

LOW-COST GRID  
INTEGRATION VIA MET-  
SMART INTERCONNECTION  
AND STORAGE INHERENT  
IN END-USE DEVICES

GRID INTEGRATION OF RENEWABLES WORKSHOP  
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TOMKATCENTER

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13 JANUARY 2011

**THREE STEP PROGRAM**  
**(THREE STAGES OF CONSCIOUSNESS**  
**AS WE INTEGRATE CARBON-FREE**  
**POWER)**

# ADVICE FROM RISØ ON INTEGRATING WIND

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“We have gone through three stages of understanding wind integration.”

- First, you add wind to the electrical system
- Then, you realize that you want to adapt the electrical system to wind (or adapt wind to the electrical system)
- Then, you realize that you want to design the electrical system around wind

# TWO EXAMPLES

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- Large scale wind penetration
- Electric Vehicles

# STAGES OF INTEGRATION CONSCIOUSNESS

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- **Add** wind to system
- **Adapt** the system to wind (or adapt wind to the system)
- **Redesign** the system around wind

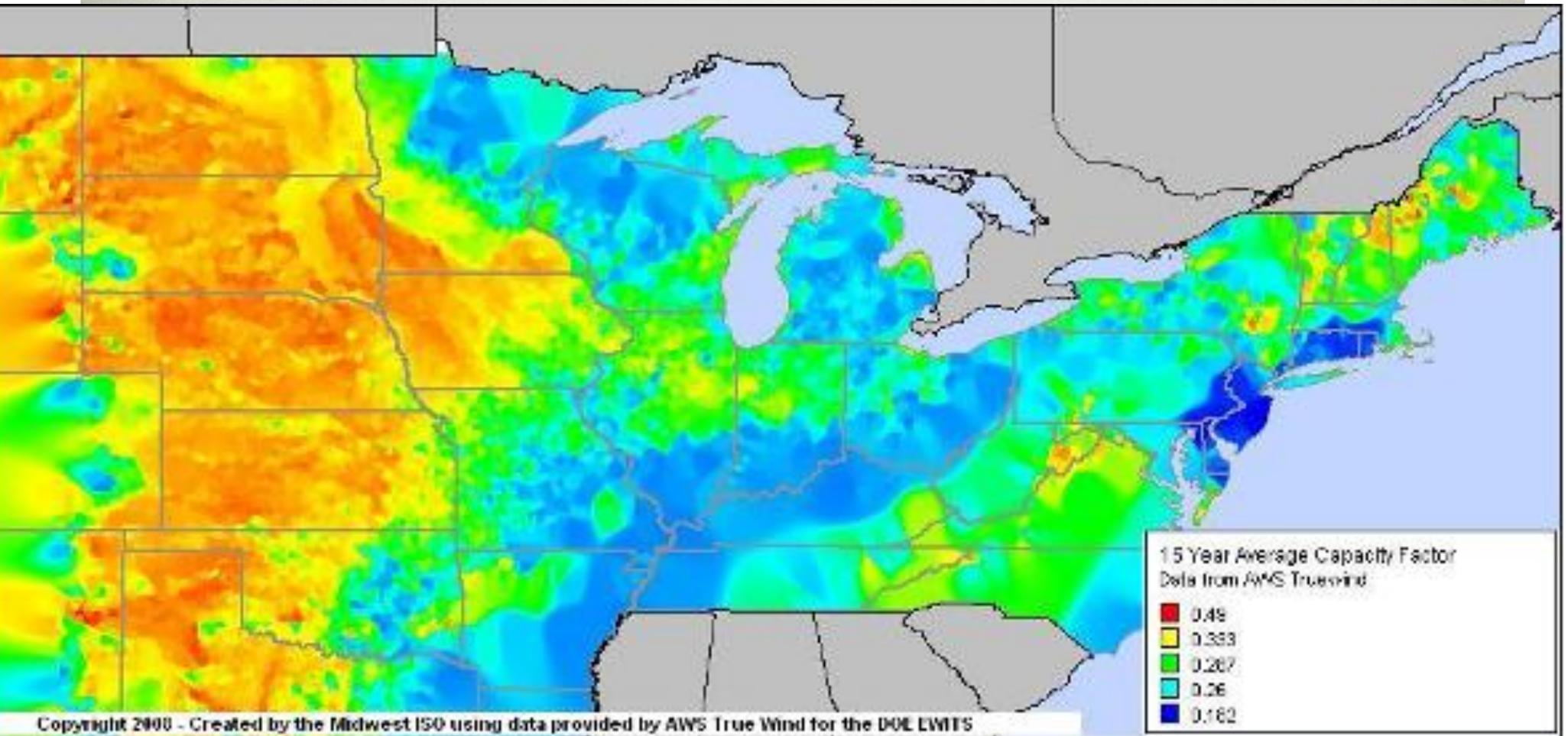
# TRANSMISSION PLANNING

# TRANSMISSION PLANNING NOW AT “ADAPT” STAGE

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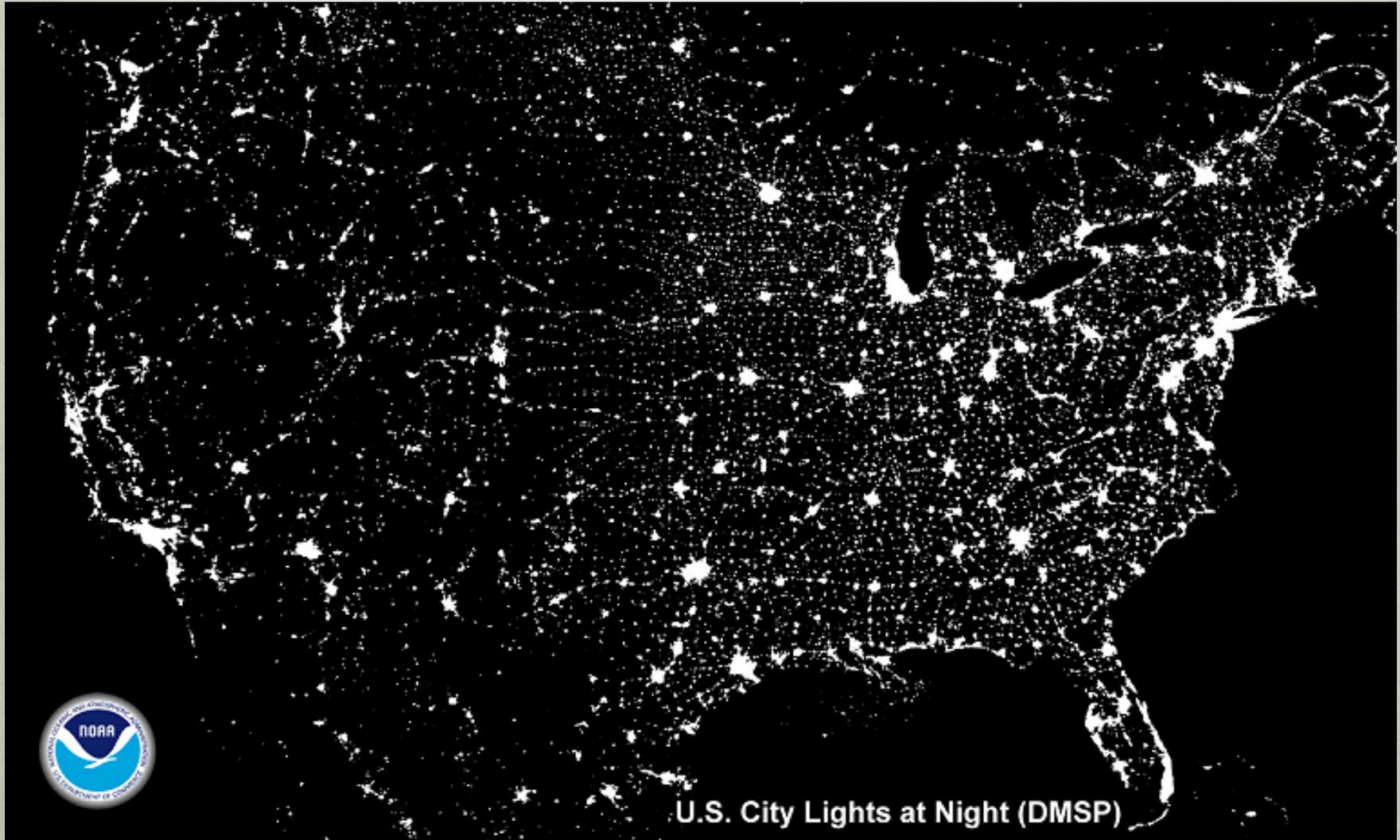
- Adapt the system to wind, e.g.
  - Load is here
  - Wind is there
  - Connect with wire

# WIND IS IN THE GREAT PLAINS



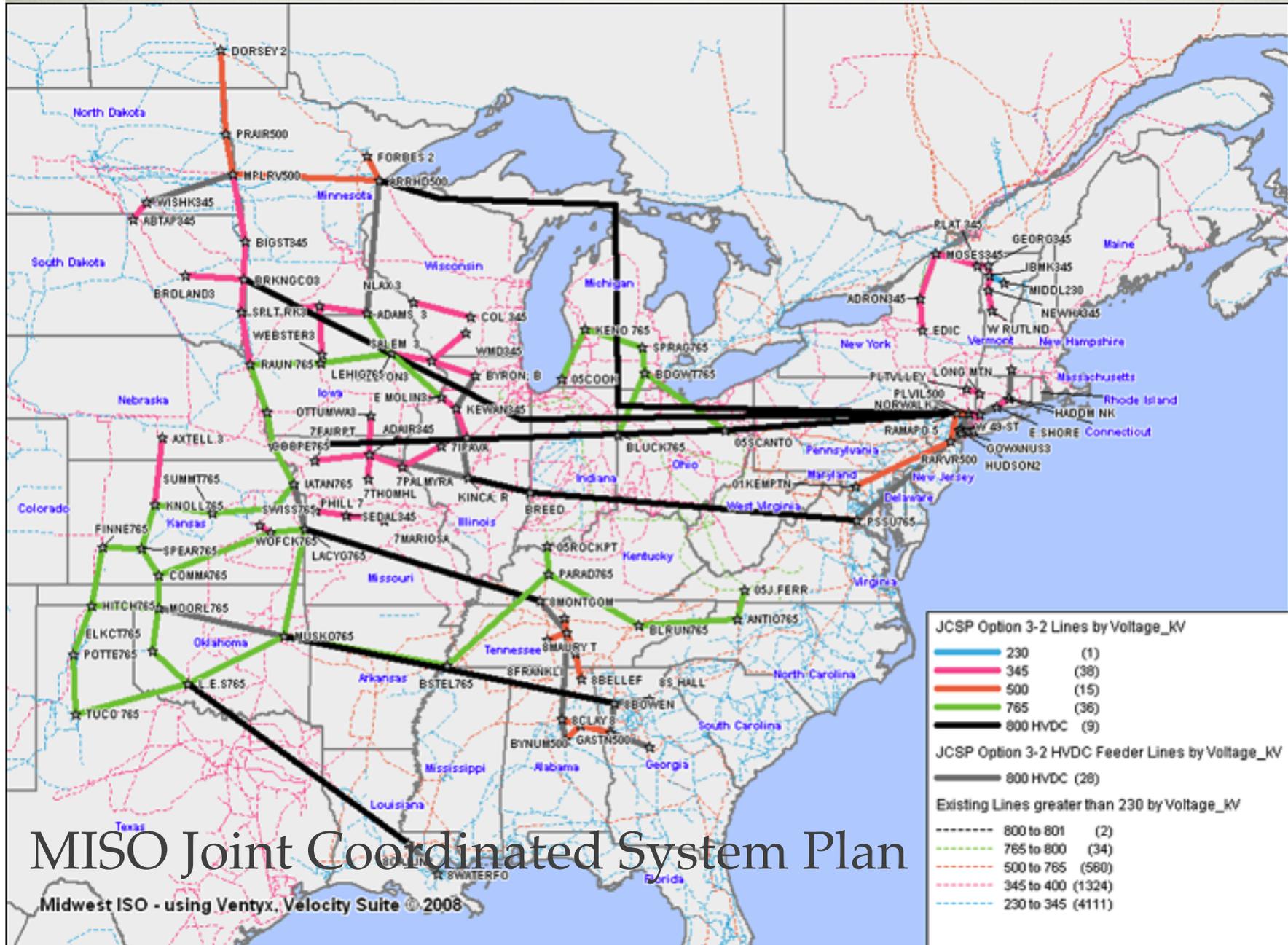
MISO Joint Coordinated System Plan

# LOAD IS ON THE COASTS



(Nighttime Image of the Planet)

