Impact of Climate Change on Forecasting

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Also,

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The Climate System And Atmospheric Variability

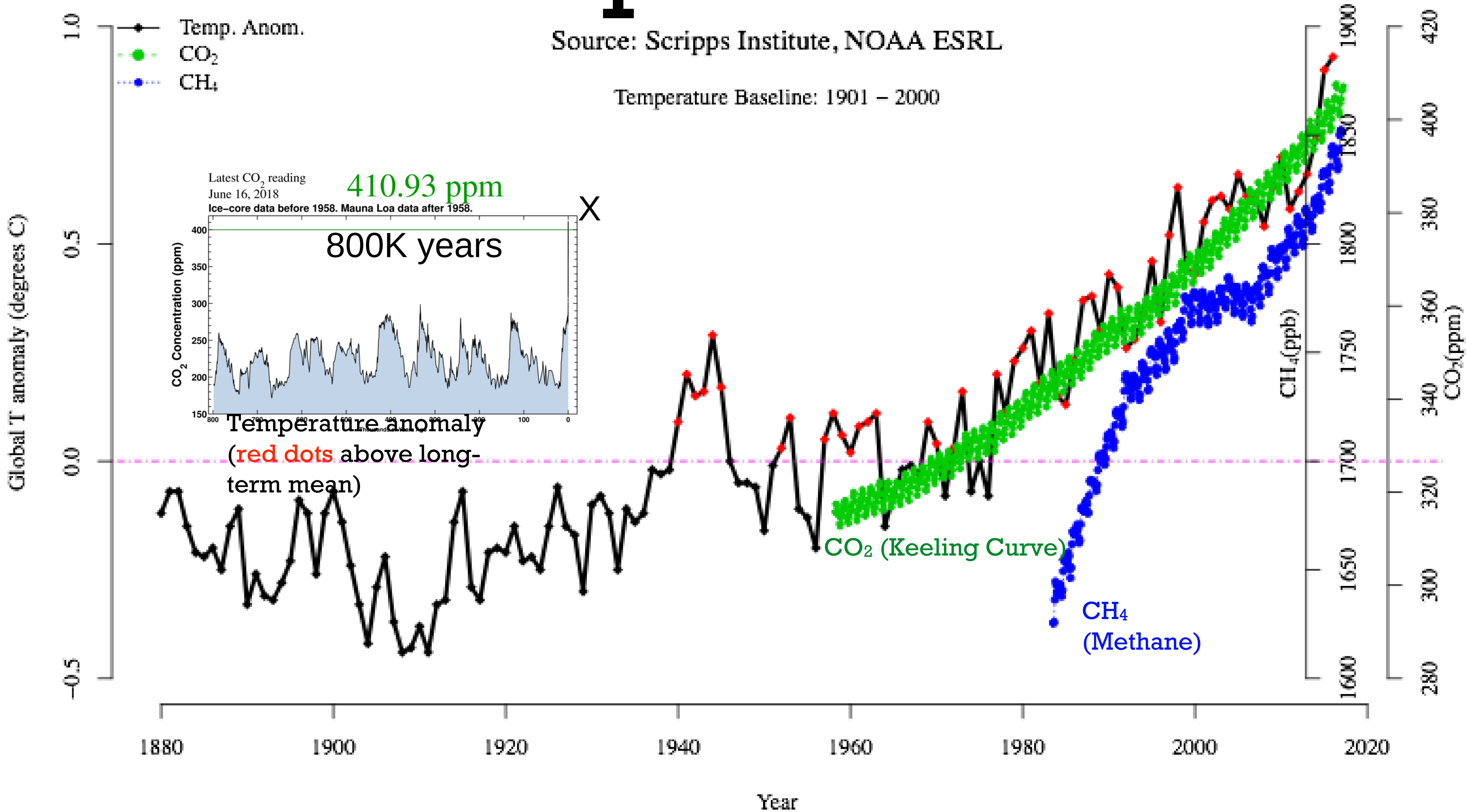
CLIMATE: "[t]he slowly varying aspects of the atmosphere-hydrosphere land surface system…characterized in suitable averages of the climate system over periods of a month or more…." (AMS Glossary 2000)

BUT: In a constantly perturbed climate system (increasing levels of H_2O [yup!], CO_2, CH_4, N_2O, etc.,→ global warming), variability becomes problematic.

ISSUE: How is resource assessment affected when you factor in trends (what makes a trend?), climate signals (teleconnections--do they interfere or re-enforce), and reference to long-term climate stations (what is a "representative" wind climatology?).

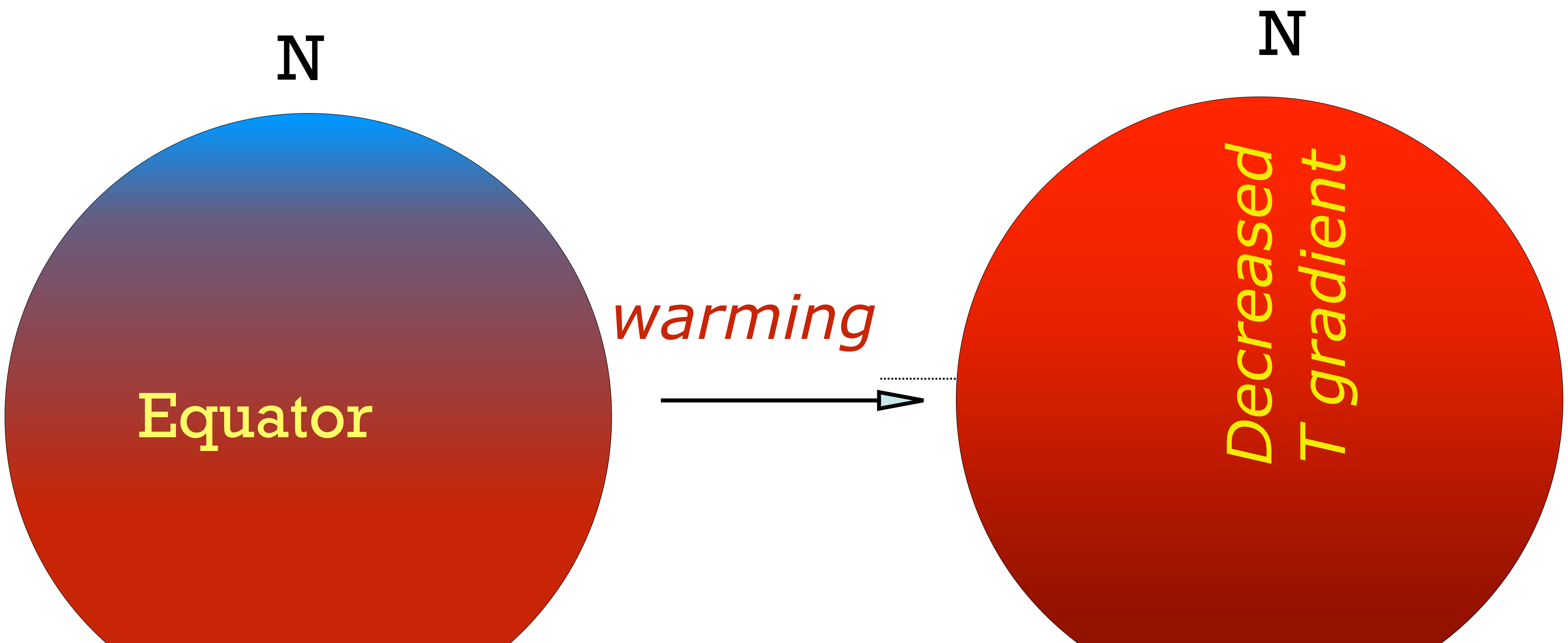
BIG QUESTION: How does atmospheric variability in all its flavors affect resource assessment ("hindcasts", e.g. Measure-Correlate-Predict) methodologies and prognostic forecasting? What are the weaknesses and caveats? What does "uncertainty" really mean?

Atmospheric State



Global Warming and Renewables

Hypothesis: leads to a reduction in the meridional thermal gradient (since higher latitudes experience greater warming) and hence the pressure gradient which affects local, regional, and synoptic-scale circulations.



Question: how will (are) these large scale changes affect(ing) the challenge of forecasting the wind, solar, and hydro power resources (not to mention load!)?

The Resource—Wind measurement requirements

At least one year of continuous measurements (at least 90% data recovery)

Wind speed/direction at multiple heights (U = Redundant sensors (primary, secondary—shadowing from tower)

$U = U_r(z/z_r)^{\alpha}$ (rarely $u_z = u^*/\kappa[\ln(z - d/z_0) + \Psi]$) so need to extrapolate

Usually cup anemometers, sometimes sonics (occasionally 3Ds)

SoDARs, LiDARs, increasingly used (towers usually only 60 m high—hub heights > 80 m; issue is $$$)

NEED A REPRESENTATIVE LONG-TERM CLIMATE STATION (Measure, Correlate, Predict—MCP)! BUT HOW DOES CLIMATE CHANGE FACTOR INTO THIS?

