Potential Climatic Impacts and Reliability of Large-Scale Onshore and Offshore Wind Farms

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Meeting future world energy needs while addressing climate change requires large-scale (multi-terawatt) deployment of low or zero greenhouse gas emission technologies. The widespread availability of wind power has fueled substantial interest in this renewable energy source as one of the needed technologies. For very large-scale utilization of this resource, there are however potential environmental impacts, and also problems arising from its inherent intermittency, in addition to the present need to lower unit costs.

To explore some of these issues, we present two studies that:

(a) Use 60-year runs of NCAR-CAM3-MLOcean-CLM 3D climate model to simulate the potential future climate effects and reliability associated with installation of wind-powered generators over vast areas of semi-arid land or coastal ocean with 25% conversion efficiency *(see Wang and Prinn, Atmos. Chem. Phys., 10, 2053–2061, 2010; Environ. Res. Lett., 6, 025101, 2011)*

(b) Use observationally-based boundary layer flux data for the USA land and coastal regions to examine the nature and reliability of the present-day wind resource *(see Bhaskar and Schlosser, MIT Joint Program Report, 2011; ACPD, in review, 2011)*

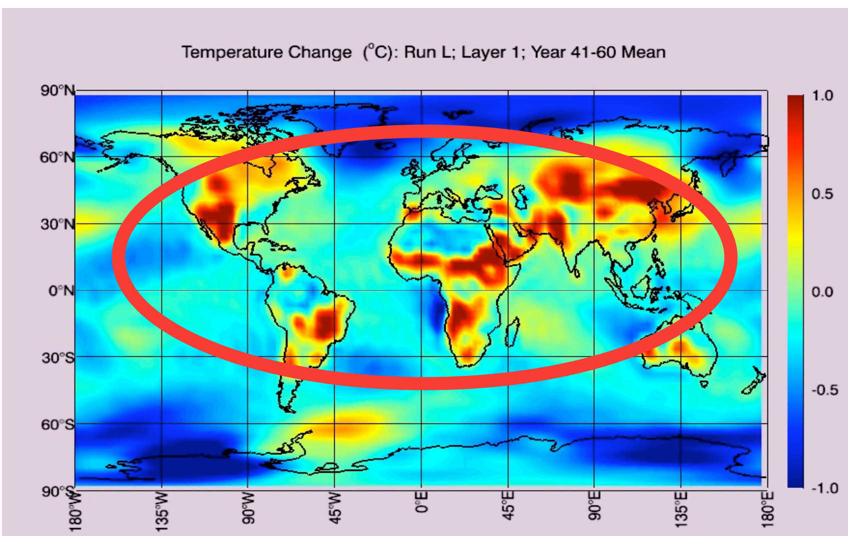
EFFECTS OF WIND TURBINE ARRAYS OVER SEMI-ARID LANDS AT LARGE SCALES ON SURFACE TEMPERATURE & CONVECTIVE & LARGE SCALE PRECIPITATION

USE CAM3-MLOcean (T42, 2.8° x 2.8°,18 levels) without and with enhanced displacement height & surface roughness (Very Low, Low, High, & Very High enhancements above standard). Generated electric power ranges from 2.3 TW (VL) to 19 (VH) TW. Use averages over the last 20 years for the wind turbine and no wind turbine cases.

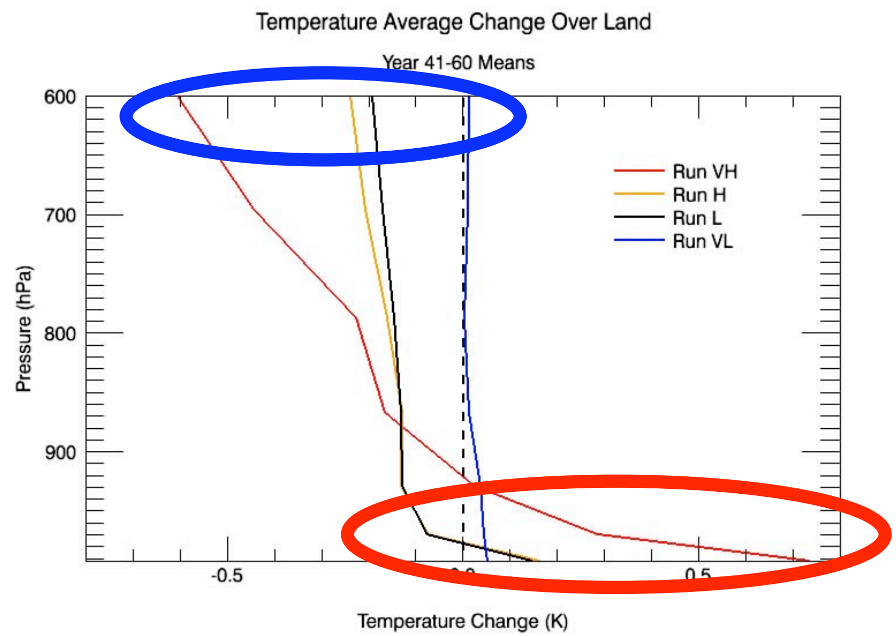
Atmospheric Wind Power Consumption, *P (x,y,t)*