# CONNECT WITH WIRE(S)



# PROBLEMS WITH MISO PLAN

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- They missed the biggest wind resource
- Power buyers get no economic development benefits, no jobs
- No analysis of leveling effect of transmission

# Data sources for assessment

## QuikSCAT

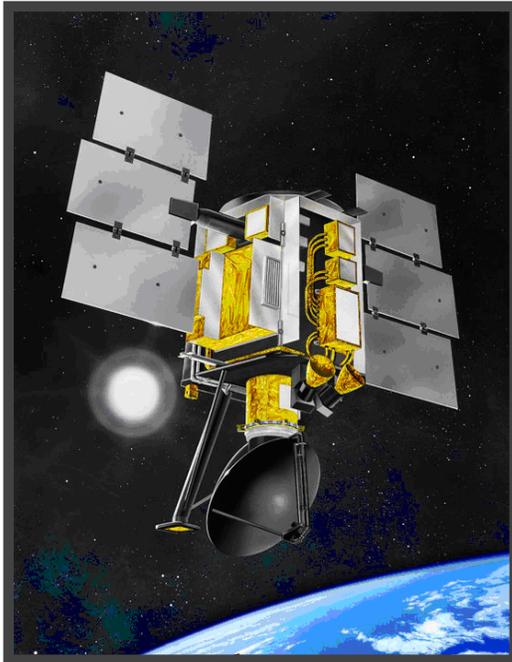


Image credit: NASA

## Met. buoy

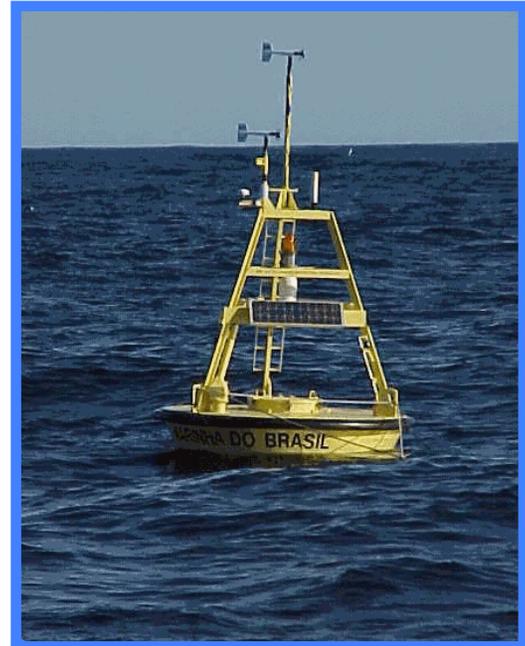
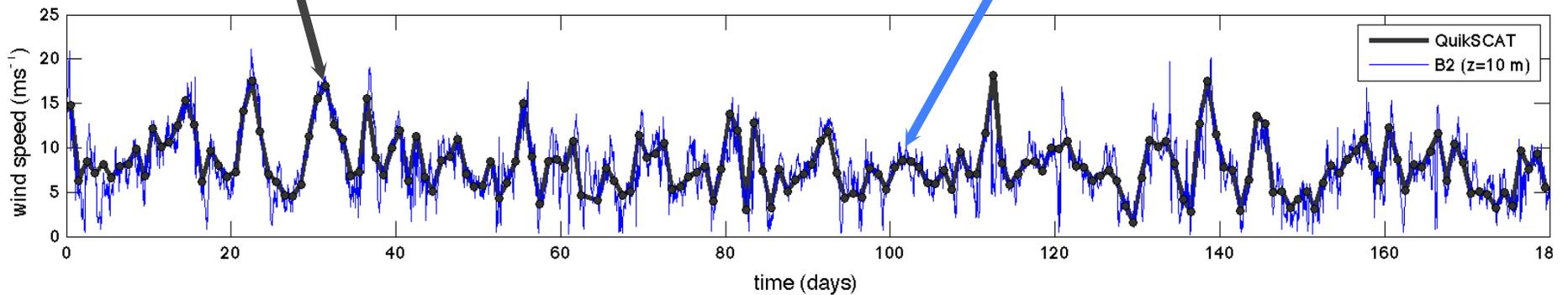


Image credit: Brazilian Navy

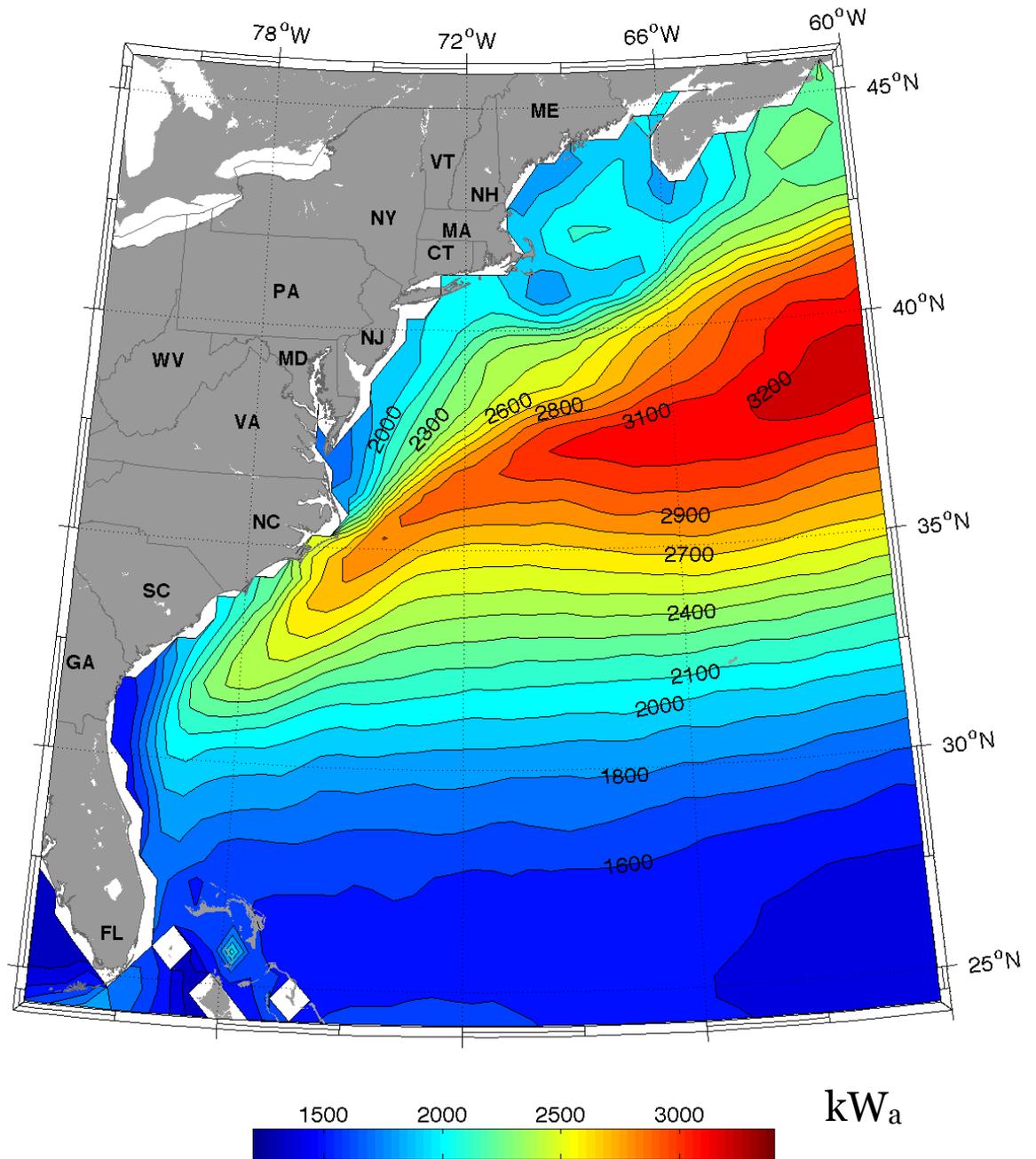


Pimenta, Kempton and Garvine (2008)