ISSUES: representativeness, tower height, uncertainty in speed/shear estimates: $U = U_0(Z/Z_0)^p$, **trends/climate change**, complex terrain ➠ terrain (accounting for stability), wake modeling

Industry practice[1]
Climate change as uncertainty

1. Related to the evaluation period (10- or 20-years) and inter-annual wind speed variability

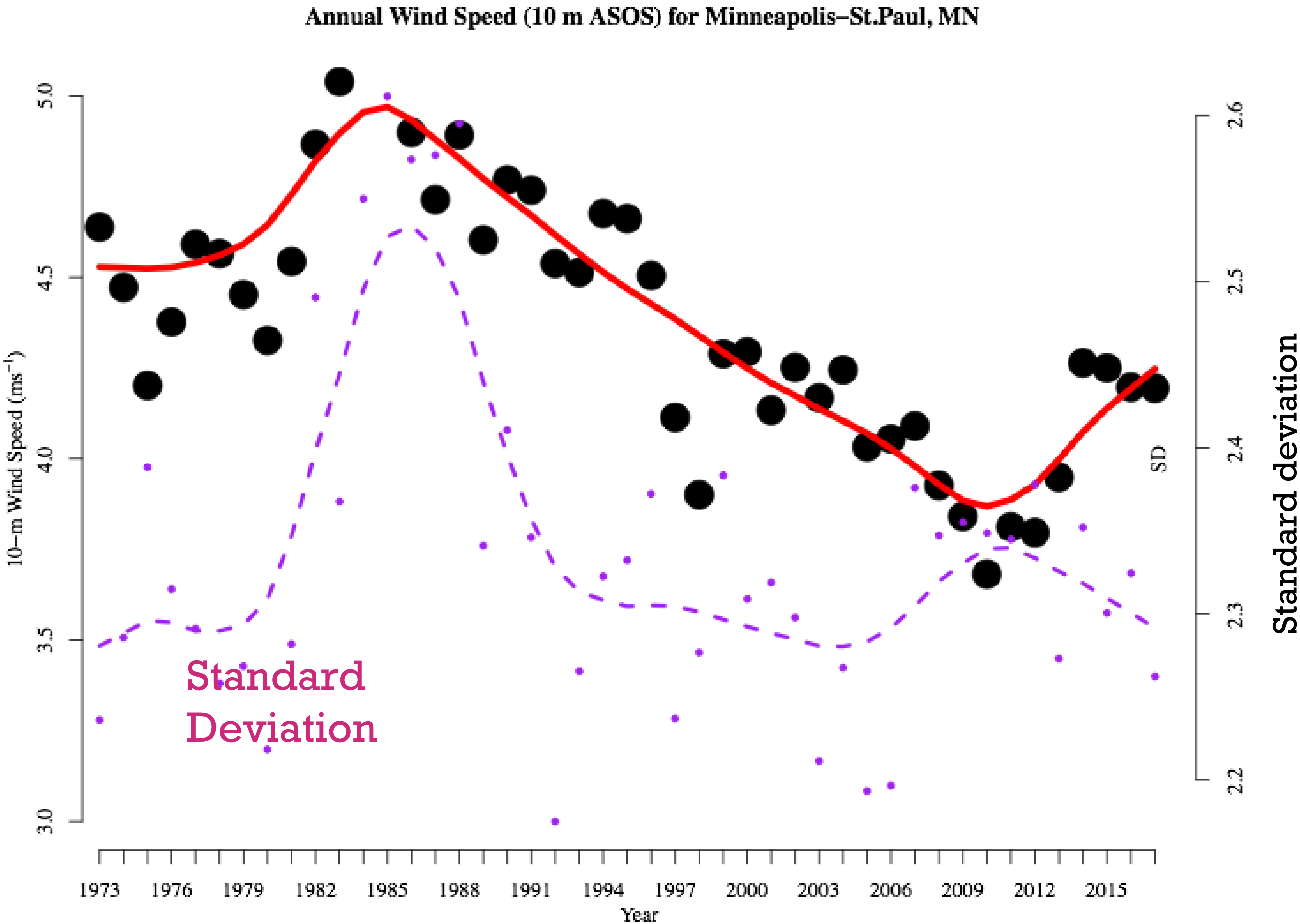
2. Address potential climate change

3. Based upon historical data: assume a 1% wind speed uncertainty due to potential climate change at the 10-year mark and 2% at 20 years (linear growth).

But this can be complicated by where long-term stations are sited! Such as….

1 Mike Markus (UL-Renewables), personal communication

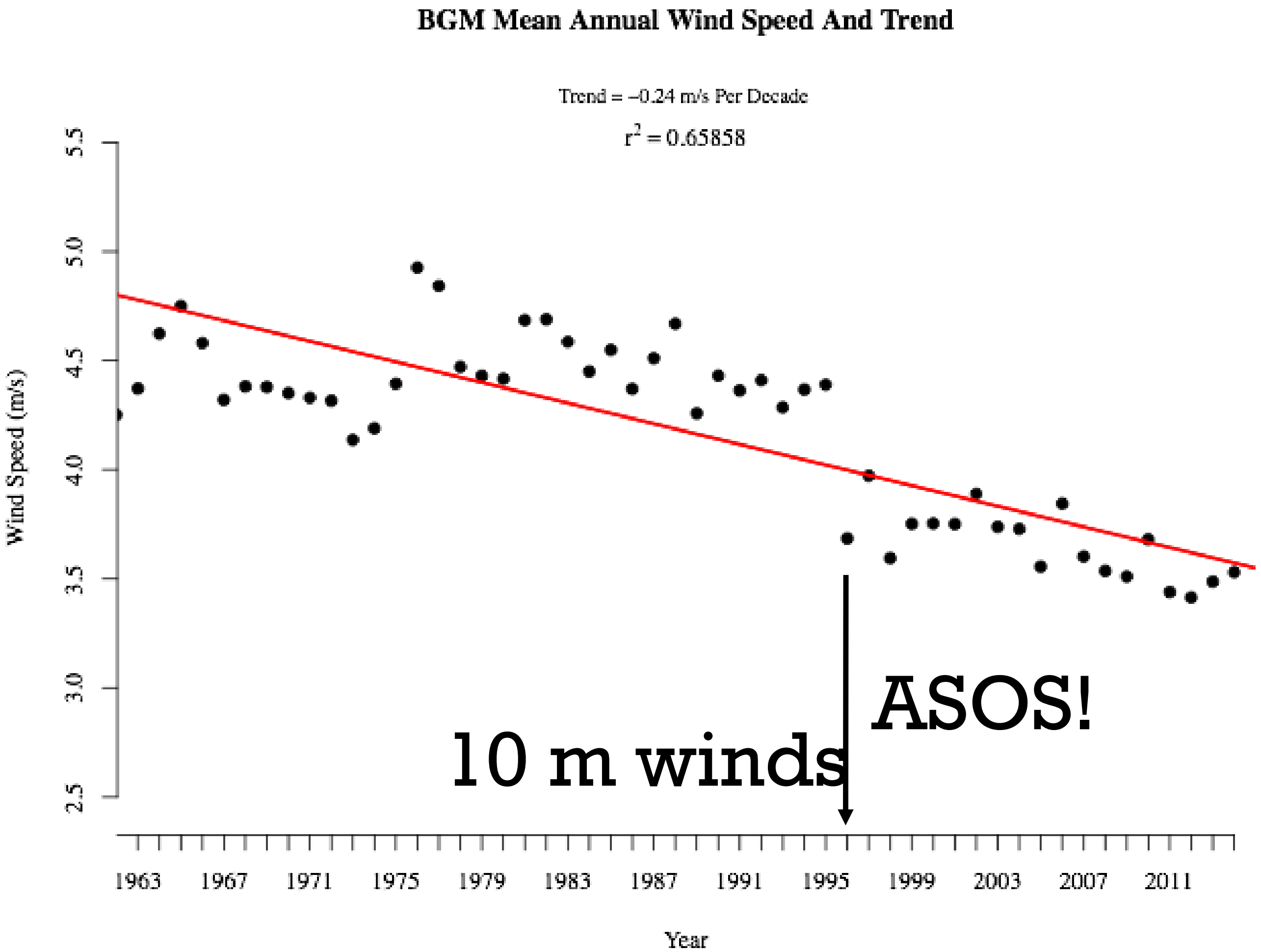
Trends(?)



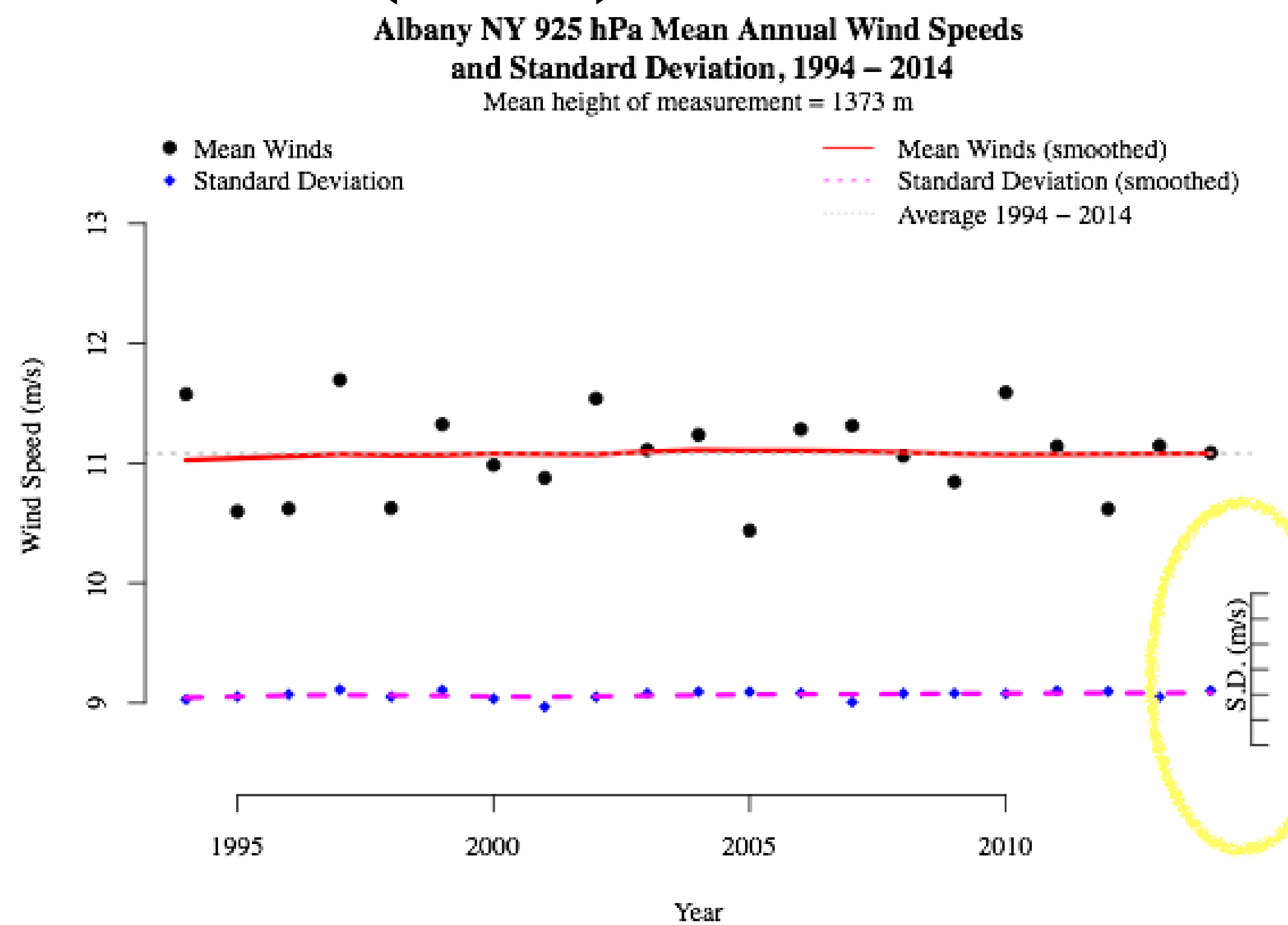
Annual Wind Speed (10 m ASOS) for Minneapolis–St.Paul, MN
10–m Wind Speed (ms⁻¹)
5.0
4.5
4.0
3.5
3.0
Year
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015
SD
2.6
2.5
2.4
2.3
2.2
Standard deviation
Standard
Deviation

Trends(?)