$$= - \{[\tau_U U + \tau_V V]^{wind} - [\tau_U U + \tau_V V]^{no\ wind}\}.$$

(Ref: Wang & Prinn, *Atmos. Chem. Phys.*, 2010)



WIND TURBINES WARM INSTALLED LAND REGIONS & WARM/COOL ELSEWHERE (Run L, generating 5TW, 58 million km^2 area)

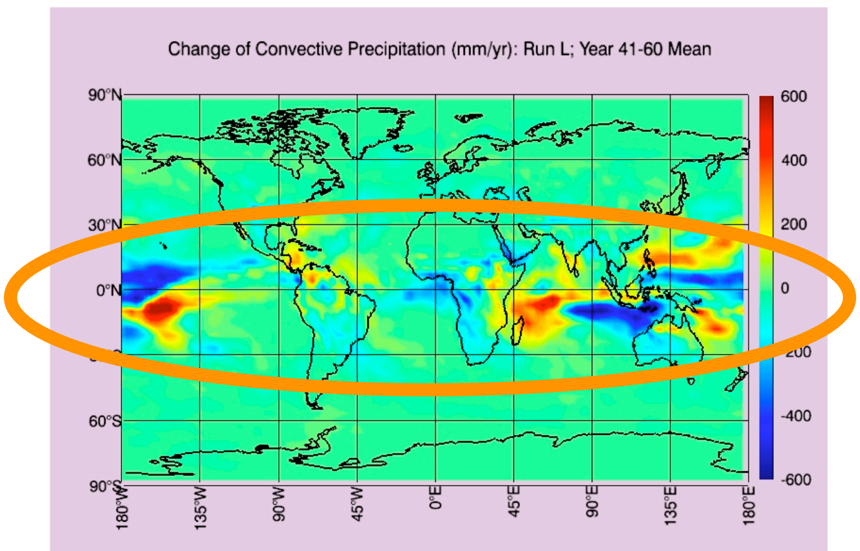


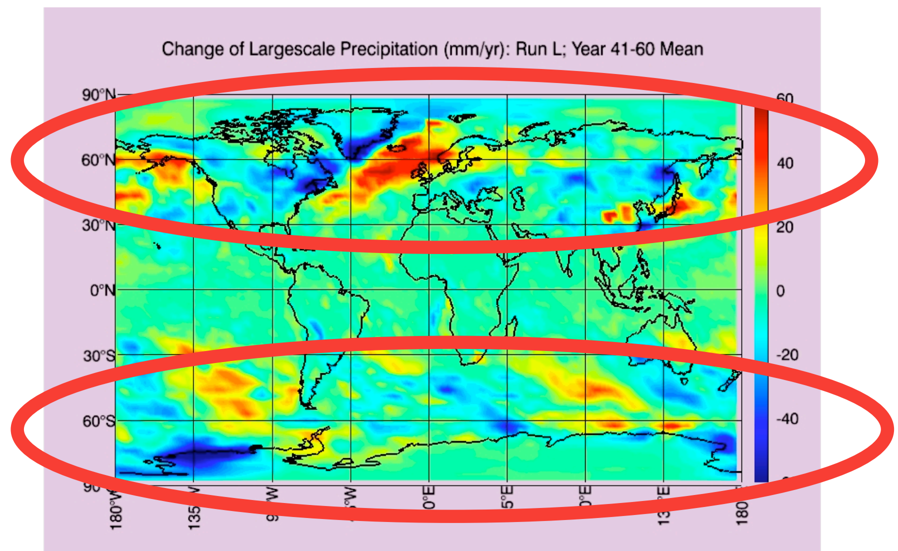
WIND TURBINES WARM SURFACE AND COOL ALOFT (all runs)

WHAT ARE EFFECTS OF WIND TURBINE ARRAYS OVER SEMI-ARID LANDS AT LARGE SCALES ON CONVECTIVE & LARGE SCALE PRECIPITATION (e. g. for case L, 5TW, 58 million km^2)

(Ref: Wang & Prinn, *Atmos. Chem. Phys.*, 2010)