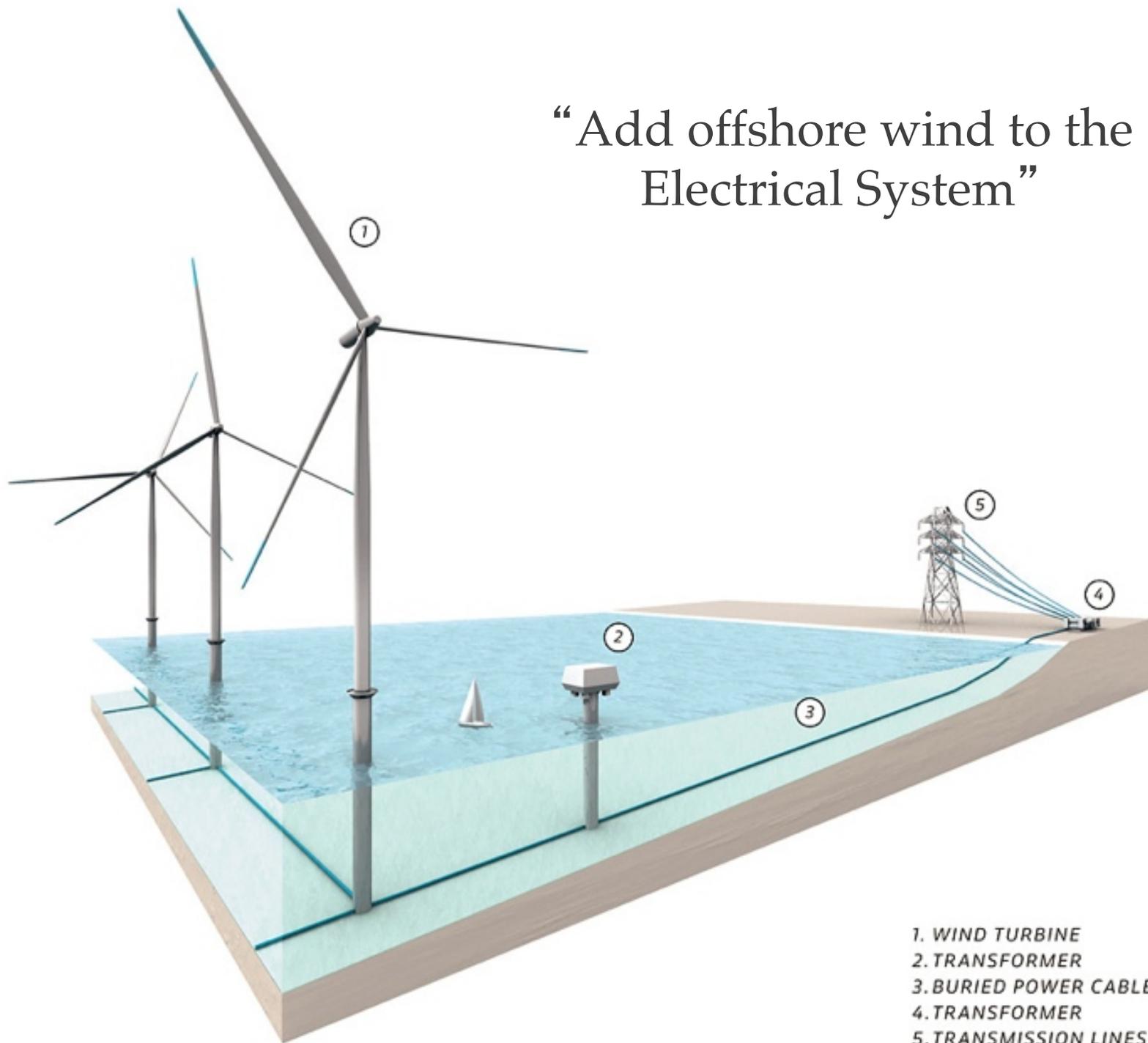
# QuikSCAT turbine output 1999-2008



Image: Repower Systems AG



# “Add offshore wind to the Electrical System”

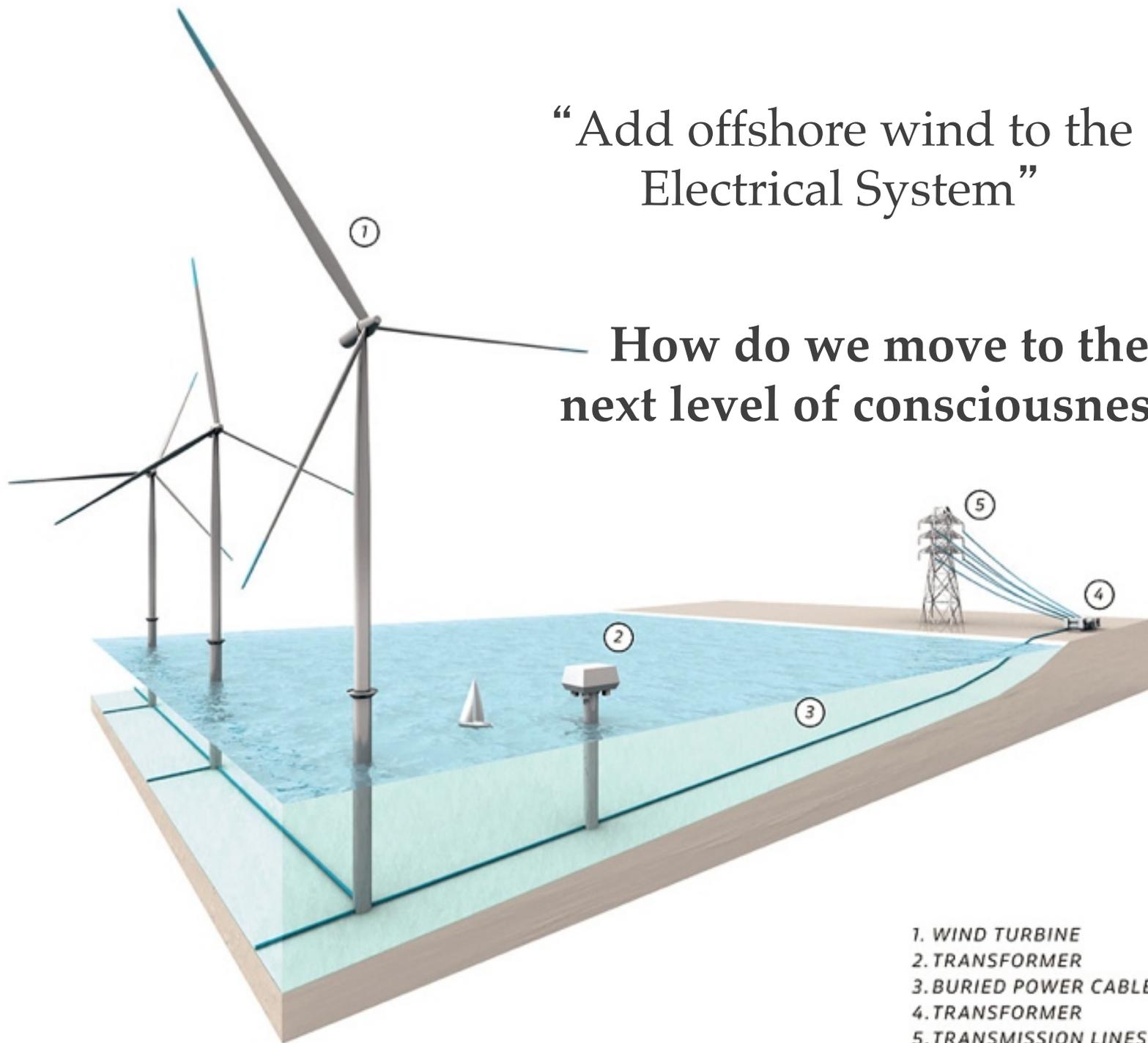


1. WIND TURBINE
2. TRANSFORMER
3. BURIED POWER CABLE
4. TRANSFORMER
5. TRANSMISSION LINES

Art: NY Times Magazine

“Add offshore wind to the  
Electrical System”

How do we move to the  
next level of consciousness?