Binghamton NY Surface Winds 1963 - 2014



Albany NY (balloon soundings) Winds at 925 mb (700 m)1994 - 2014

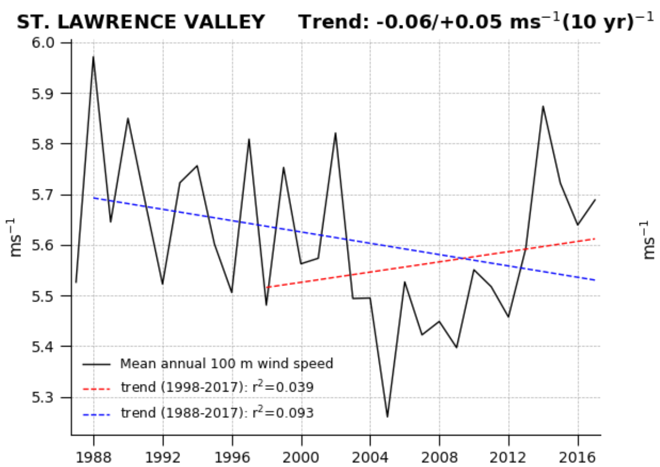


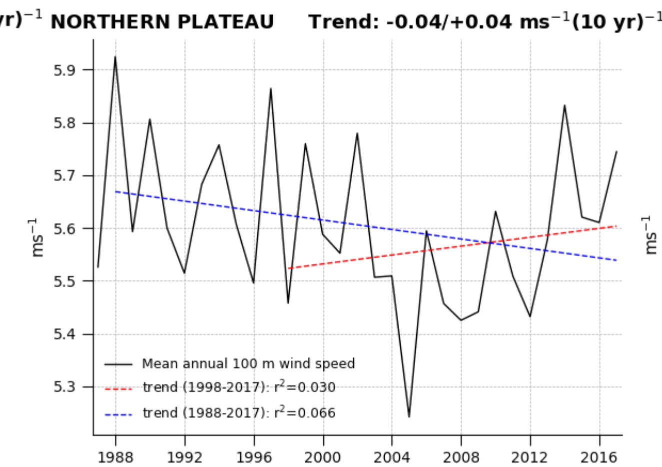
This is part of the challenge with working with historical datasets—

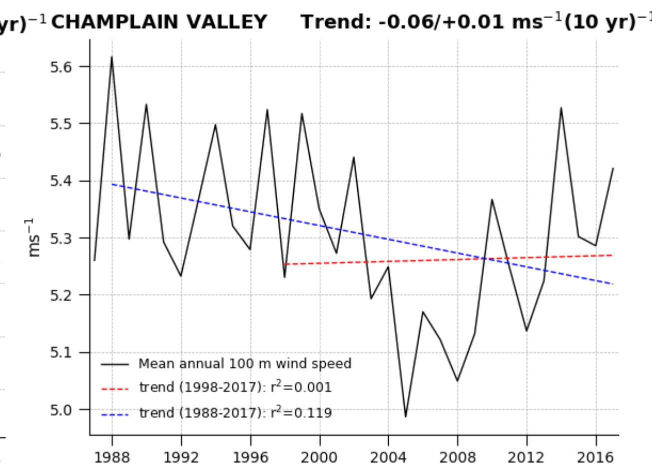
how do you know there really is a trend?

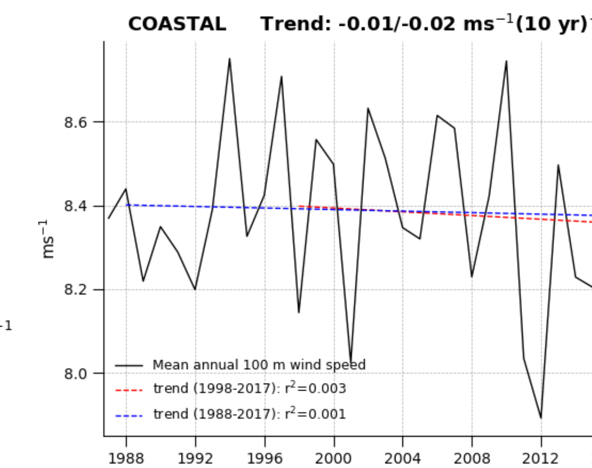
Wind (ERA-Interim) New York State

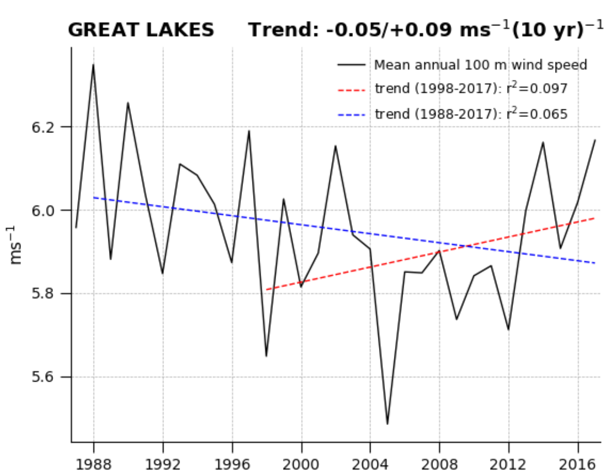
General downward trend, but no statistically significant trends in ERA-Interim data