WIND TURBINES CHANGE (SHIFT) GLOBAL CONVECTIVE & LARGE SCALE PRECIPITATION PATTERNS





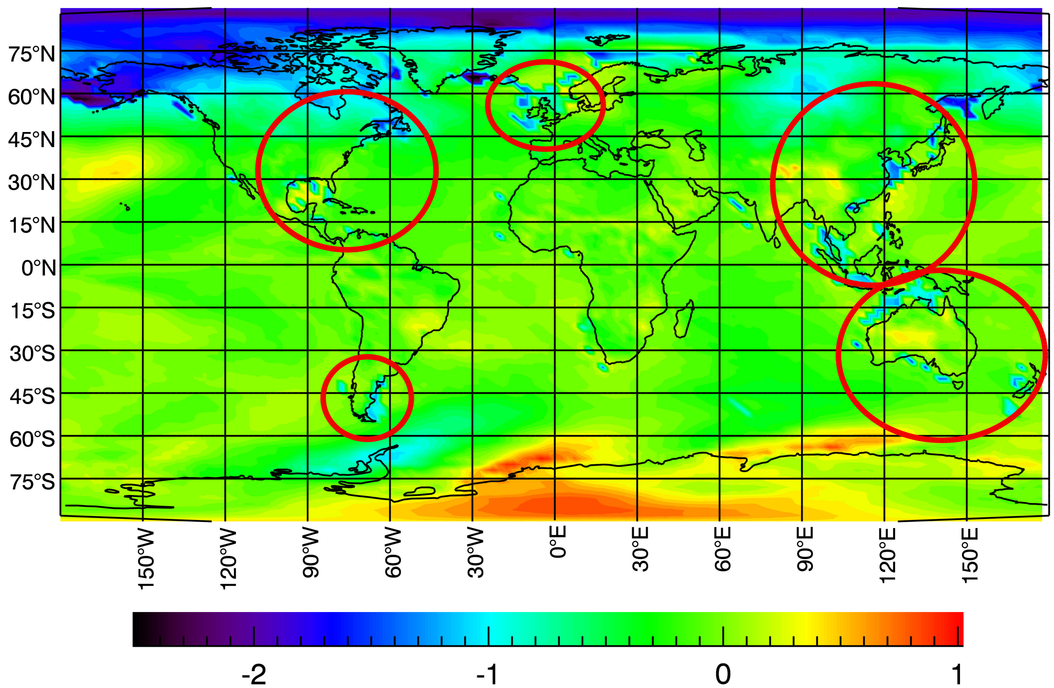
WHAT ARE EFFECTS OF WIND TURBINE ARRAYS AT LARGE SCALES OVER COASTAL WATERS (200, 400, 600m deep) ON SURFACE TEMPERATURE.

USE CAM3-MLOcean-CLM (26 level, 2° x2.5°) without & with enhanced surface drag coefficients; High (x8) and Low (x2) above standard values.

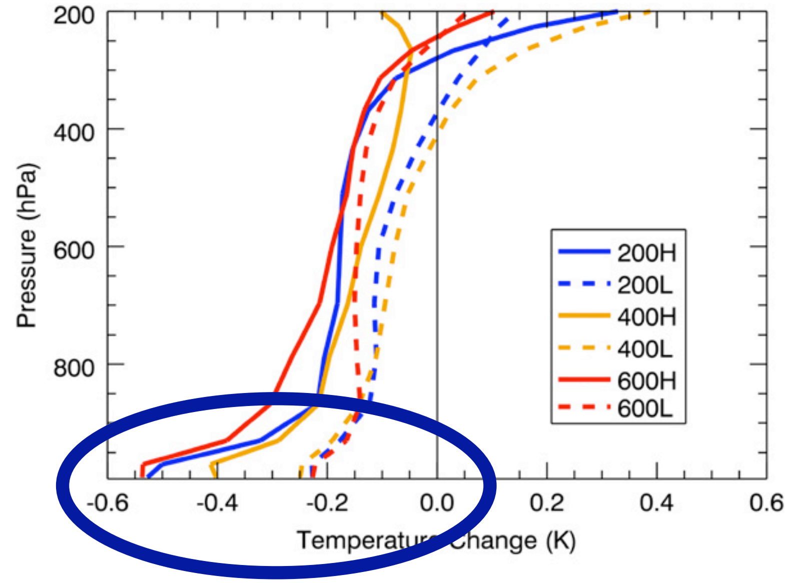
Electric Power generated ranges from 1.7 TW (case 200L) to 11.9 TW (case 600H).