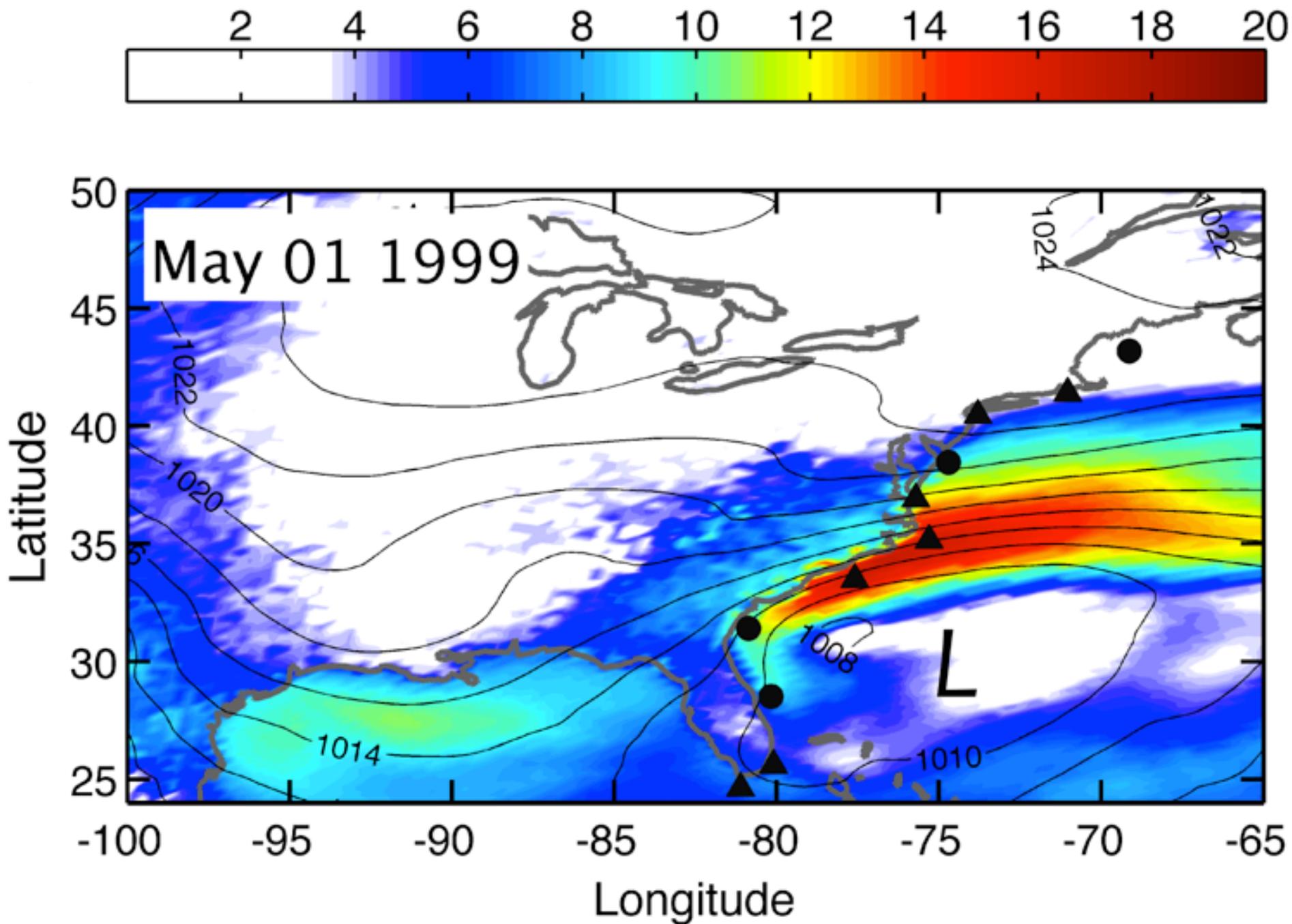


Art: NY Times Magazine

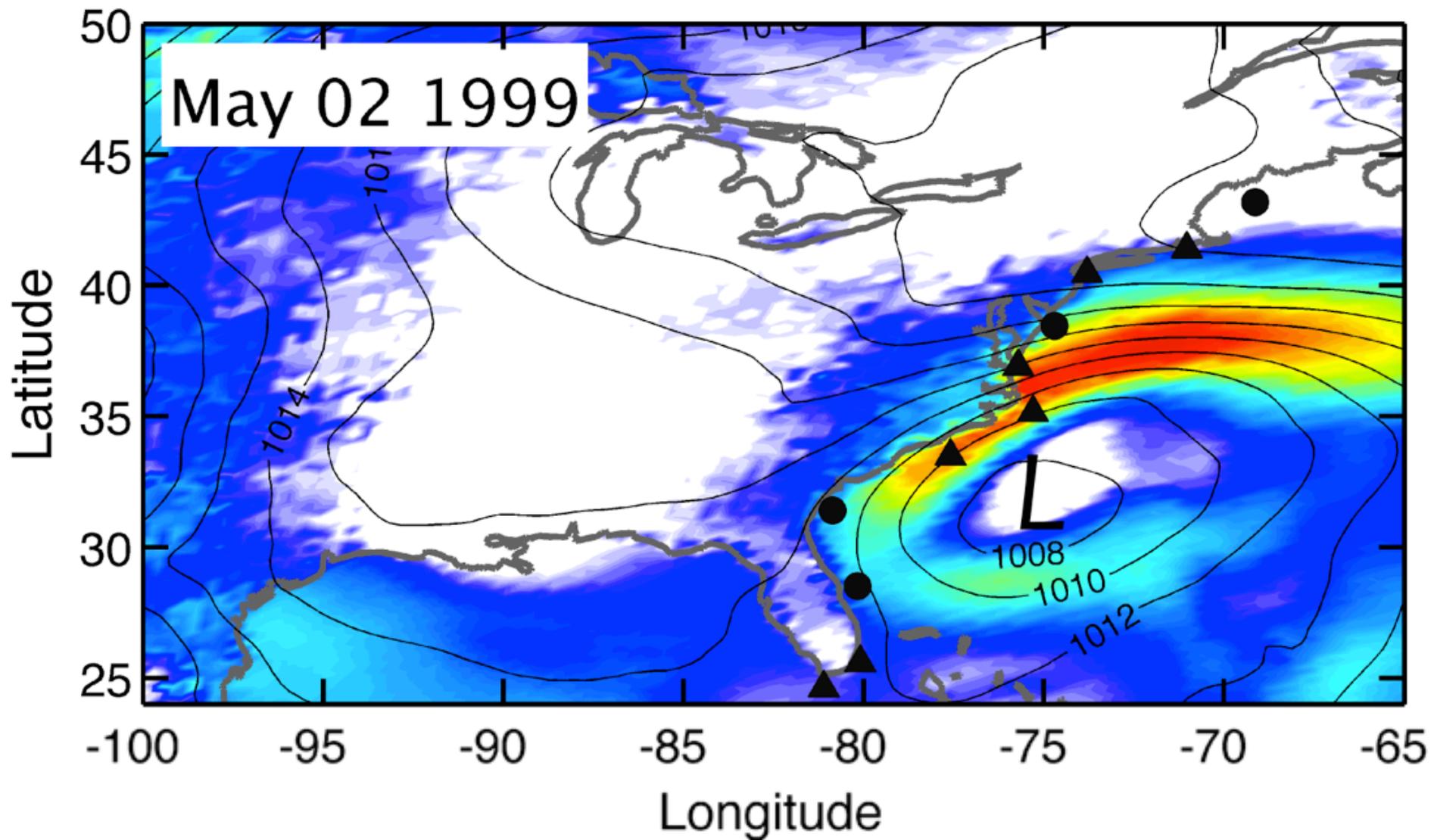
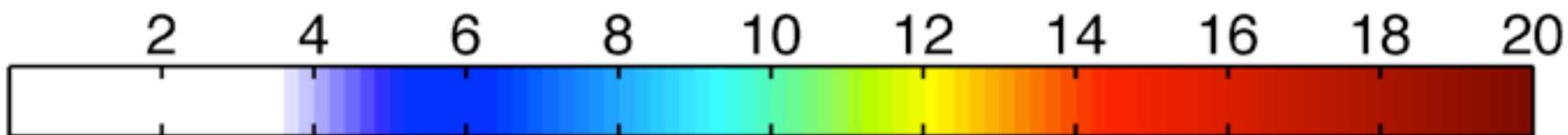
# DESIGN TRANSMISSION AROUND WIND

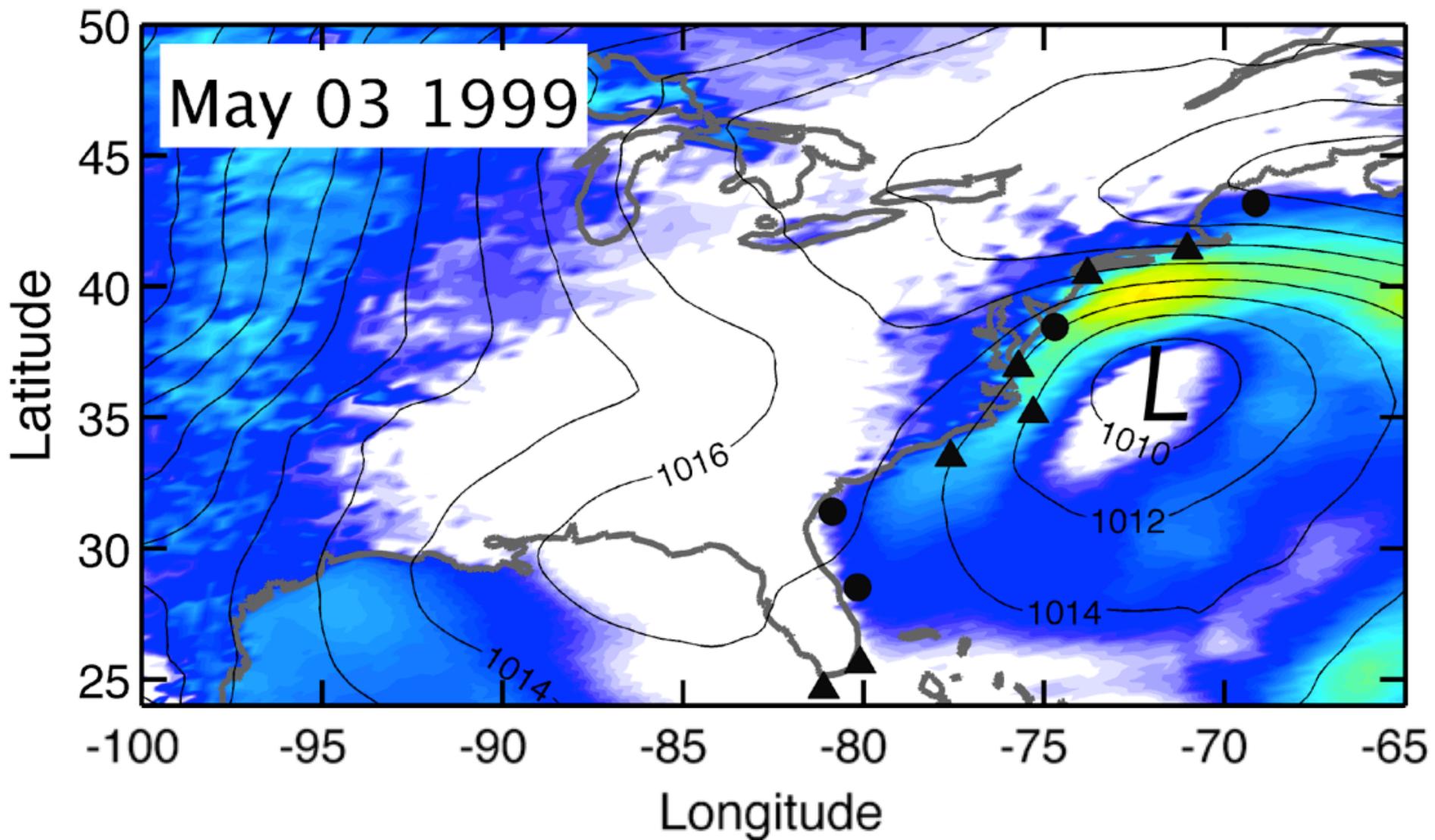
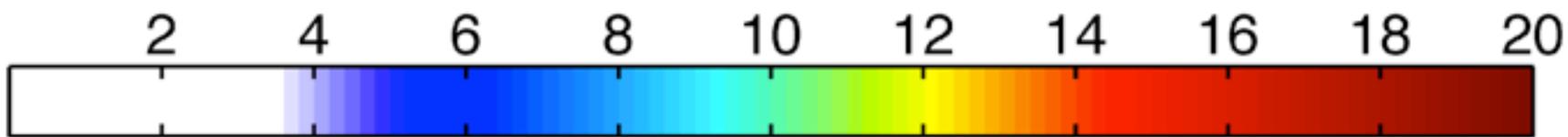
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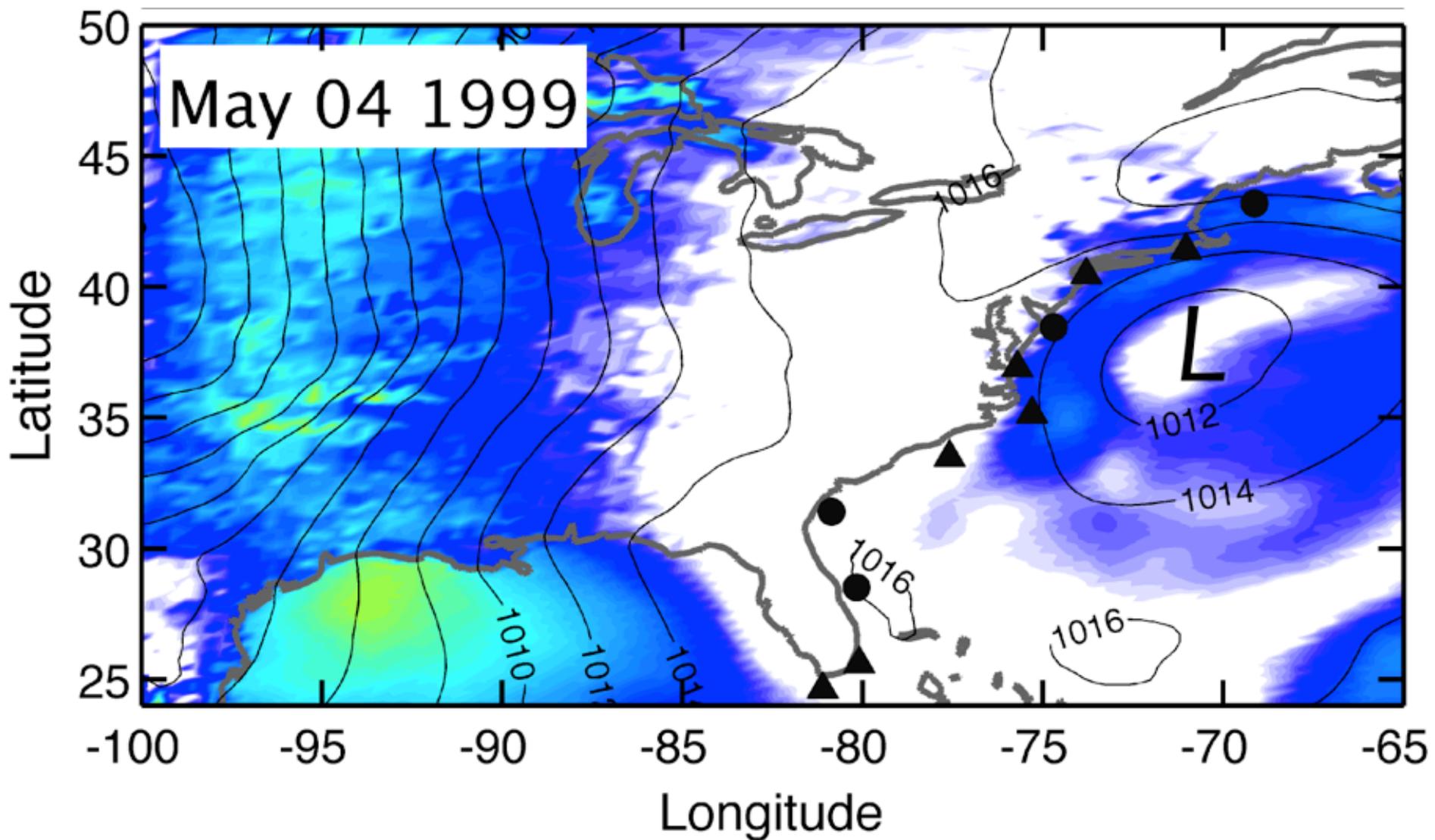
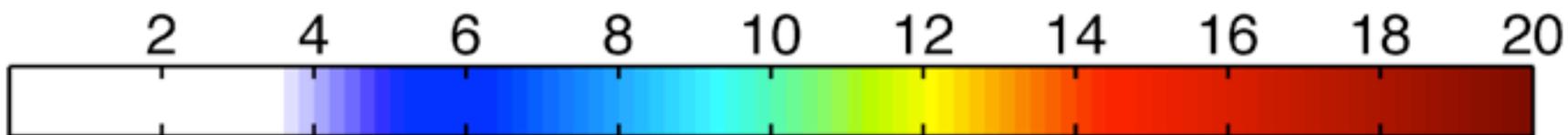
- If we have wind here,
- Where do we add wind to level power?
  - Requires time-series meteorology, not just “resource” data
- **Then** decide where to run transmission
- Example, 4 days of weather ...