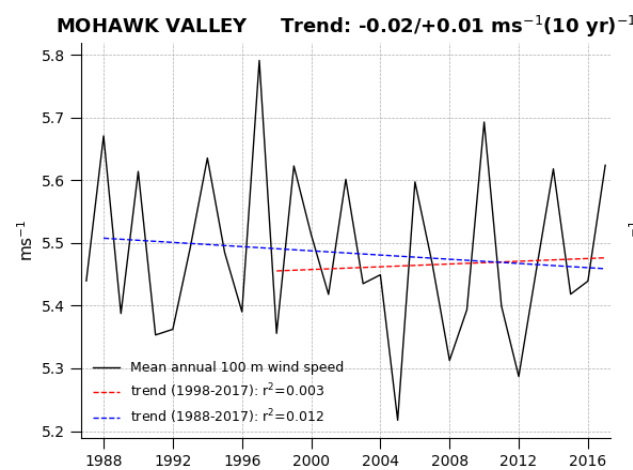


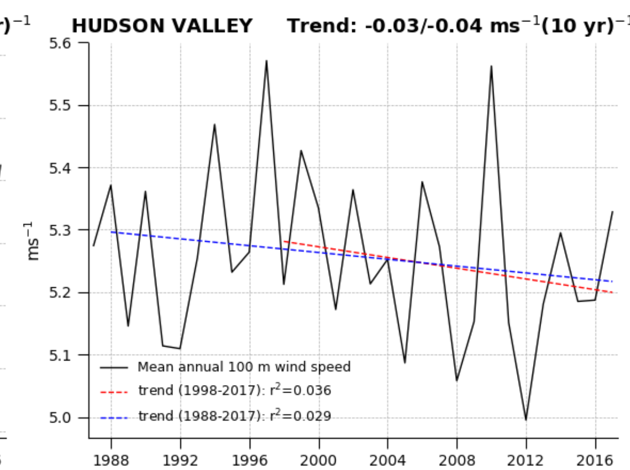


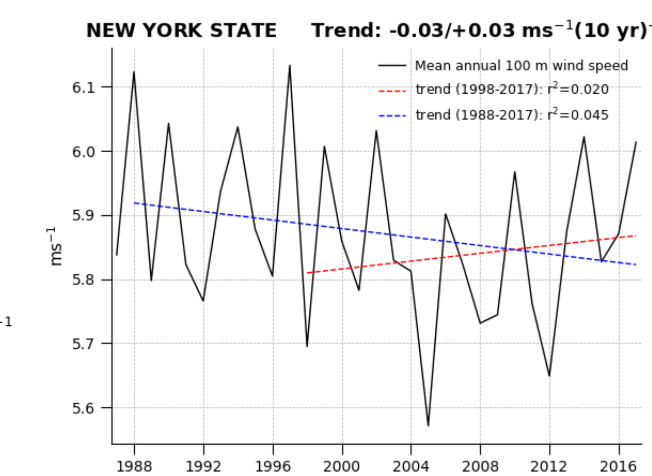


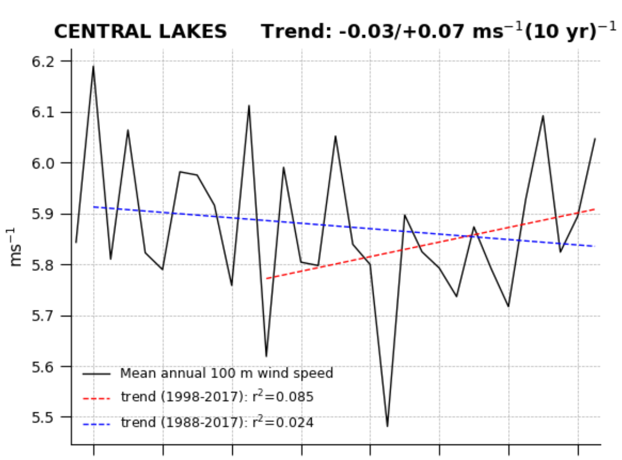


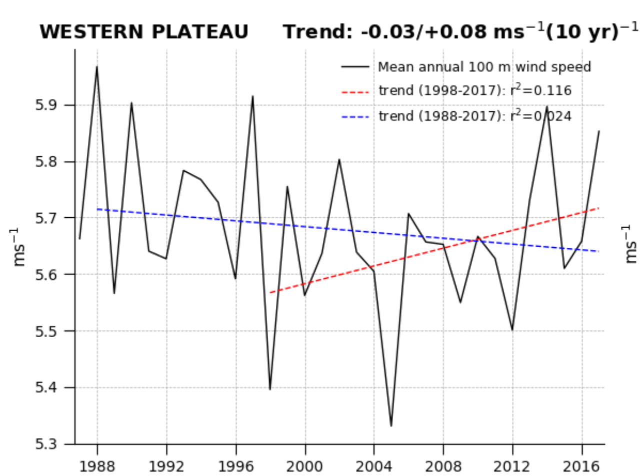


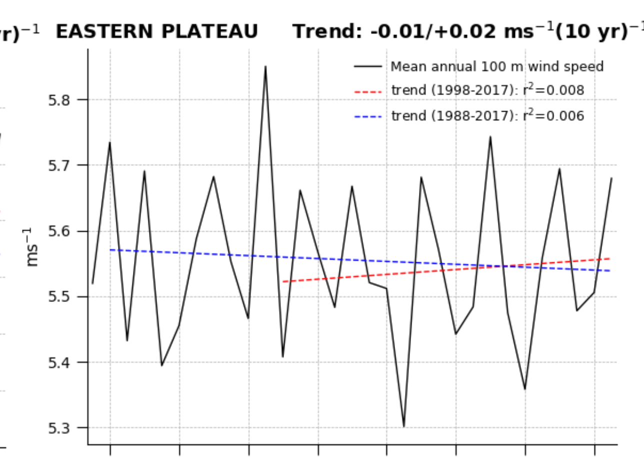








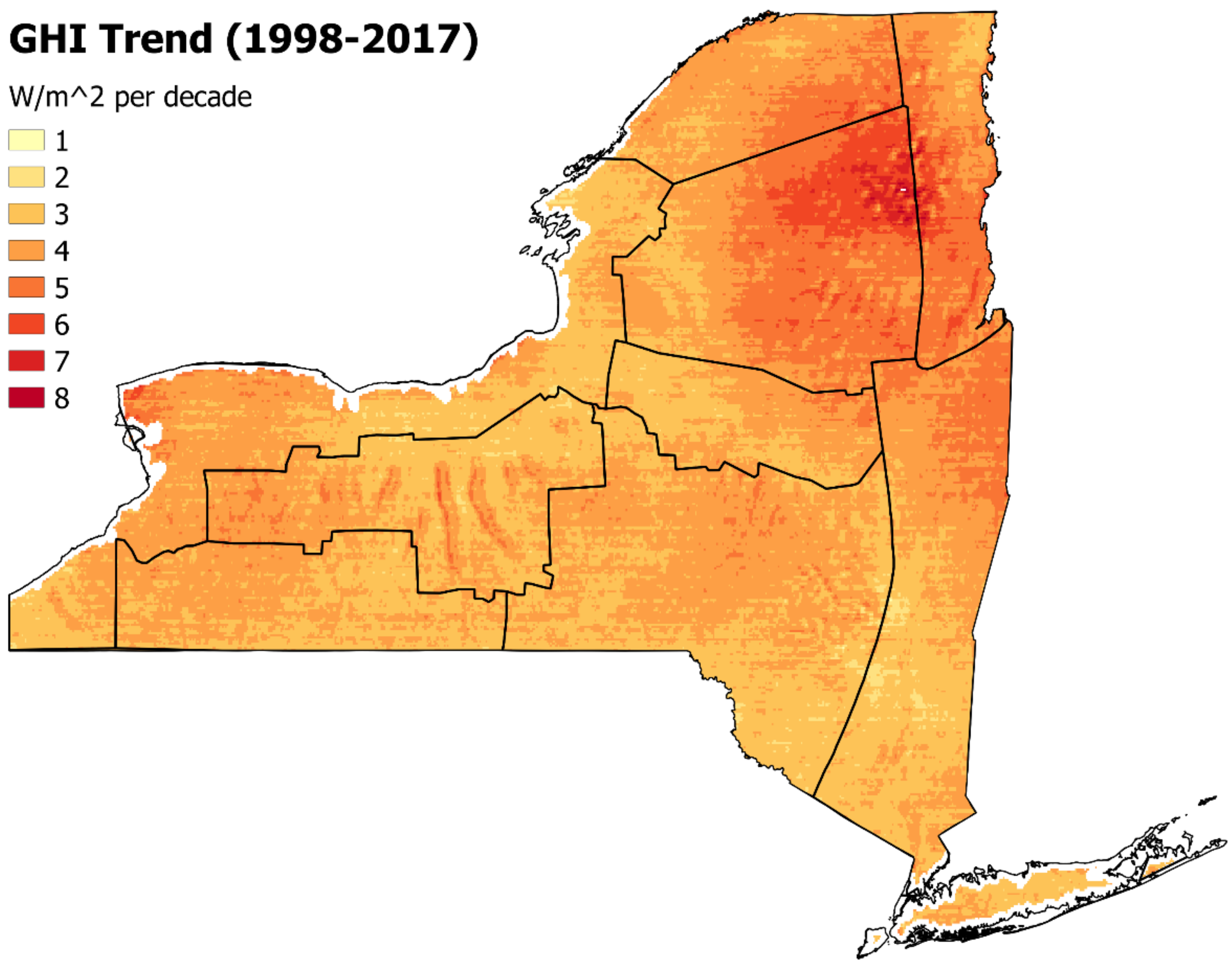




Jason Covert

Solar Radiation

+4.1% per decade state-wide



Only local (intra-climate division) statistical significance

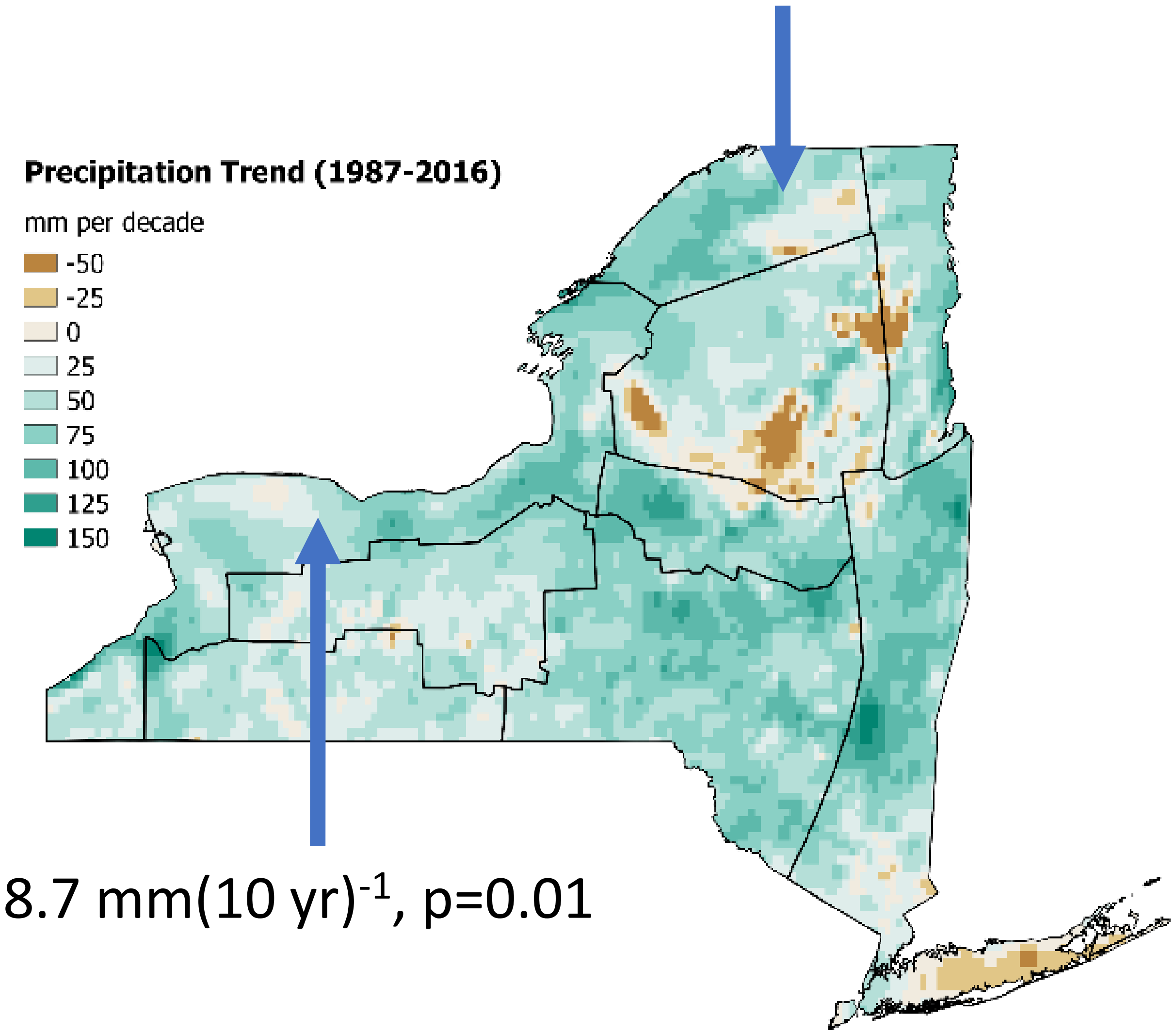
SolarAnywhere™ data

St. Lawrence Valley
Northern Plateau
Champlain Valley
Great Lakes
Mohawk Valley
Hudson Valley
Central Lakes
Western Plateau
Eastern Plateau