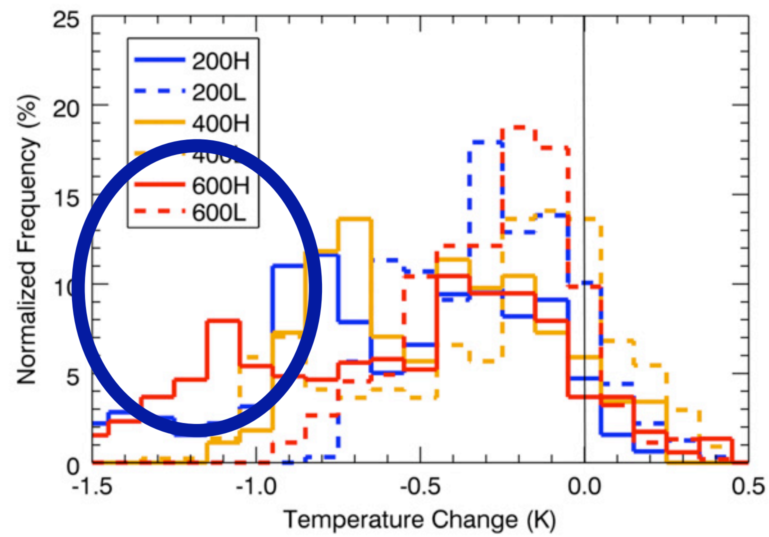
(Ref: Wang & Prinn, *Environ. Res. Lett.* , 2011)

WHAT ARE EFFECTS OF WIND TURBINE ARRAYS AT LARGE SCALES OVER COASTAL WATERS (200, 400, 600m deep; High (x8) and Low (x2) increases in surface drag) ON SURFACE TEMPERATURE
(Ref: Wang & Prinn, *Environ. Res. Lett.* , 2011)



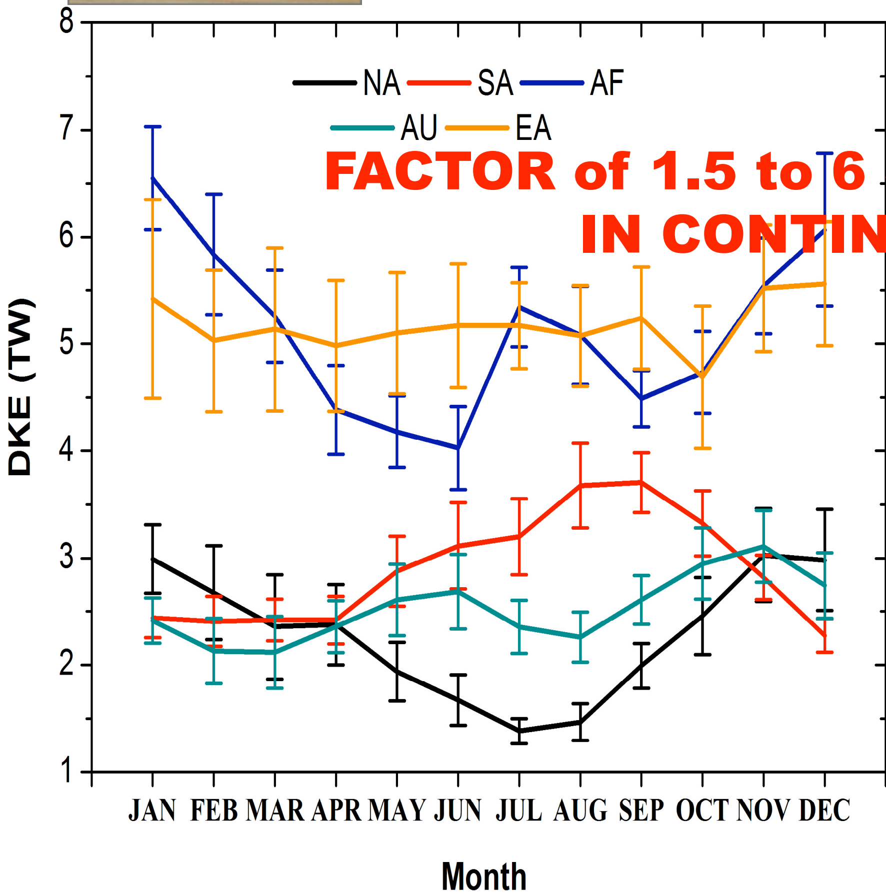
WIND TURBINES COOL INSTALLED COASTAL WATER REGIONS (DUE TO ENHANCED LATENT HEAT FLUXES) & WARM/COOL ELSEWHERE, BUT LOWER TELECONNECTION EFFECTS THAN LAND CASE (MAP FOR RUN 600H)

