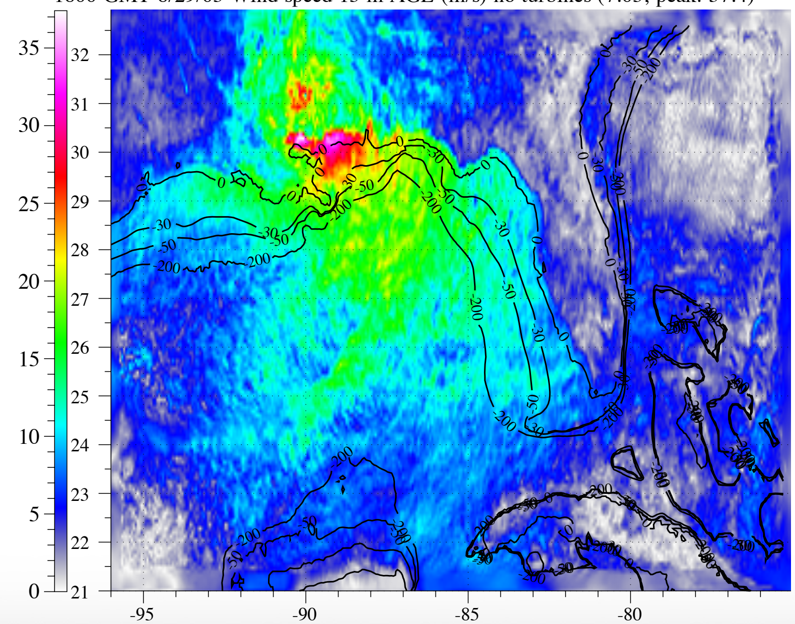


No turbines

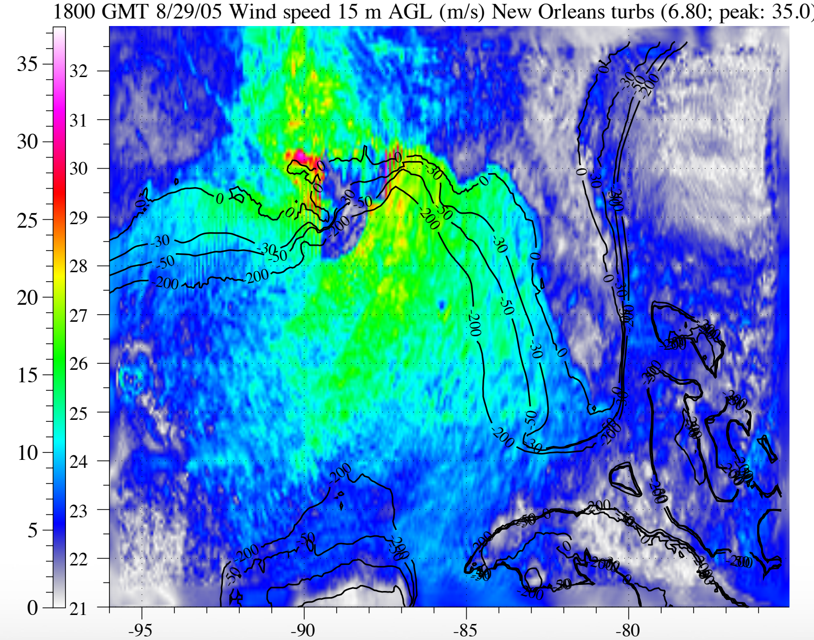


With turbines

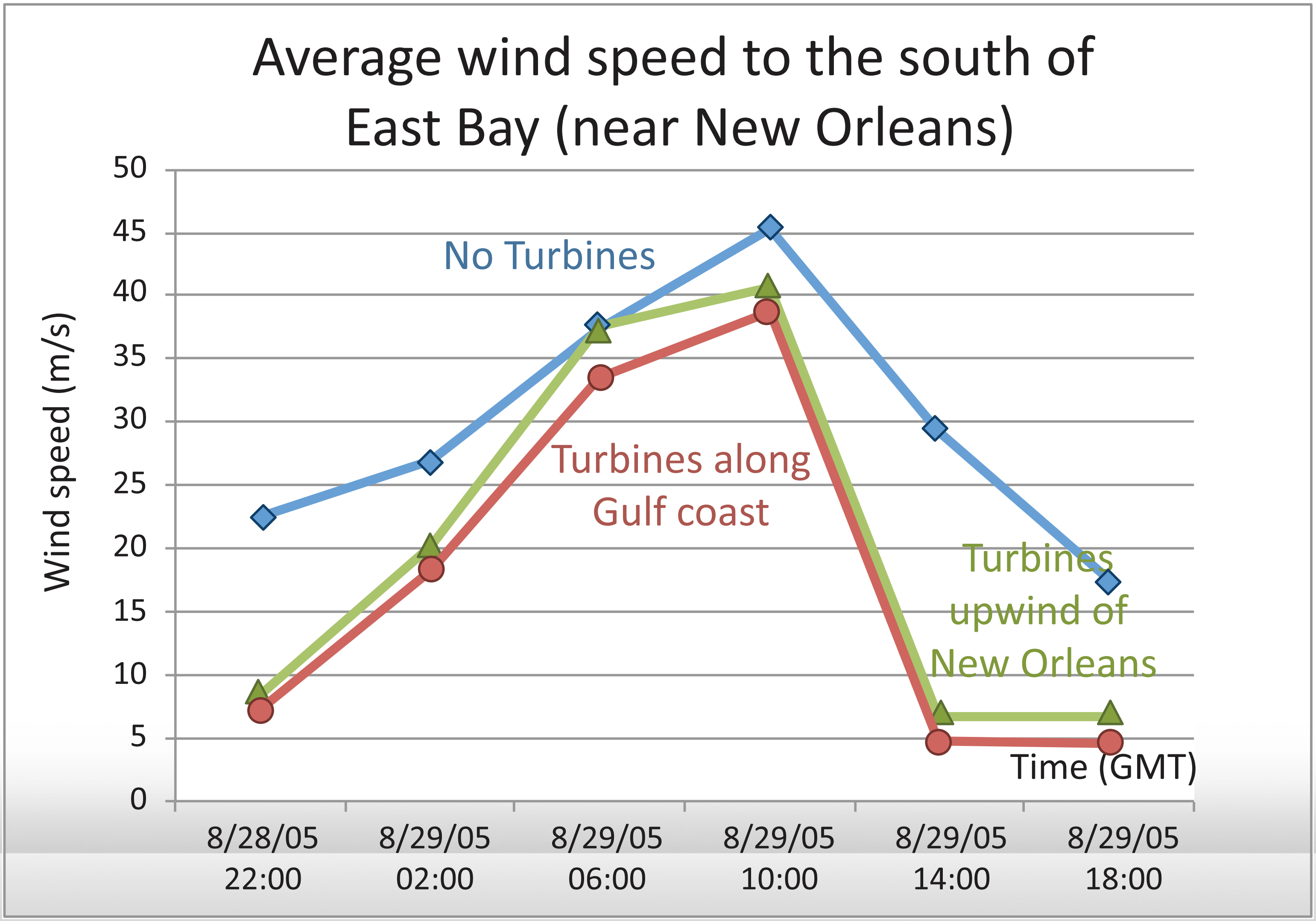
Hurricane Katrina Surface Winds
August 29, 18:00 GMT