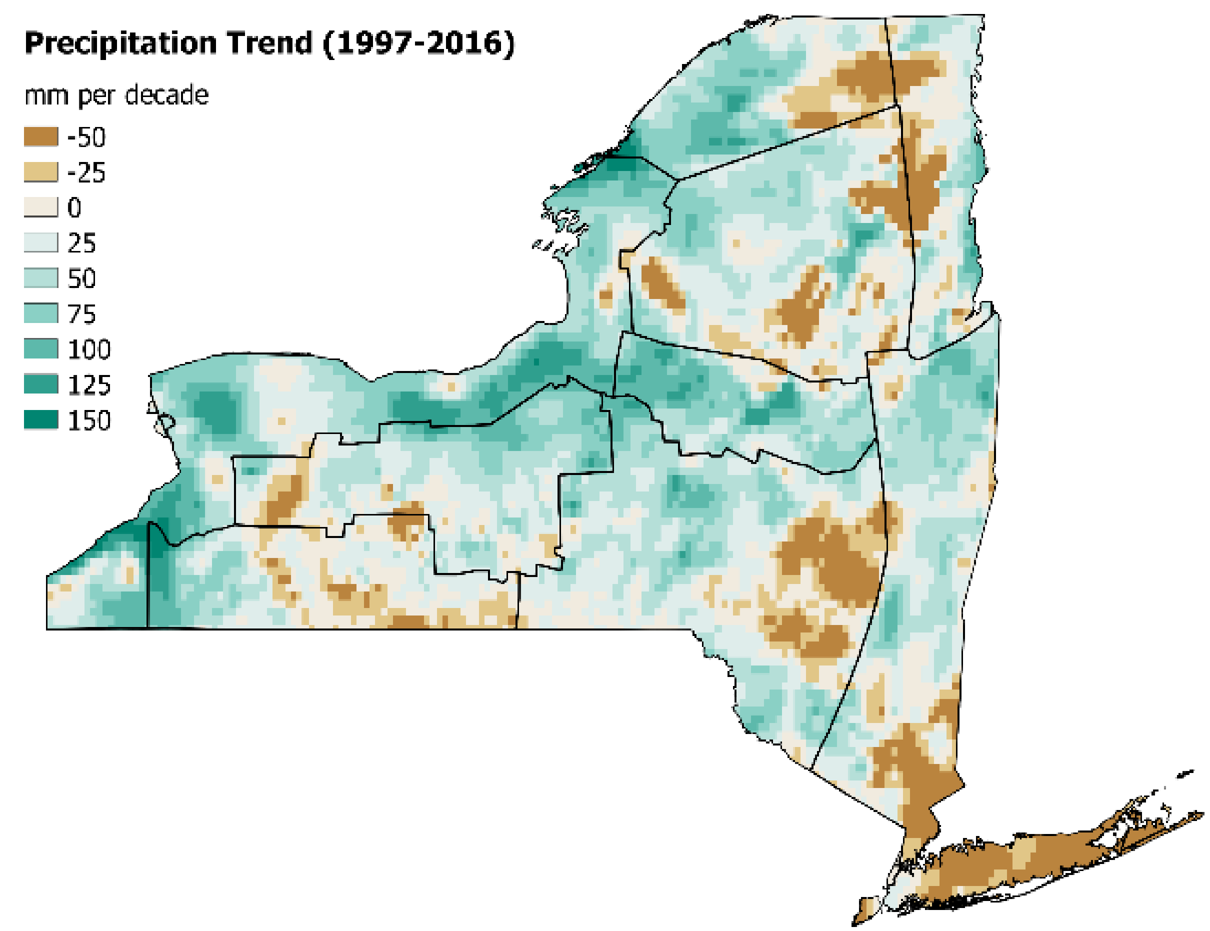
Precipitation

More localized extremes and trend reversals for 20 year trend

+59.2 mm$(10\ yr)^{-1}$, $p=0.03$



+58.7 mm$(10\ yr)^{-1}$, $p=0.01$



- Statistically significant 30-year trends in St. Lawrence Valley and Great Lakes region
- State wide trend of +43.0 mm$(10\ yr)^{-1}$, $p=0.18$

Future Climate?

Repr
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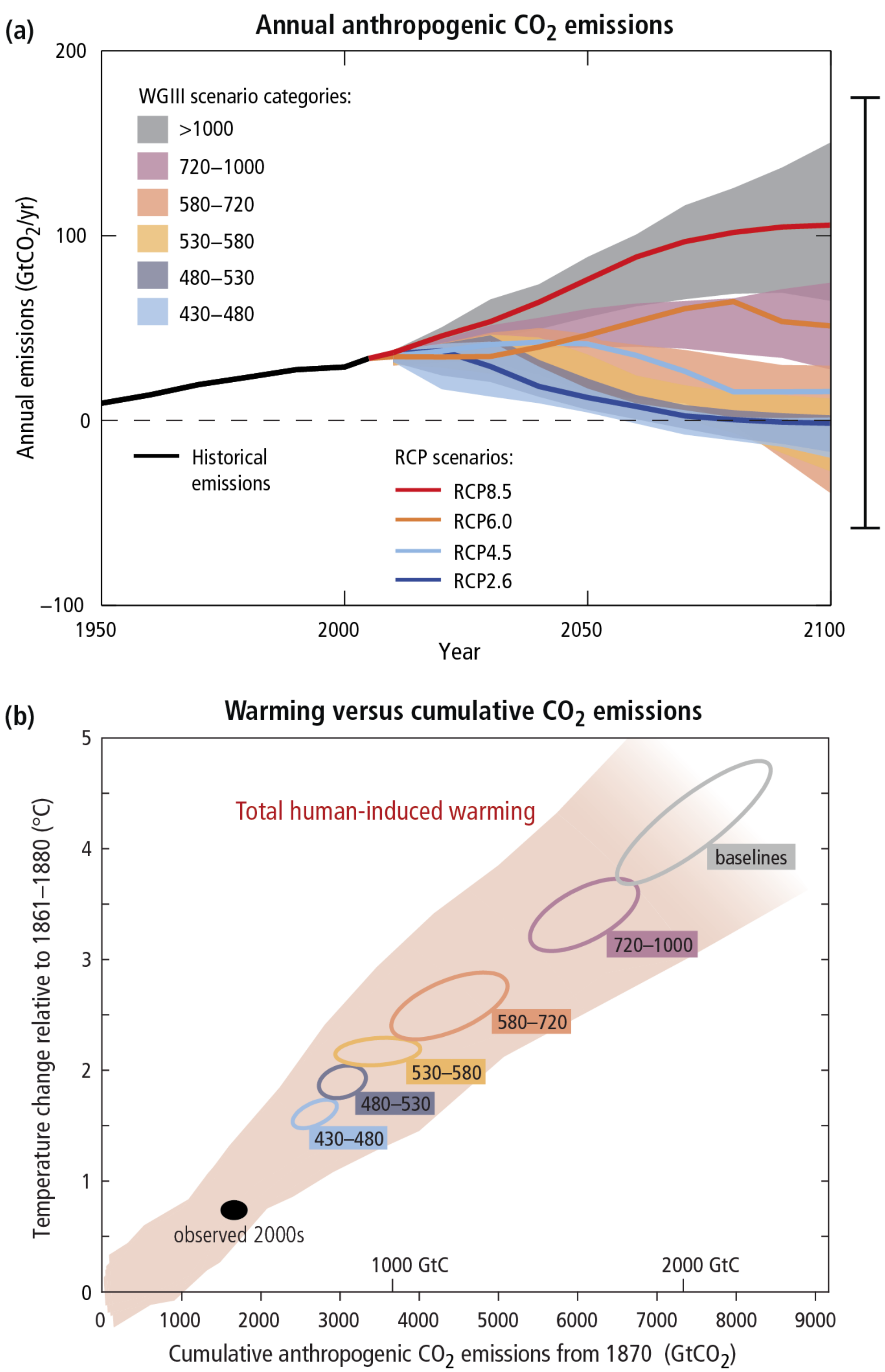
scen
CO2
reas
Look
give



RCP)
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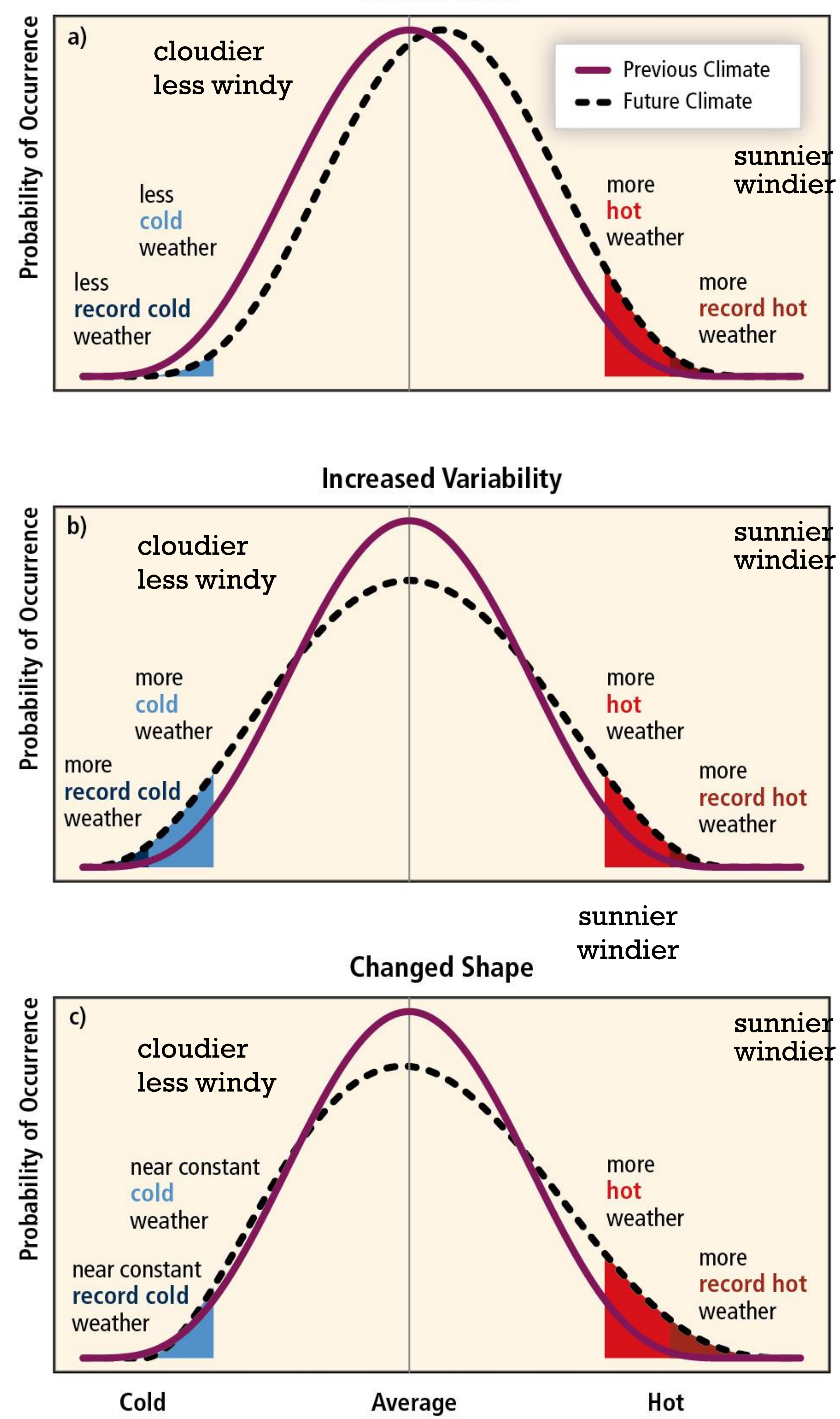
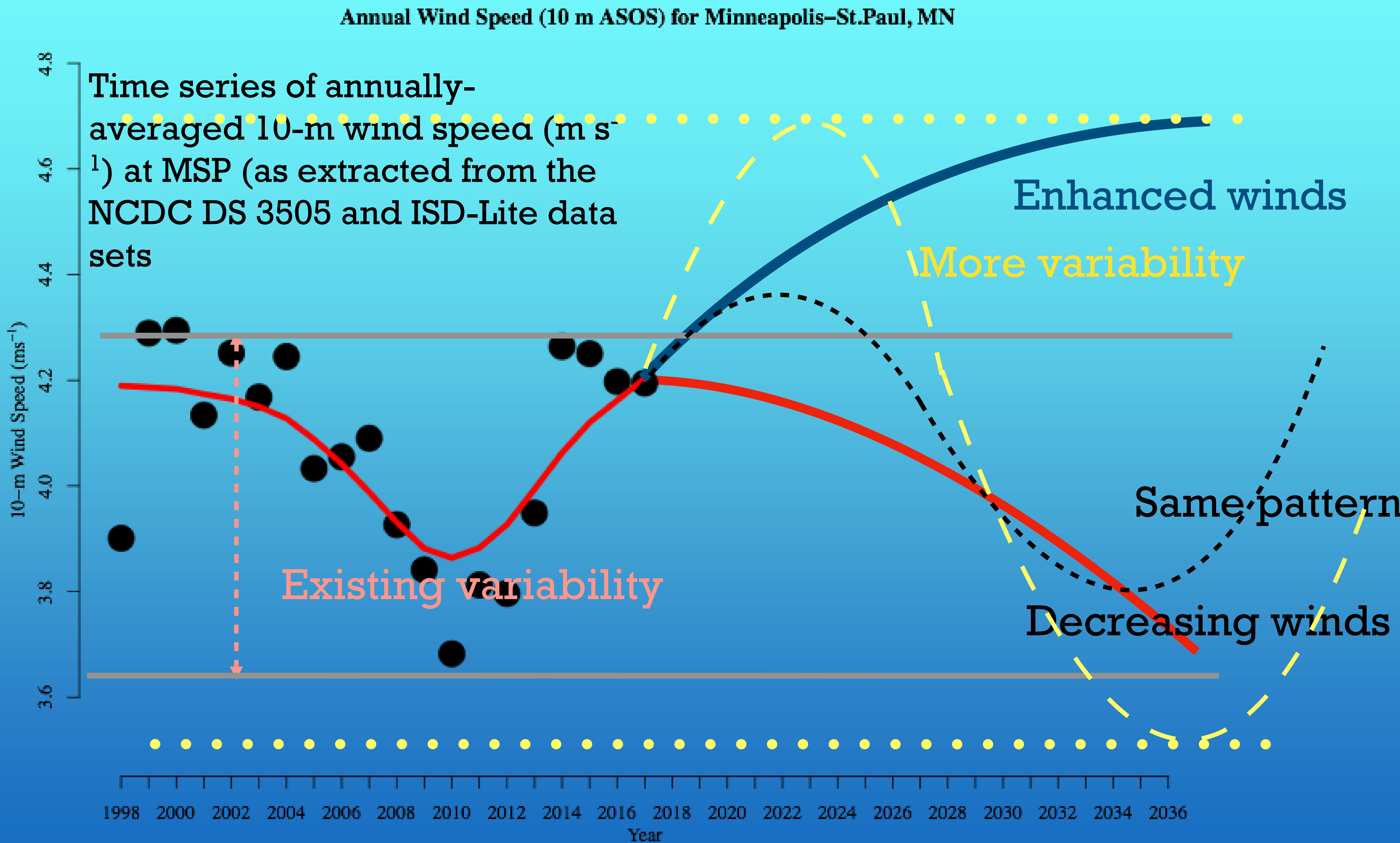