Kempton et al, 2010, *Proceedings of the National Academy of Sciences*, 107 (16).



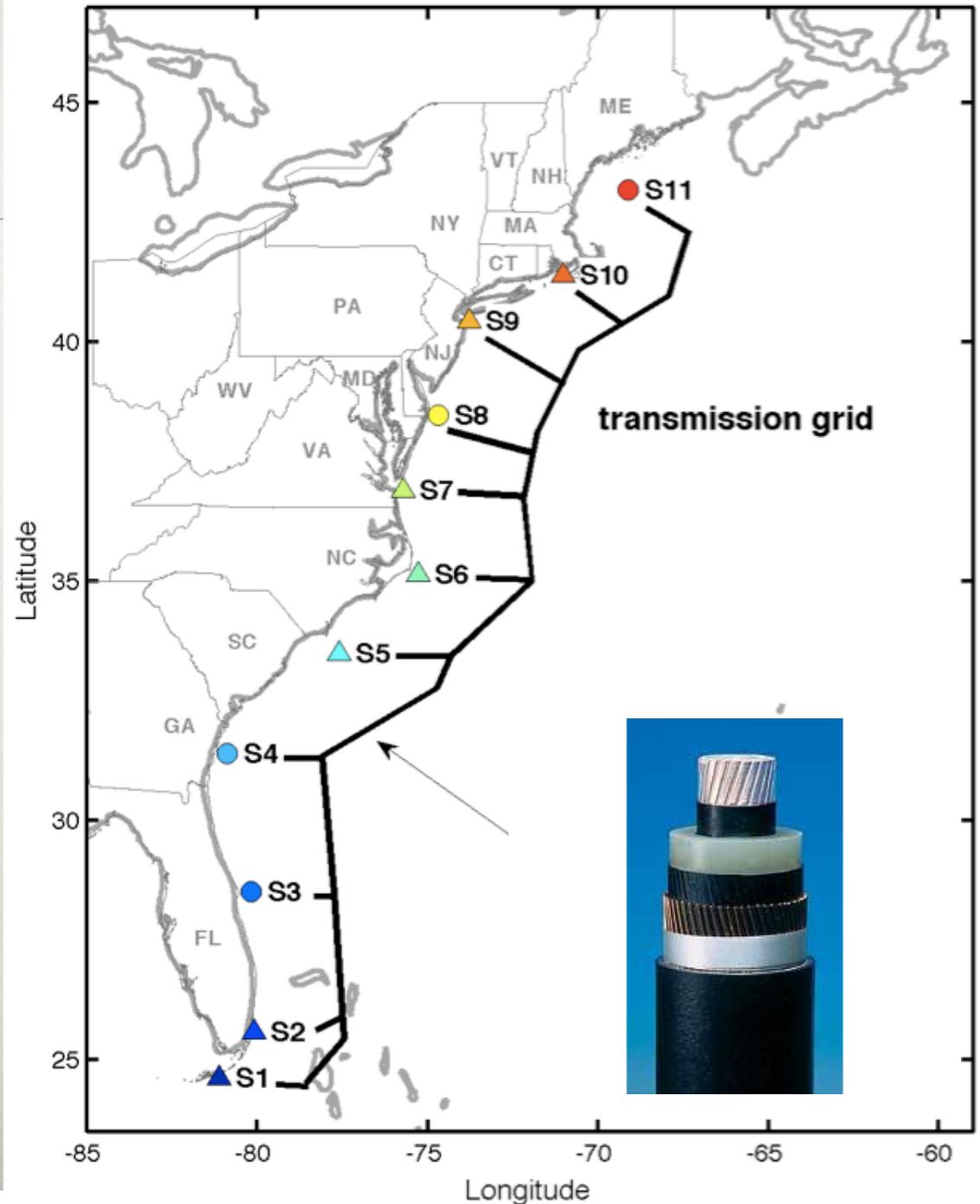




**How would you align transmission?**

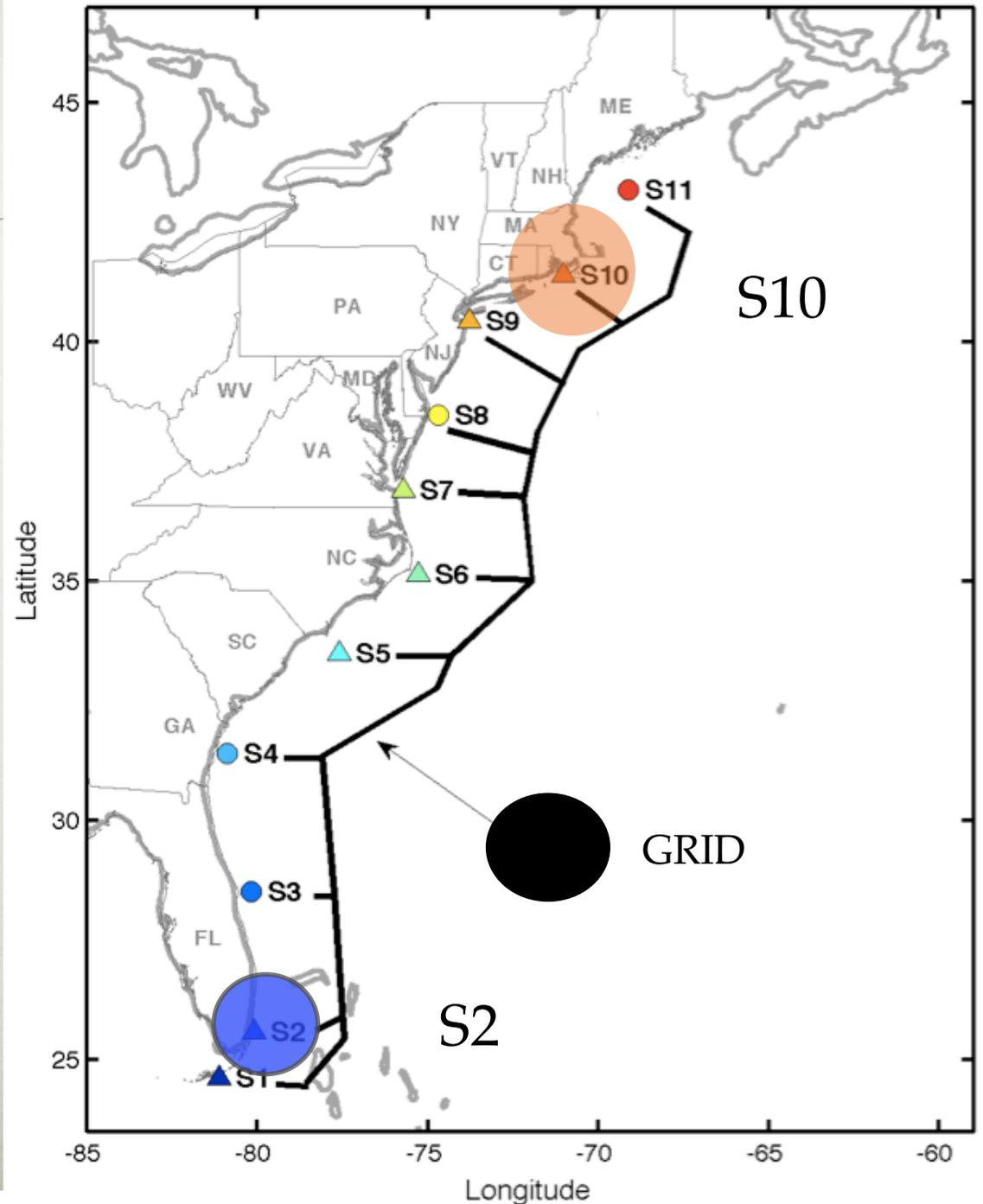
# TRANSMISSION N-S ON SHELF

- Weather data from each station S1 - S11
- Transmission "pools" power
- Principle: *Design the transmission system around meteorological patterns.*

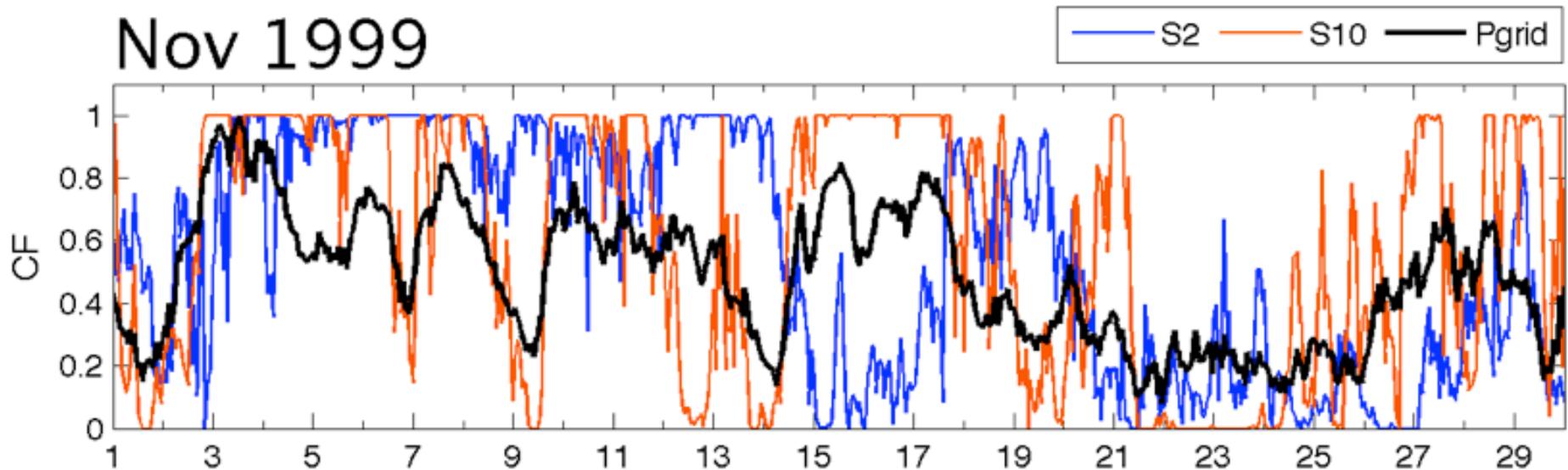


# COMPARE RESULTING POWER

- Individual wind production at S2 and S10 (BLUE and ORANGE)
- Pooled production from transmission (BLACK)