No turbines



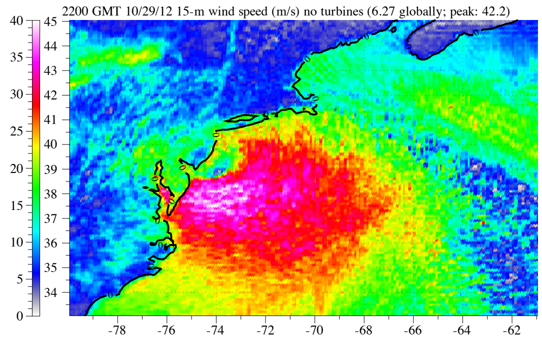
With turbines



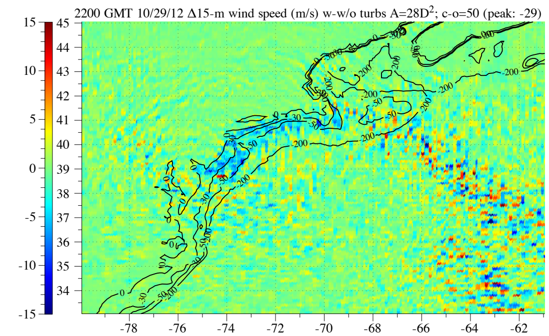
Average wind speed to the south of East Bay (near New Orleans)
50
45
40
35
30
25
20
15
10
5
0
Wind speed (m/s)
No Turbines
Turbines along Gulf coast
Turbines upwind of New Orleans
Time (GMT)
8/28/05 22:00
8/29/05 02:00
8/29/05 06:00
8/29/05 10:00
8/29/05 14:00
8/29/05 18:00

Hurricane Sandy

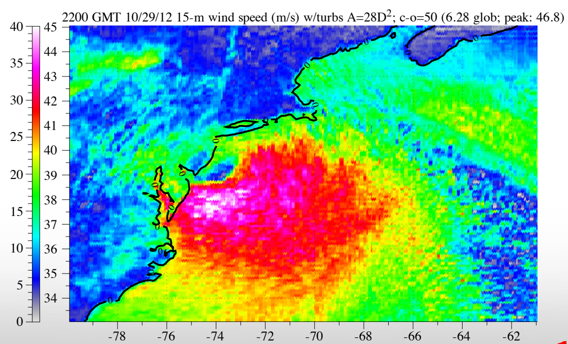
22 GMT 10/29/12



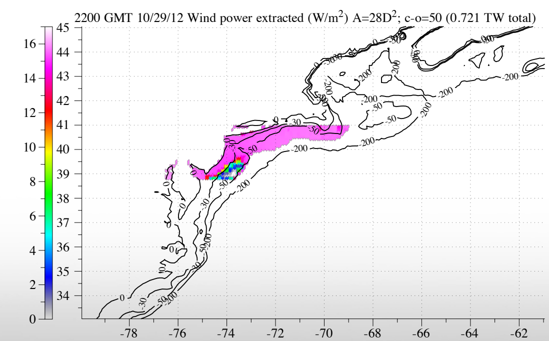
15-m above sea wind speed (m/s) without turbines



15-m wind speed reduction up to 29 m/s; storm surge reductions 12-21%



Wind power extracted (W/m^2) (total=0.72 TW =1/16th world 2030 all-purpose end-use WWS power demand



15-m wind speed (m/s) with turbines

Conclusions

300 GW+ walls of wind turbines can dissipate hurricane winds by 25-41 m/s, or up to 50% and storm surge by 6-79% while generating normal electric power year around, paying for themselves.

Sea walls do not reduce wind speeds nor generate power. They reduce storm surge impacts only.

Turbines first see slower outer rotational winds, reducing these wind speeds, reducing wave heights, friction, and convergence to the center, increasing central pressure, preventing winds from reaching destruction speeds.