What’s next?


Annual Wind Speed (10 m ASOS) for Minneapolis–St.Paul, MN
Time series of annually-averaged 10-m wind speed (m s-1) at MSP (as extracted from the NCDC DS 3505 and ISD-Lite data sets
Enhanced winds
More variability
Same pattern
Decreasing winds
Existing variability
10–m Wind Speed (ms−1)
3.6
3.8
4.0
4.2
4.4
4.6
4.8
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
Year

A Global Look at Future Trends in the Renewable Energy Resource

Shengzhe Chen and Jeffrey M. Freedman, Atmospheric Sciences Research Center State University of New York at Albany
Daniel B Kirk-Davidoff and Michael Brower, UL-AWS Truepower

Sponsors
UL- AWS Truepower
University at Albany Center of Excellence in Atmospheric Sciences

CMIP5 Members

Climate Model Inter-comparison Project

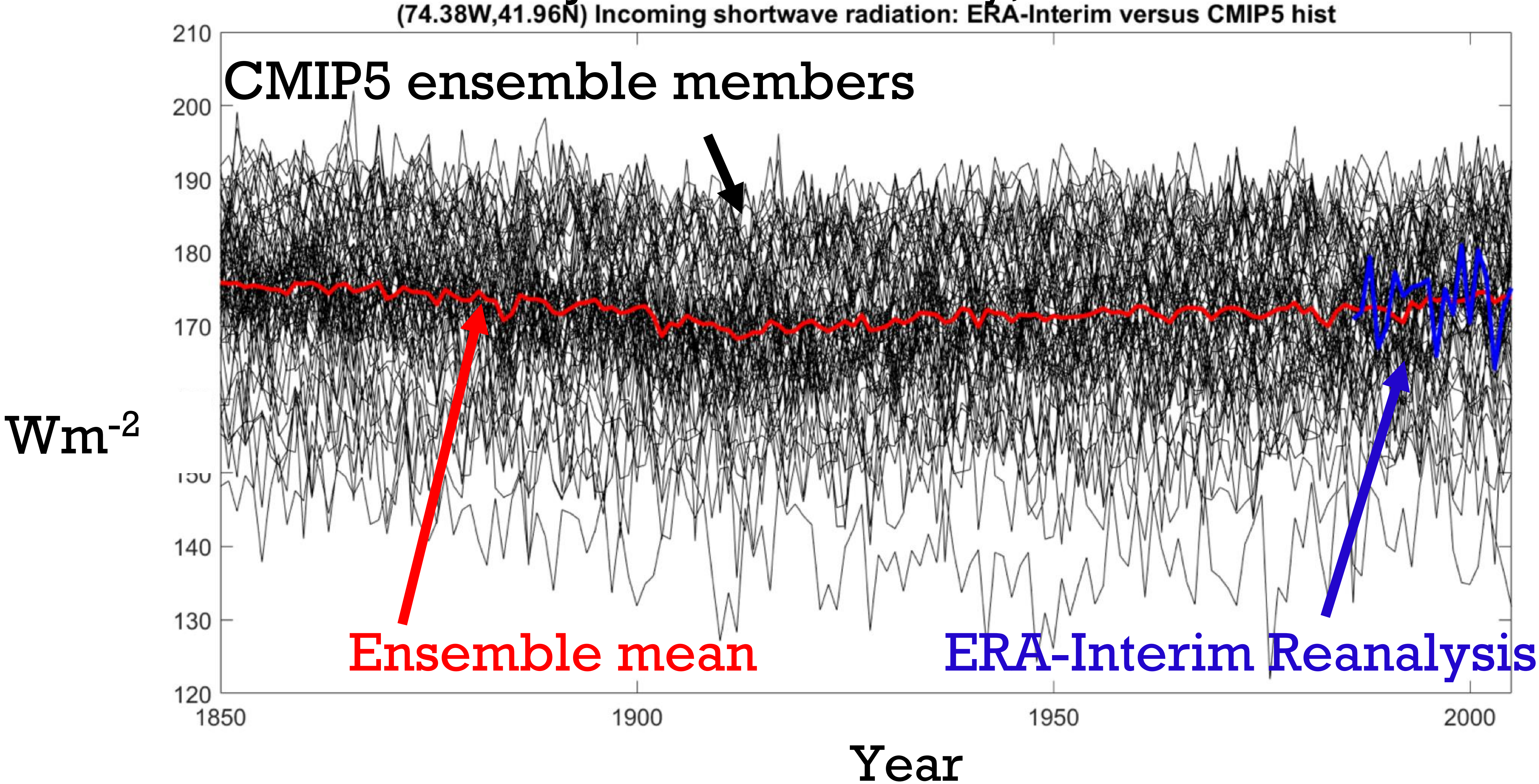
The Members (40 here)—monthly output (but not all have 10 m winds!)

ACCESS1-0	CESM1-CAM5	EC-EARTH	GISS-E2-R	IPSL-CM5B-LR
ACCESS1-3	CESM1-CAM5-1-FV2	FGOALS-g2	GISS-E2-R-CC	MIROC5
bcc-csm1-1	CESM1-WACCM	FIO-ESM	HadGEM2-AO	MIROC-ESM
bcc-csm1-1-m	CMCC-CESM	GFDL-CM3	HadGEM2-CC	MIROC-ESM-CHEM
BNU-ESM	CMCC-CM	GFDL-ESM2G	HadGEM2-ES	MPI-ESM-LR
CanESM2	CMCC-CMS	GFDL-ESM2M	inmcm4	MPI-ESM-MR
CCSM4	CNRM-CM5	GISS-E2-H	IPSL-CM5A-LR	MRI-CGCM3
CESM1-BGC	CSIRO-Mk3-6-0	GISS-E2-H-CC	IPSL-CM5A-MR	NorESM1-M