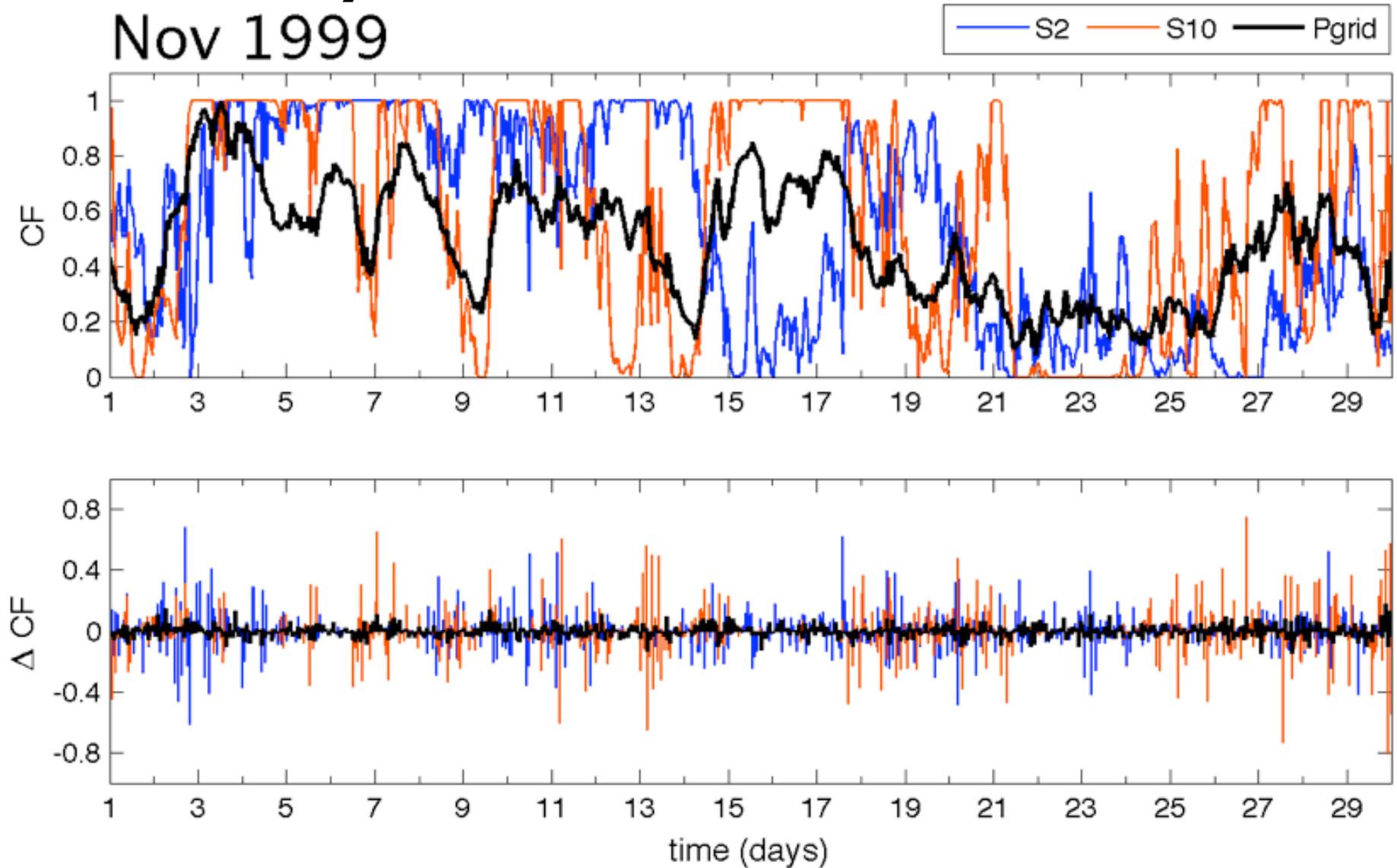
# Result: Single Sites (color) vs. Grid (black)

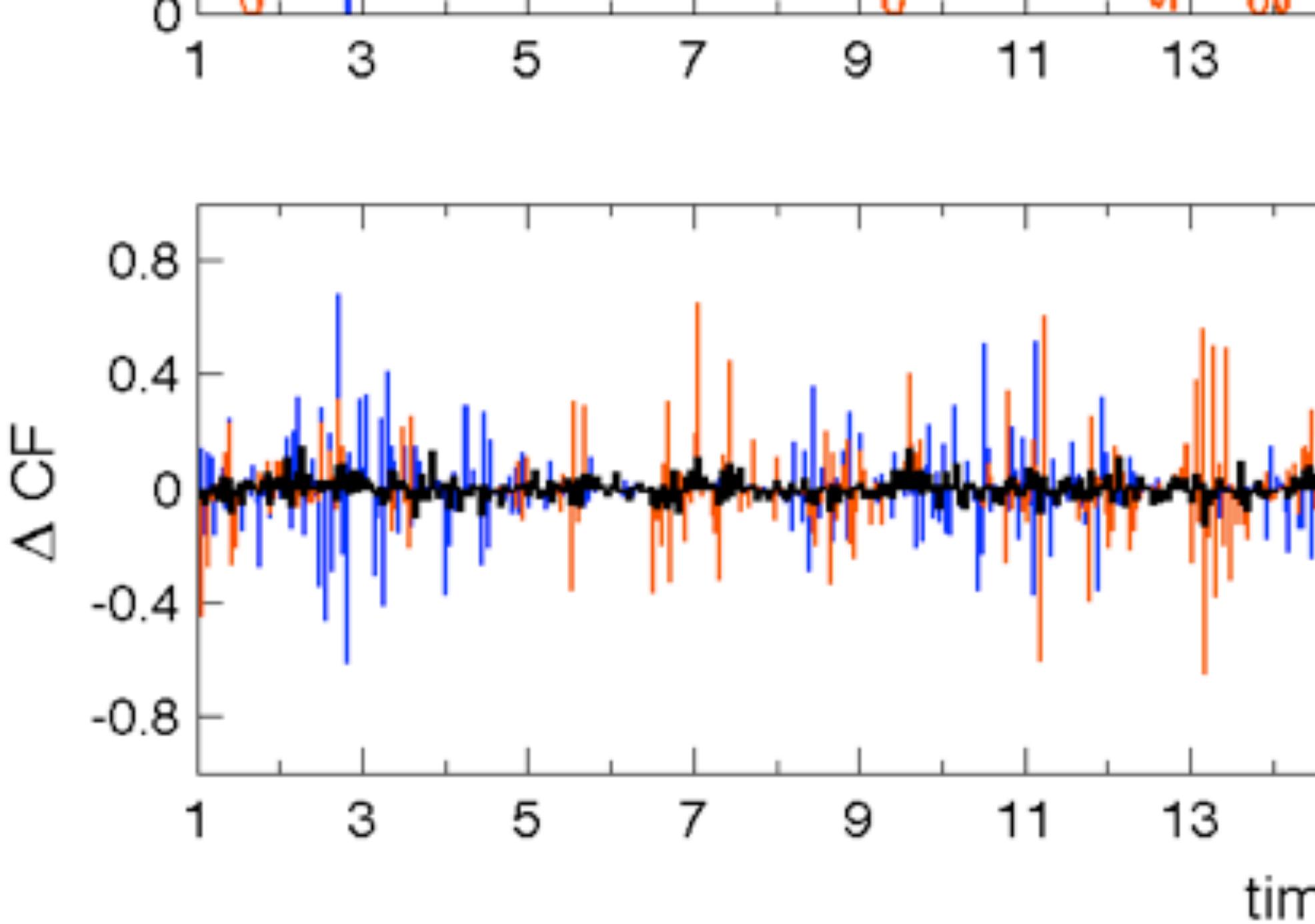


- Individual simulated wind farms show frequent, rapid fluctuation in output
- Power from combined grid changes more slowly, rarely reaches min or max power

# Hourly Fluctuations in Month

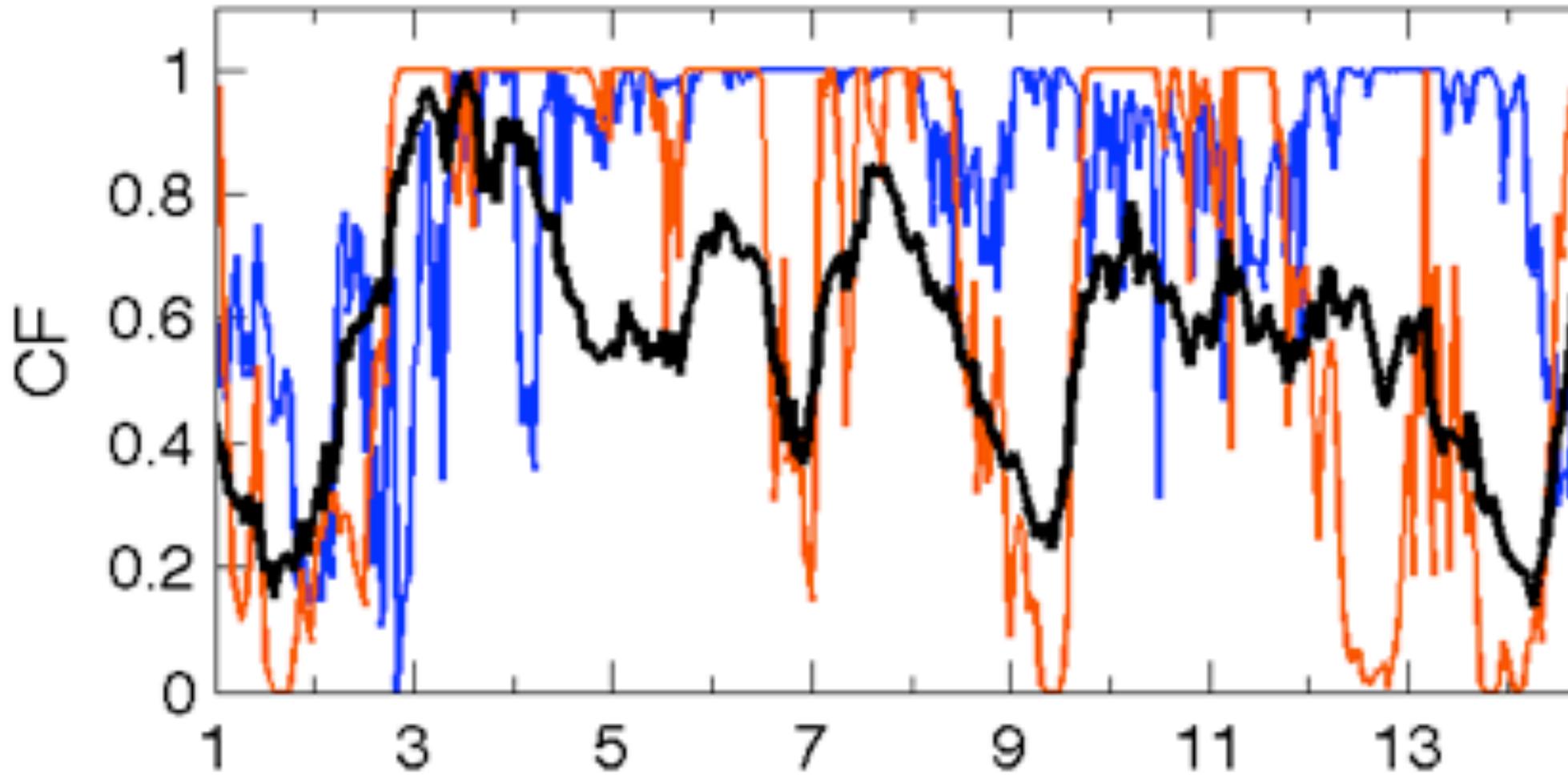
Nov 1999



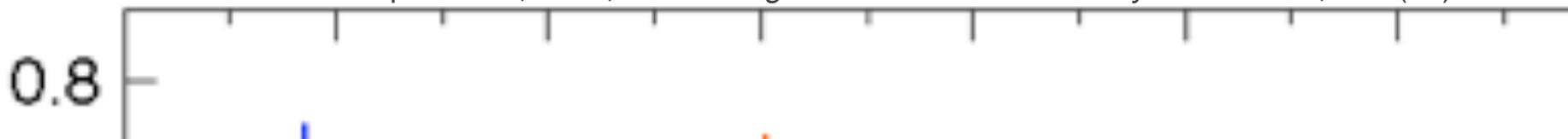


Kempton et al, 2010, *Proceedings of the National Academy of Sciences*, 107 (16).