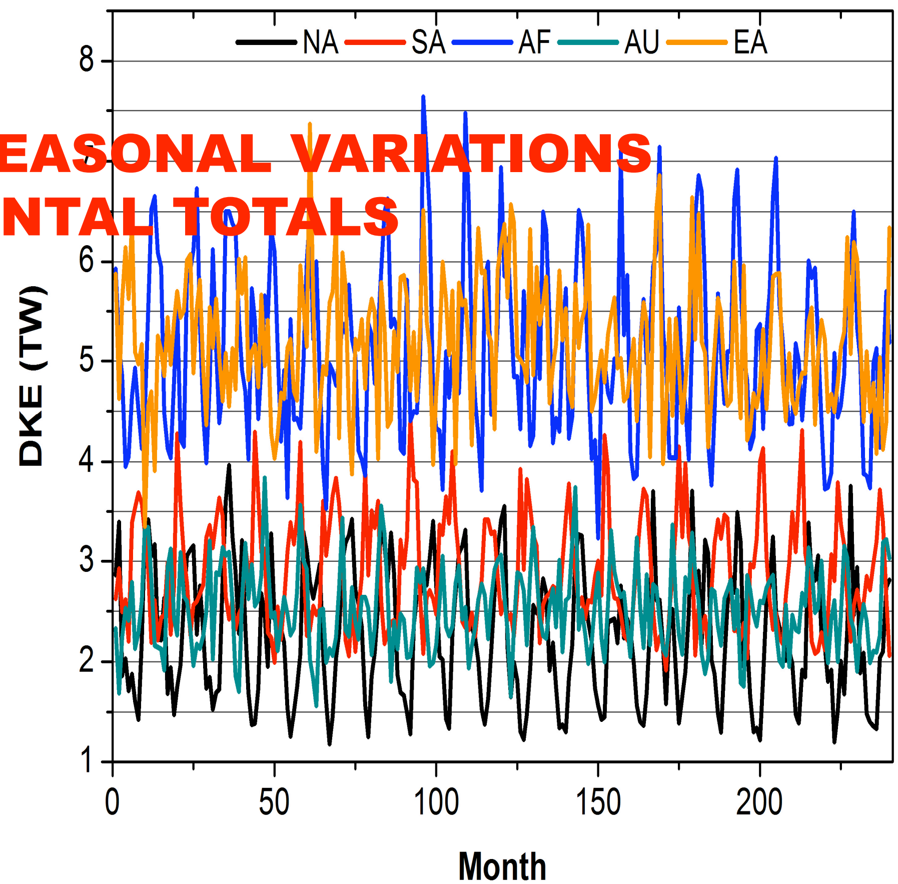




MAXIMUM COOLING AT SURFACE & FOR HIGH DRAG and LARGE AREA (depth) CASES

INTERMITTENCY CHALLENGE ON LAND (Run L): (a) Twenty-year averages and standard deviations, and (b) All values, of the monthly mean wind power consumption (TW) by simulated wind turbines installed in various continents: North America (NA), South America (SA), Africa and Middle East (AF), Australia (AU), and Eurasia (EA).