Two scenarios: Representative Concentration Pathways 4.5 and 8.5

Make sense out of this…

"Historical": Just south of Albany, NY

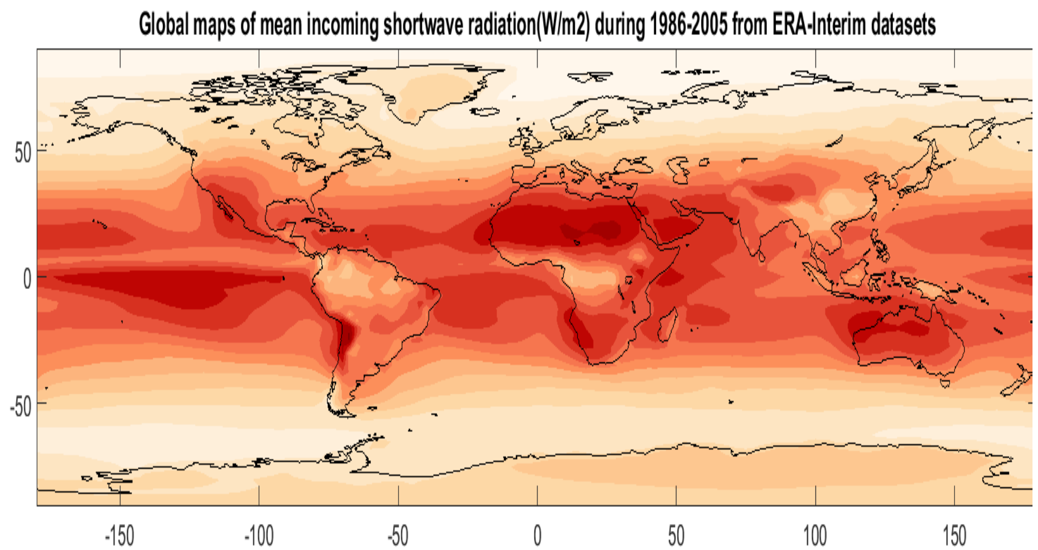


Need to deal with large ensemble spread

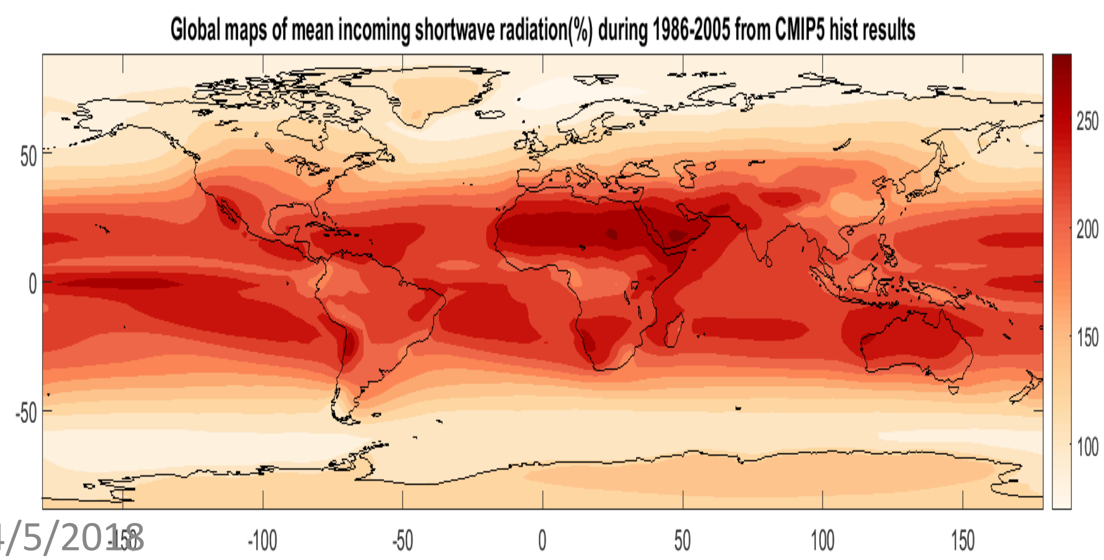
Note that fewer members available for wind (23) versus irradiance, precipitation (40)

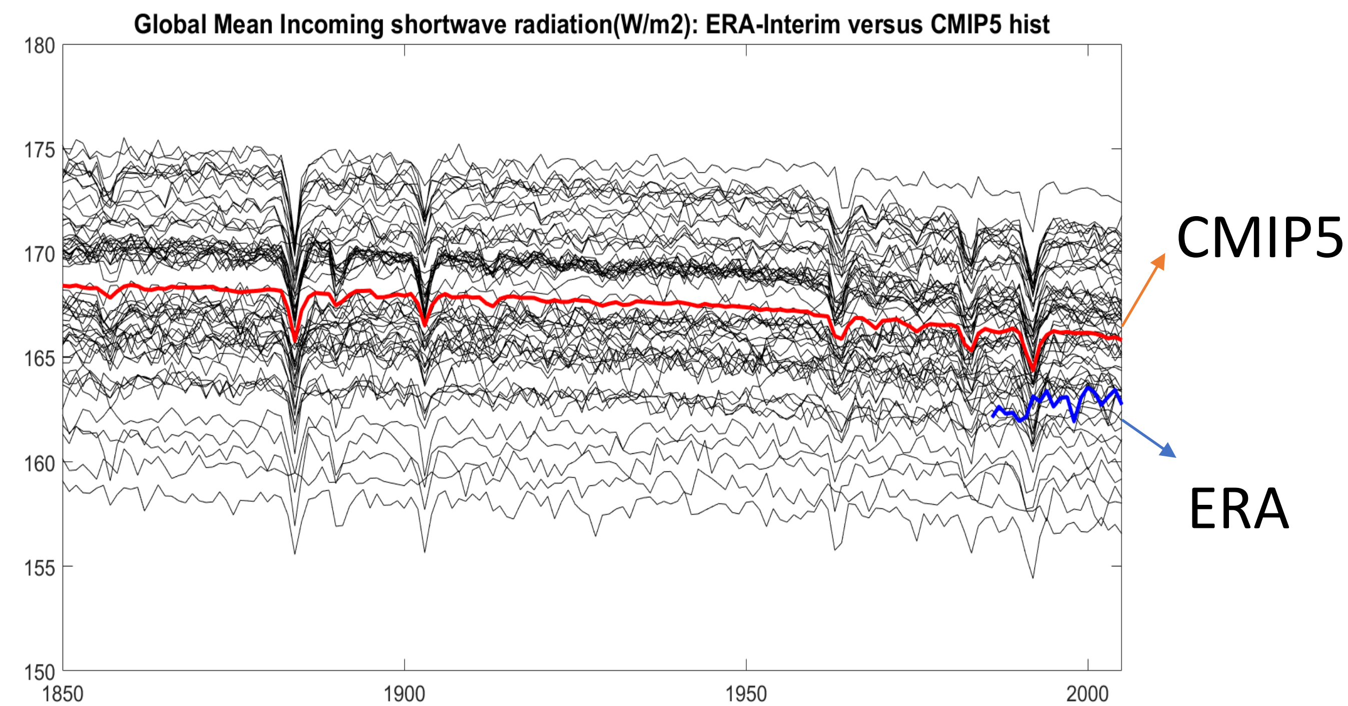
ERA vs CMIP5 (1986-2005)
Solar Irradiance

ERA



CMIP5



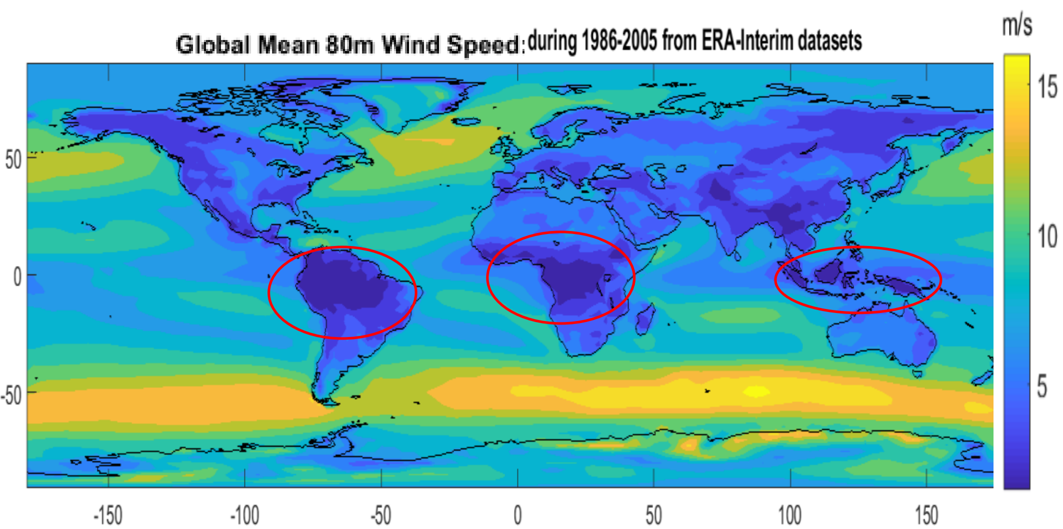


- ➢ No significant trends during 1986-2005 CMIP5 historical simulations.
- ➢ CMIP5 ensemble means tends to overestimate the global mean solar irradiance.

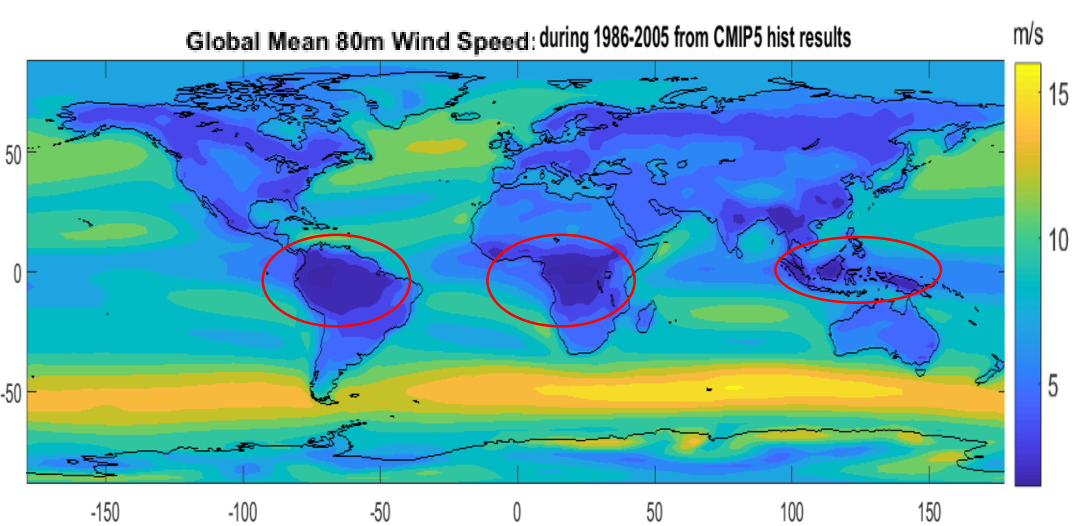
- ➢ Spatial patterns of historical CMIP5 ensemble mean correspond well with ERA-Interim means.