# Nov 1999

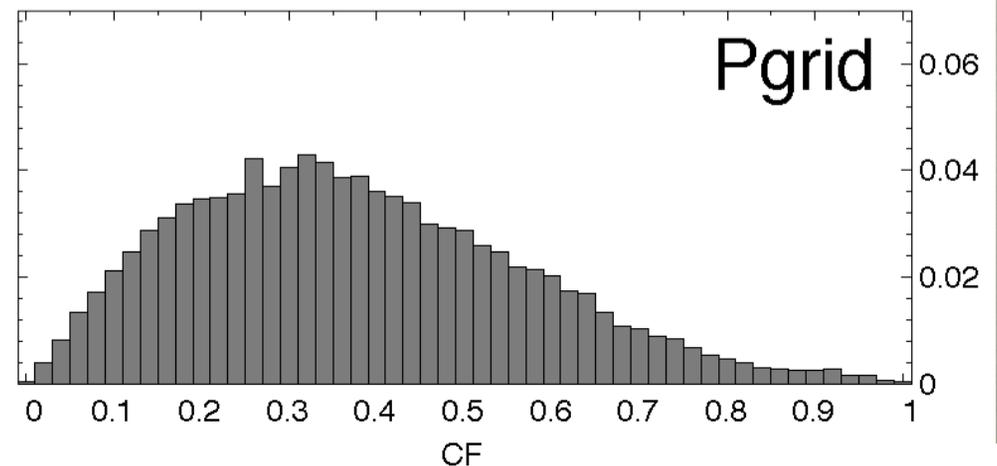
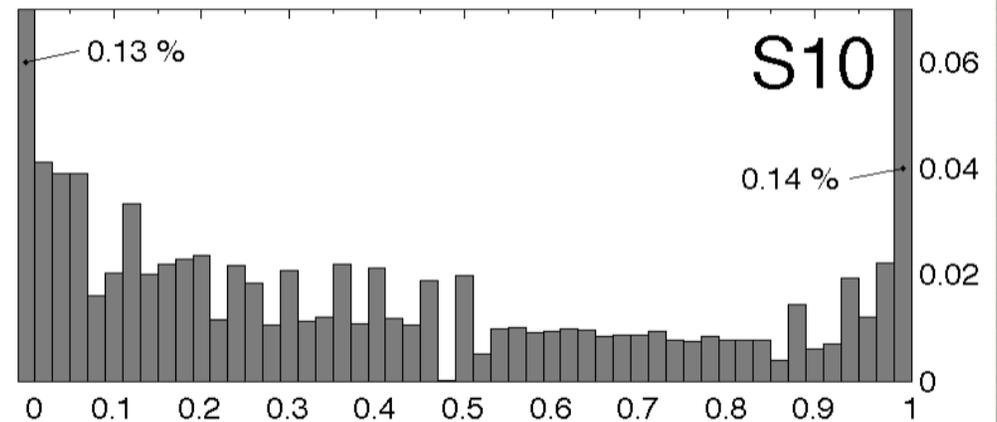
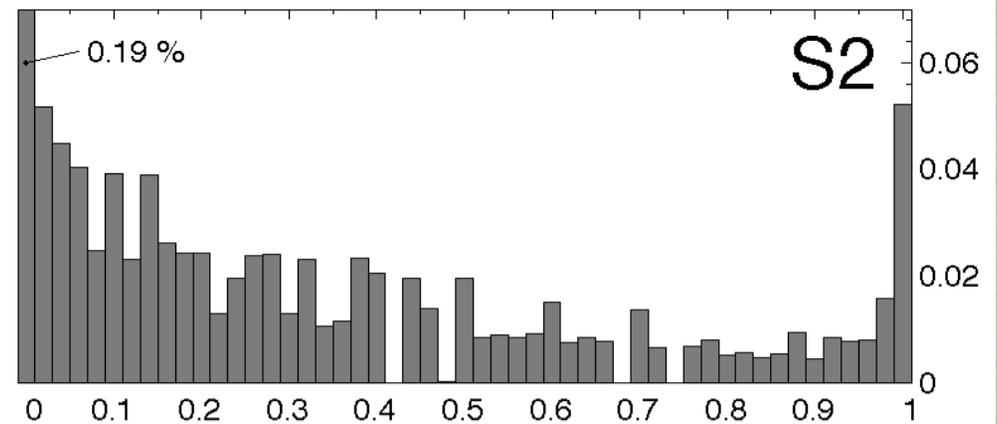


Kempton et al, 2010, *Proceedings of the National Academy of Sciences*, 107 (16).



# DISTRIBUTION OF CFS

- Single stations have many high or zero capacity factor values
- Combined grid clusters around mid-range values



# ALREADY A PLANNED PROJECT WITH INVESTORS



# ELECTRIC VEHICLES

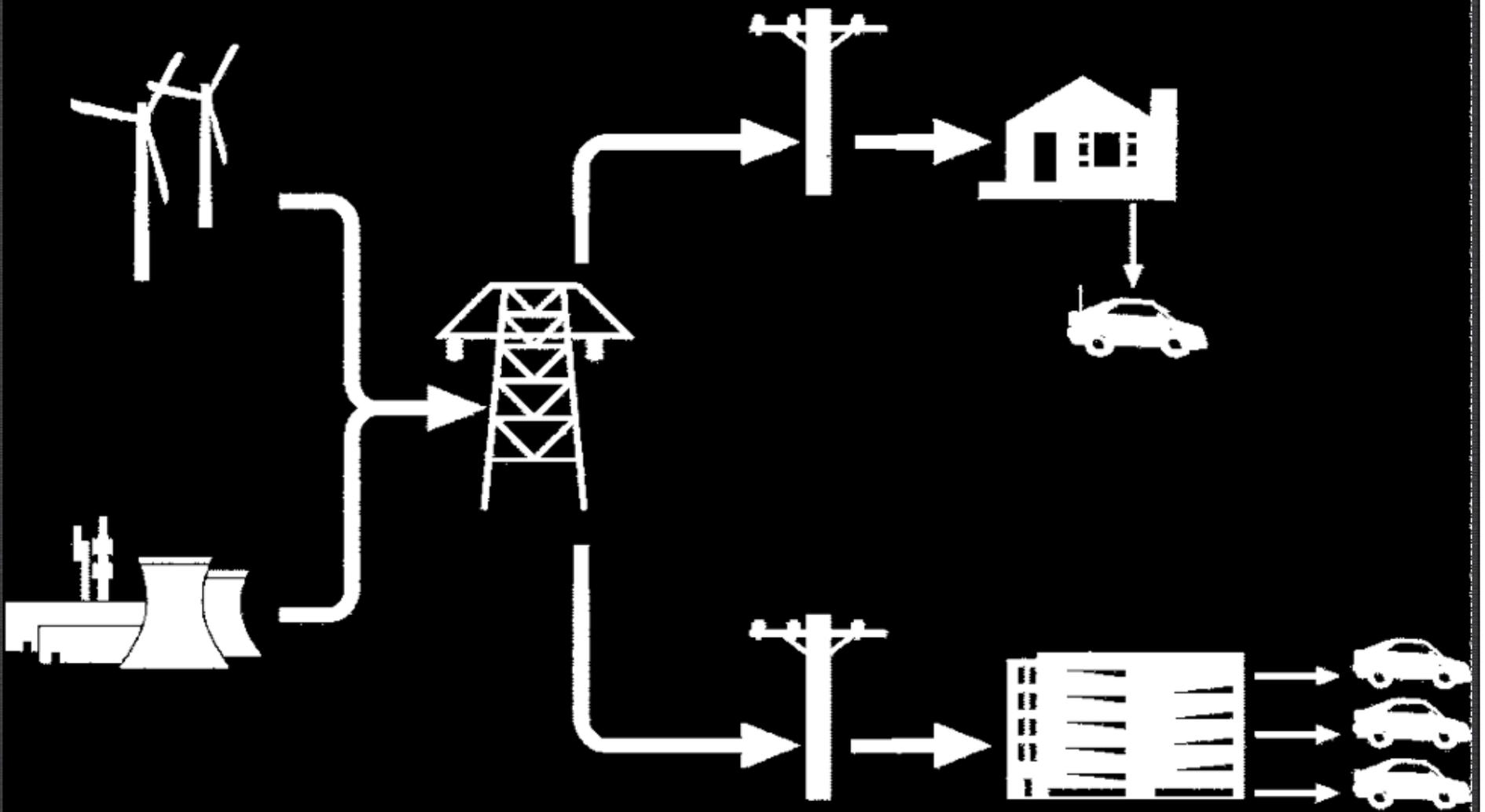
DELAWARE INNOVATION:  
THE GRID-INTEGRATED  
VEHICLE, WITH  
VEHICLE-TO-GRID POWER

# ELECTRIC VEHICLES

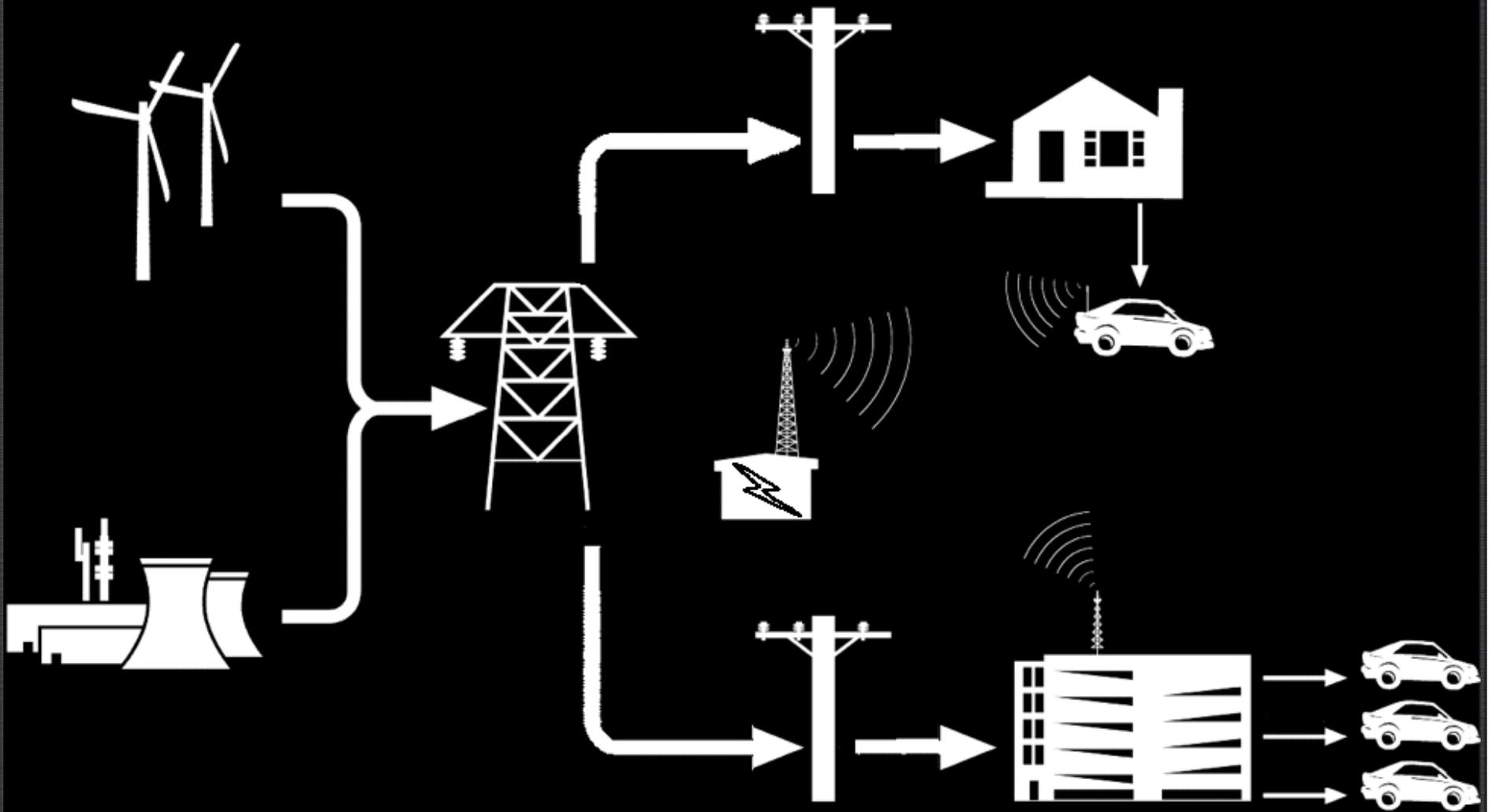
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- Three Stages:
  - 1. Electricity as a fuel for cars (how to make it more like gasoline?)
  - 2. Adapt to the electric system (control the charge of EVs)
  - 3. Design the system around EVs (very low-cost storage at the end of the grid)