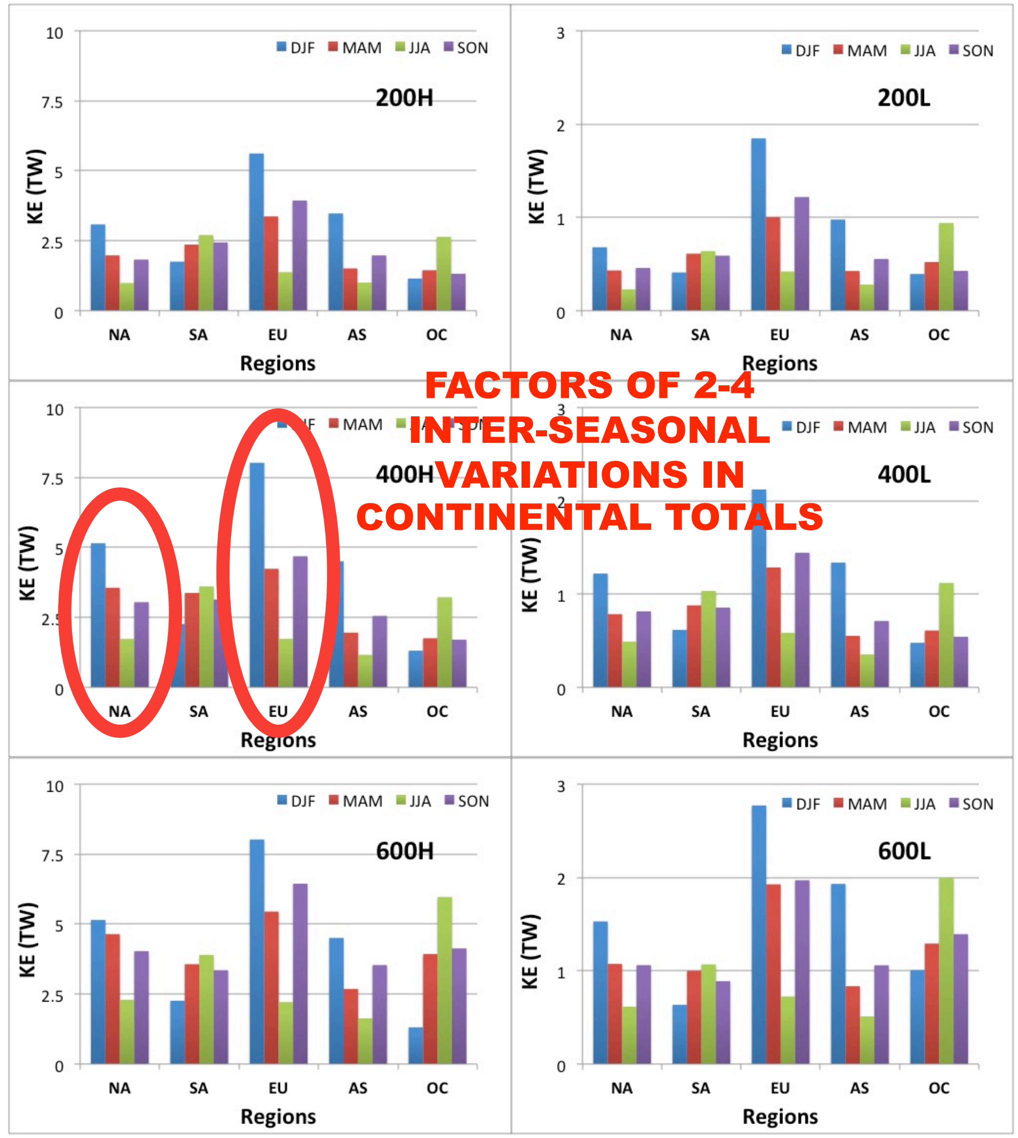




FACTOR of 1.5 to 6 SEASONAL VARIATIONS IN CONTINENTAL TOTALS

NEED BACKUP GENERATION CAPACITY,
POSSIBLY INCLUDING ON-SITE ENERGY STORAGE

INTERMITTENCY CHALLENGE OVER COASTAL OCEAN: **Twenty-year averages** of the **seasonal mean wind power consumption (TW)** **by simulated windmills installed in coastal waters of:** **North America (NA), South America (SA), Europe (EU), South-East & South Asia (AS), and Oceania (OC).**



AGAIN, NEED BACKUP GENERATION CAPACITY,
POSSIBLY INCLUDING ON-SITE ENERGY STORAGE

OUR LAND & OCEAN INSTALLATION STUDY IS EXPLORATORY

While our method involving varying the surface friction parameters has been shown to capture certain features of the effects of turbines on the local wind using mesoscale models (Frandsen et al, 2006; Vermeer et al., 2003), the dependence of our results on the methods chosen to simulate wind turbine effects over land and ocean needs further validation.