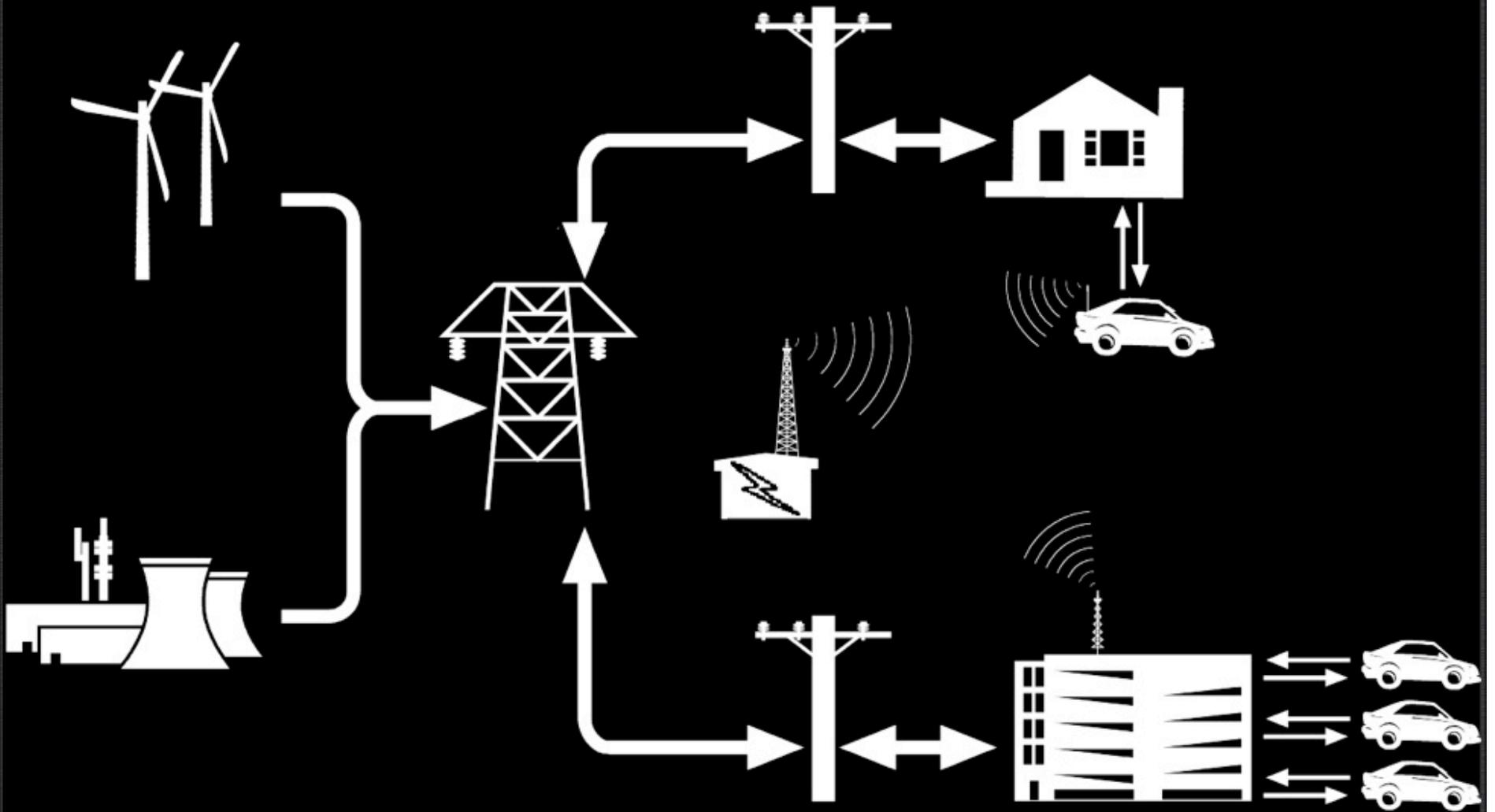
# ELECTRICITY AS A FUEL



# ADAPT: LOAD CONTROL



# REDESIGN: 2-WAY POWER



# EVs AS A POWER RESOURCE

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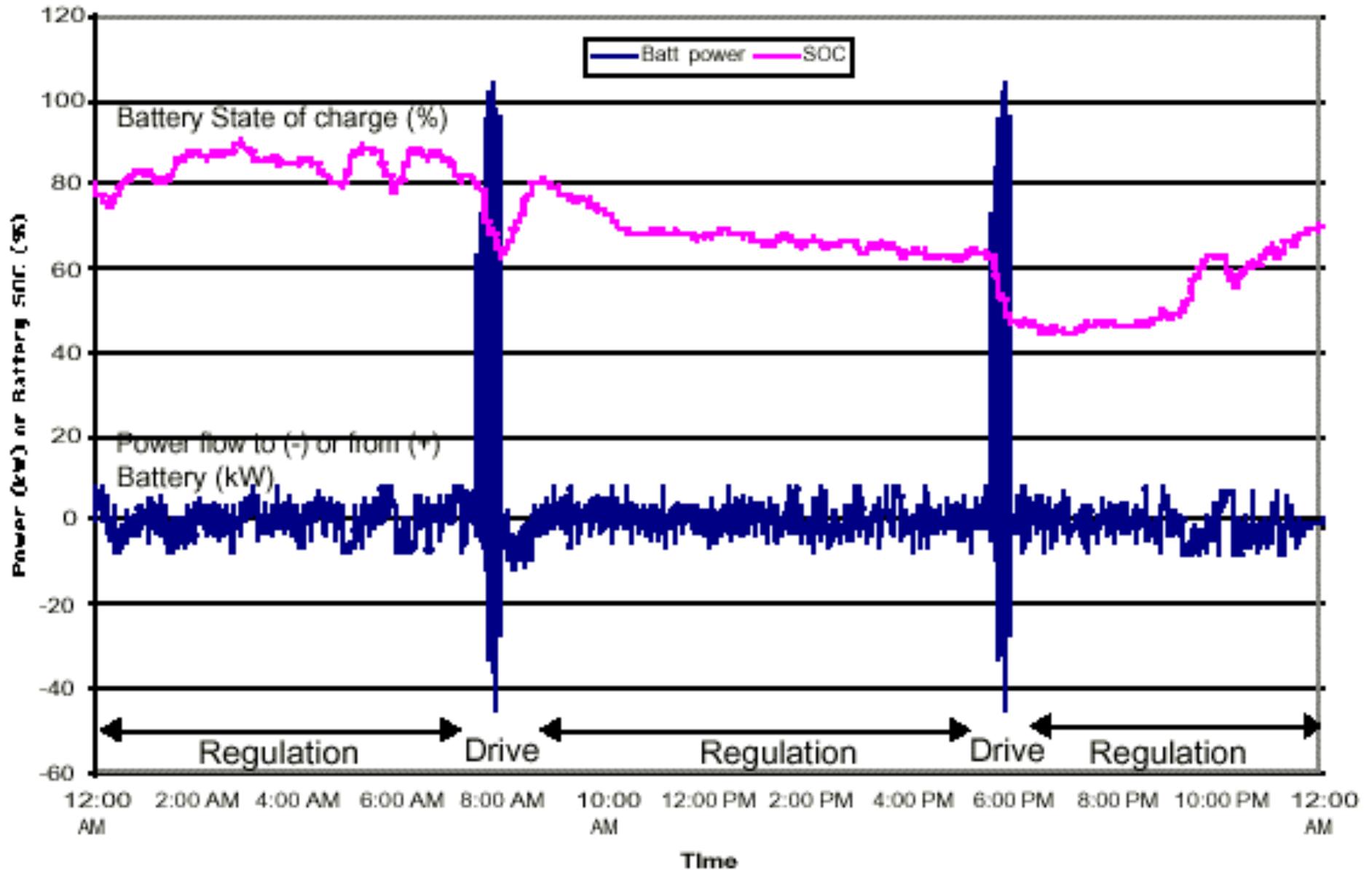
- US car used 1 hour/day, parked 23 h/d
- Practical power through grid
  - 10 - 20 kW in US homes
  - 3.6 - 10 kW in EU homes
- Cars as significant power? Compare:
  - Vehicle fleet at 10 - 15 kW each car, with
  - Total load for country (GW)

# HOW MUCH POWER IN CARS?

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	Denmark	UK	USA
Light vehicles ( $10^6$ )	1.9	28.5	191
Power per connection (kW)	10	10	15
<b>Vehicle power (GW)</b>	<b>19</b>	<b>285</b>	<b>2,865</b>
Country Average Electric Load (GW)	3.6	40	417

# A DAY OF DRIVING AND POWER BALANCING



# AGGREGATING EVS FOR THE ISO

## Vehicle to Grid -- Coalition Server

University of Delaware

### Coalition Status

ISO	Power Capacity Up (kW)	Power Capacity Down (kW)	Power Requested (kW)	Power Provided (kW)	Energy Charge (kWh)	Energy Empty (kWh)	Number of Cars
PJM	49.37	49.37	-14.80	-15.81	104.30	35.70	4
CAL-ISO	0.00	0.00	0.00	0.00	0.00	0.00	0
Simulated-ISO	0.00	0.00	0.00	0.00	0.00	0.00	0

Hide Charts

CAL-ISO

Simulated-ISO

PJM

### Individual Vehicle Status

Car Name	Power Capacity Up (kW)	Power Capacity Down (kW)	Power Requested (kW)	Power Provided (kW)	Energy Charge (kWh)	Energy Empty (kWh)	Miles	Volts (V)	Amps (A)	Monthly Credit (\$)
UD-296	0.00	0.00	0.00	0.00	29.05	5.95	91.30	211	22.5	33.17
UD-170	11.23	11.23	-3.36	-3.95	12.60	22.40	39.60	234	16.9	76.31
DEState5205	10.70	10.70	-3.21	-2.05	33.25	1.75	104.50	214	9.6	21.73
DEState0000	17.36	17.36	-5.21	-5.70	31.50	3.50	99.00	248	23	24.59
UD-210	10.08	10.08	-3.02	-4.09	26.95	8.05	84.70	210	19.5	23.38

# STORAGE IN LOADS, VERY LOW COST

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- Incremental cost on an existing EV is much lower cost than dedicated storage
- On-board intelligence, ~\$400
- Communications, ~\$200
- EV\*: \$40/kW; \$20/kWh
- PHEV\*: \$200/kW; \$75/kWh

\*Assume: PHEV 3 kW; 8 kWh, EV 15 kW; 30 kWh

# CONCLUSIONS

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- Integration
  - Three stages: add / adapt / redesign
- Transmission
  - Find asynchronous resources
  - Met-smart alignment
- Existing storage in loads
  - EVs, building heat, etc

END

MORE INFORMATION:

[WWW.CARBONFREE.UDEL.EDU](http://WWW.CARBONFREE.UDEL.EDU)