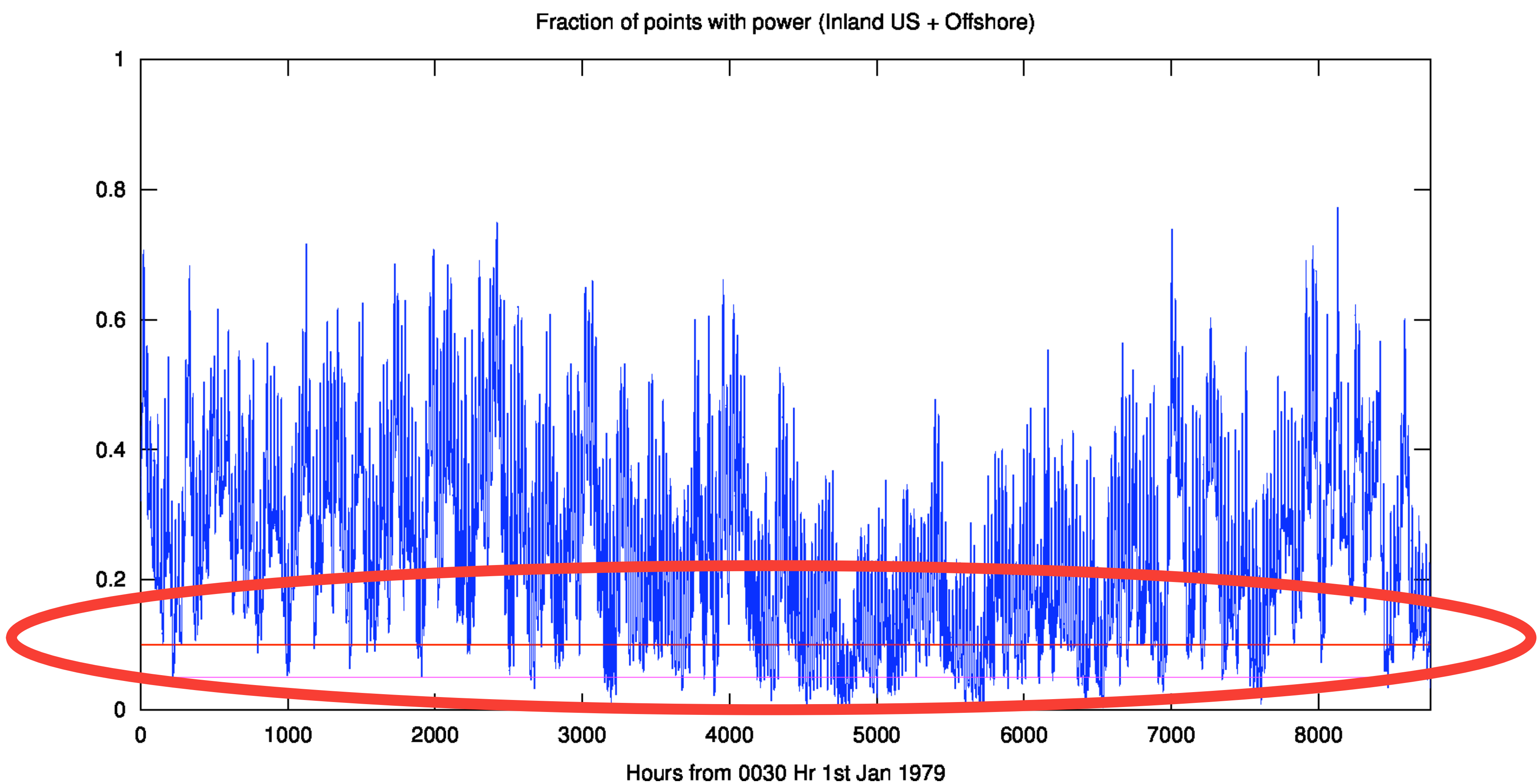
Also, the realism of the surface and atmospheric boundary layer physics in our chosen climate model needs careful scrutiny. Investigations with alternative models, including higher-resolution climate models with fully dynamical three-dimensional oceans are warranted.

Simultaneously, appropriate field experiments will need to be conducted to test and improve the accuracy of the parameterizations used in these models and to validate the conclusions drawn from modeling and theoretical studies.

INTERMITTENCY IN USABLE WIND RESOURCE

Fraction of grid-points with usable power. Continental USA + 100km Offshore for e.g. 1979 using NASA-MERRA meteorological reanalysis data. Fractions lowest in Summer. Oscillations largest in Winter. Red line denotes 10% and maroon line 5% of total area with usable power (>200 w/m^2 power density ~ > 5m/s at 80m).

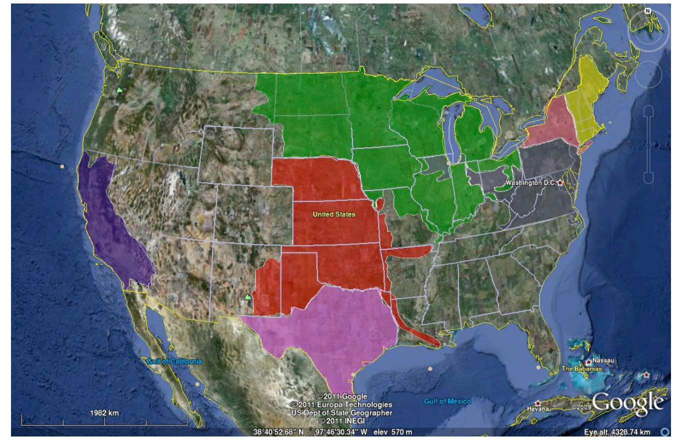
(Bhaskar & Schlosser, 2011)



INTERMITTENCY IN REGIONAL WIND RESOURCE

Seven Independent Service Operators. Percent of total hours per year with usable power output from less than 5% & 10% of region, and number of times power descends below the levels of 5% and 10% of the region having usable power.

(Bhaskar & Schlosser, 2011)

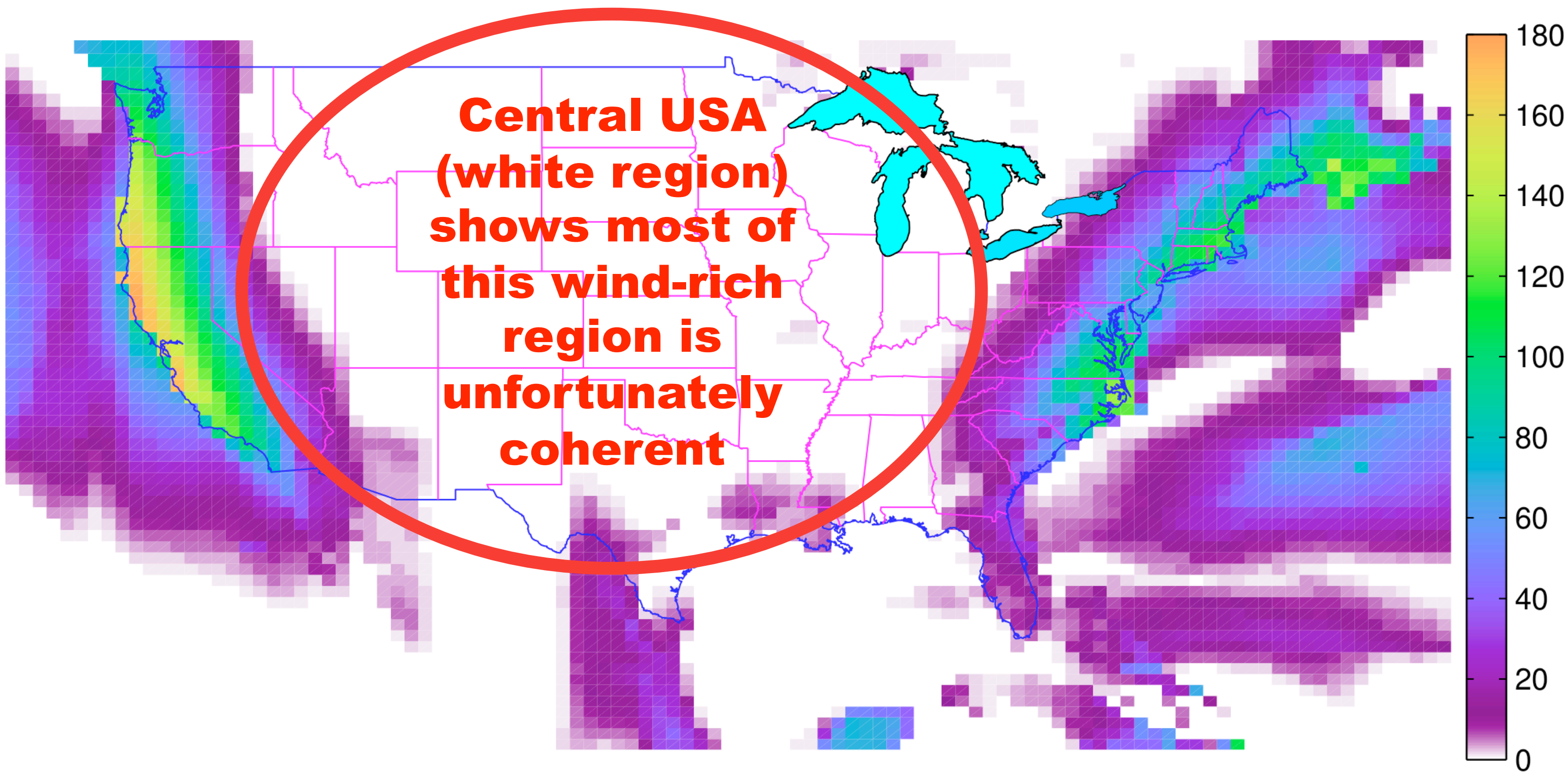


ISO	% of total hours/yr with power less than 5%	% of total hours/yr with power less than 10%	Level crossing rate 5%	Level crossing rate 10%
California	53	70	298	263
ERCOT	29	46	239	262
MISO	15	31	150	212
NEISO	56	71	198	161
NYISO	56	70	198	160
PJM	46	64	213	189
SWPP	17	32	180	238

COHERENCE IN INTERMITTENCY IN LOCAL WIND RESOURCE

For each grid point with no power, the number of grid points in the surrounding (1000 km x 1000 km) region having at least 50% power to help compensate.

(Bhaskar & Schlosser, 2011)



Wind is expected to be a significant part of the future energy mix, but at exactly what scale should depend on its reliability, cost and environmental impacts.

THANK YOU

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