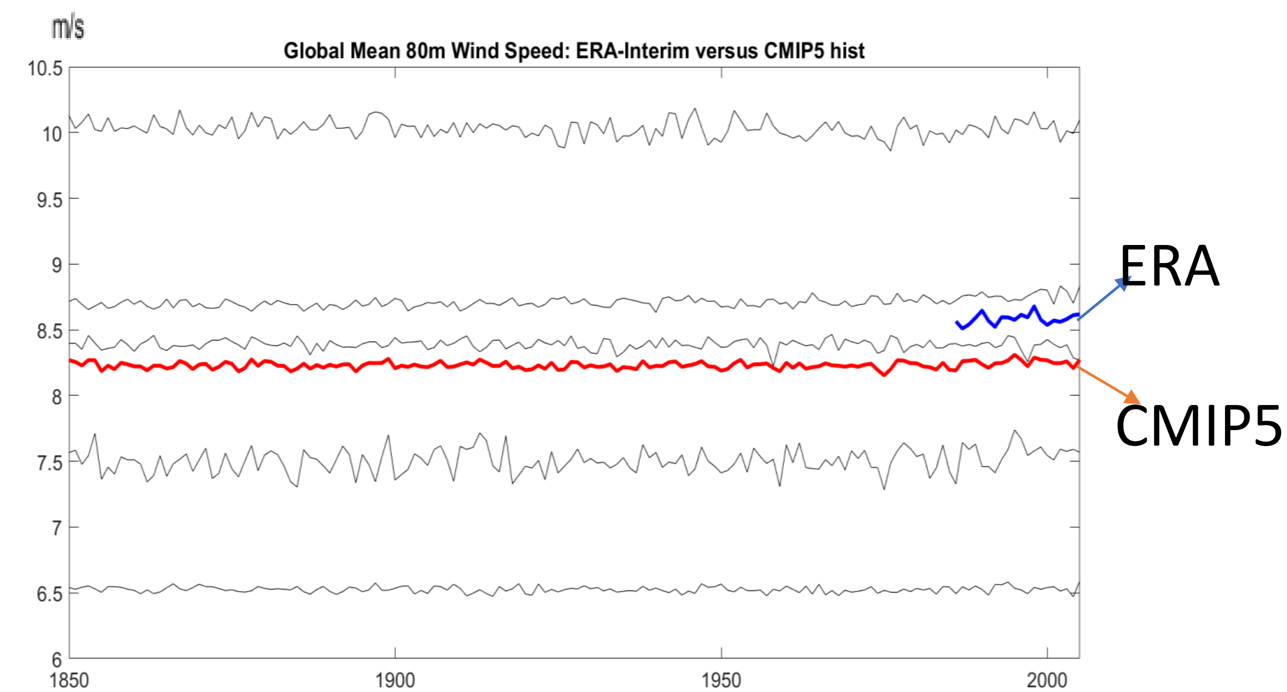
ERA vs CMIP5 (1986-2005): Wind

ERA



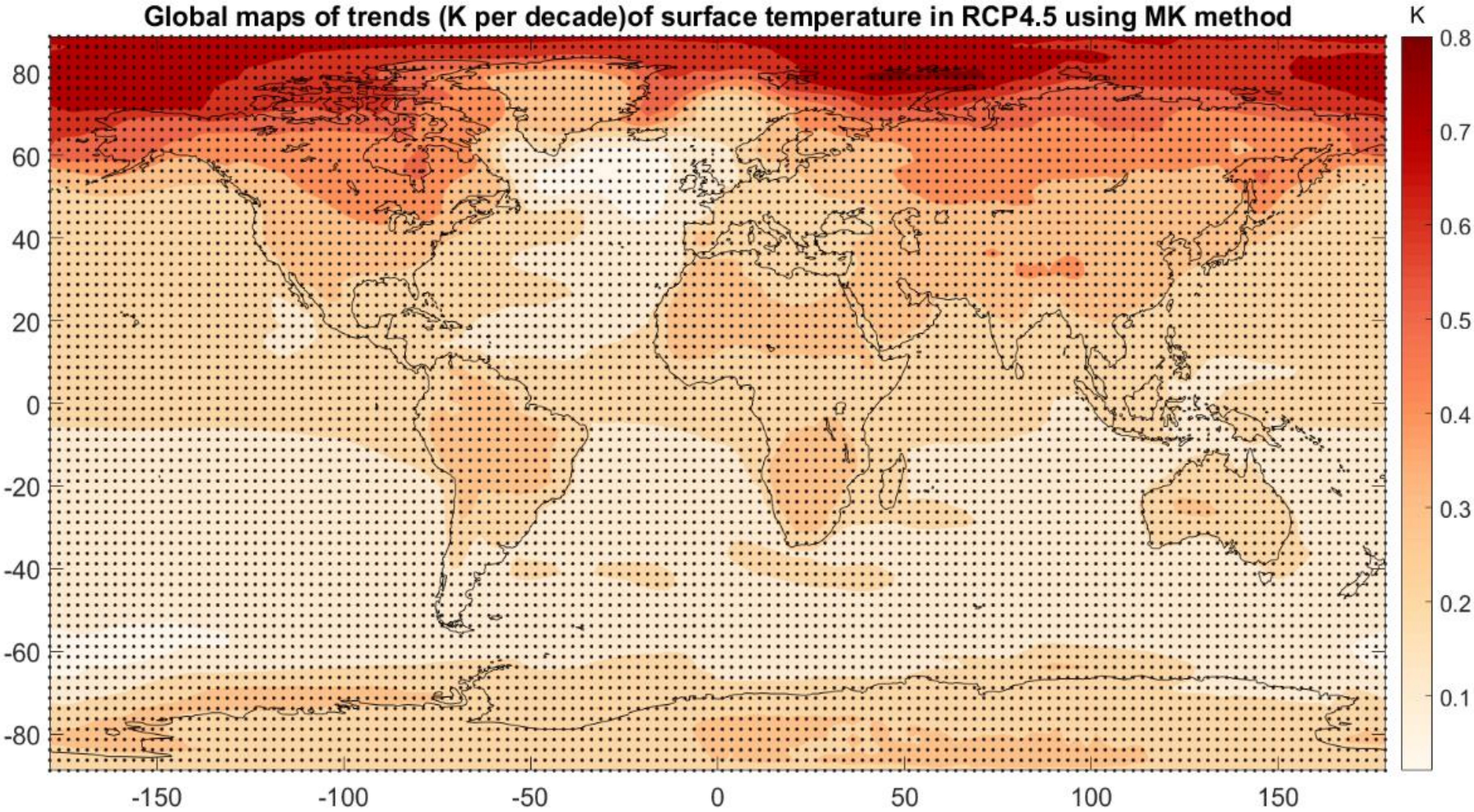
CMIP5





- ➢ No significant trends during 1986-2005
- ➢ As with solar irradiance, good spatial correspondence between ERA and CMIP5 ensemble mean.

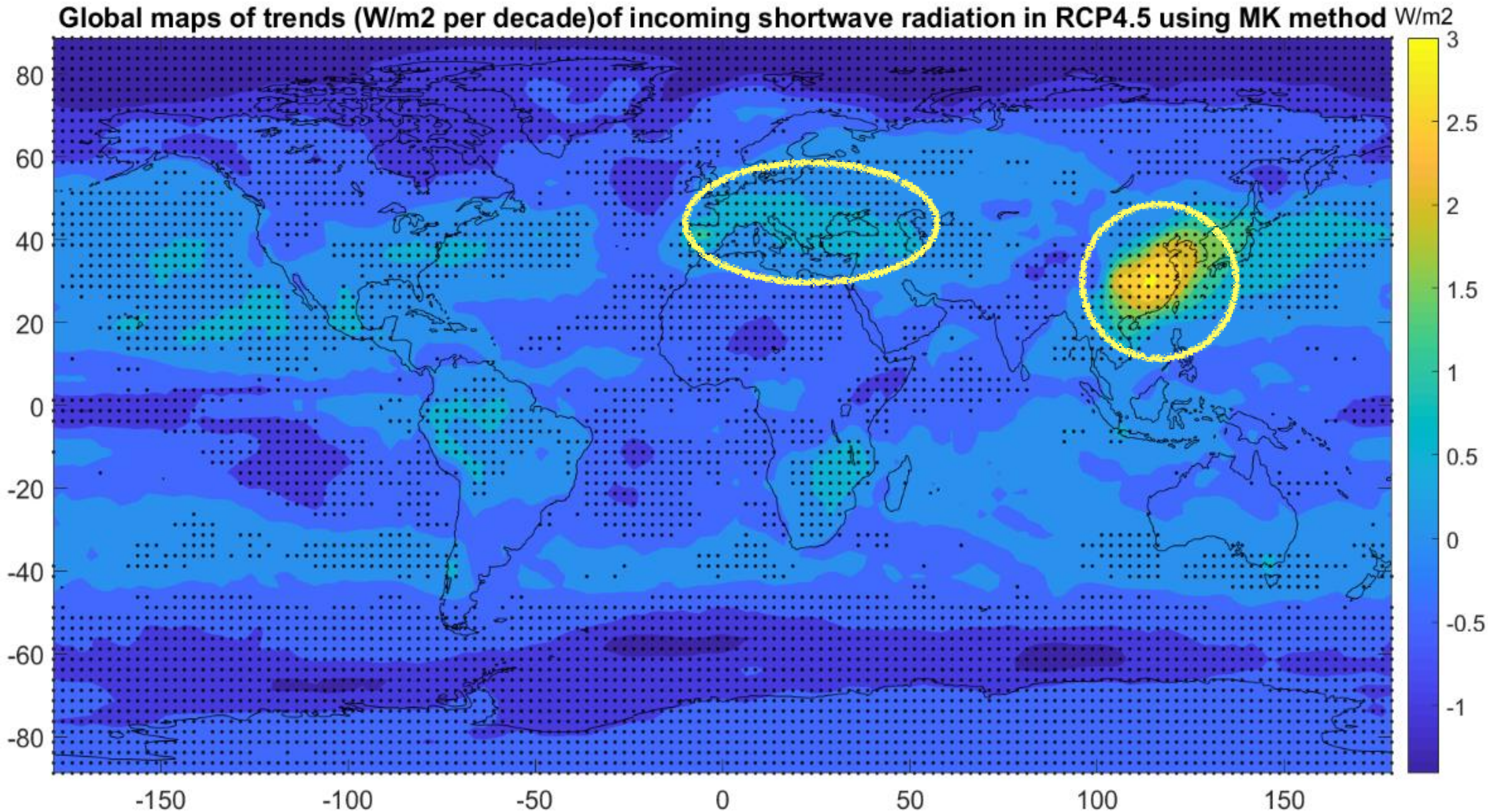
Global (Ensemble Mean) Trends Temperature (RCP 4.5)



degree K decade^{-1}

Stippled areas indicate significant according to Mann-Kendall (Kendall 1938; Mann 1945) test—gets warmer everywhere—largest trend in Arctic (no surprises here)—affects load forecasting for sure!

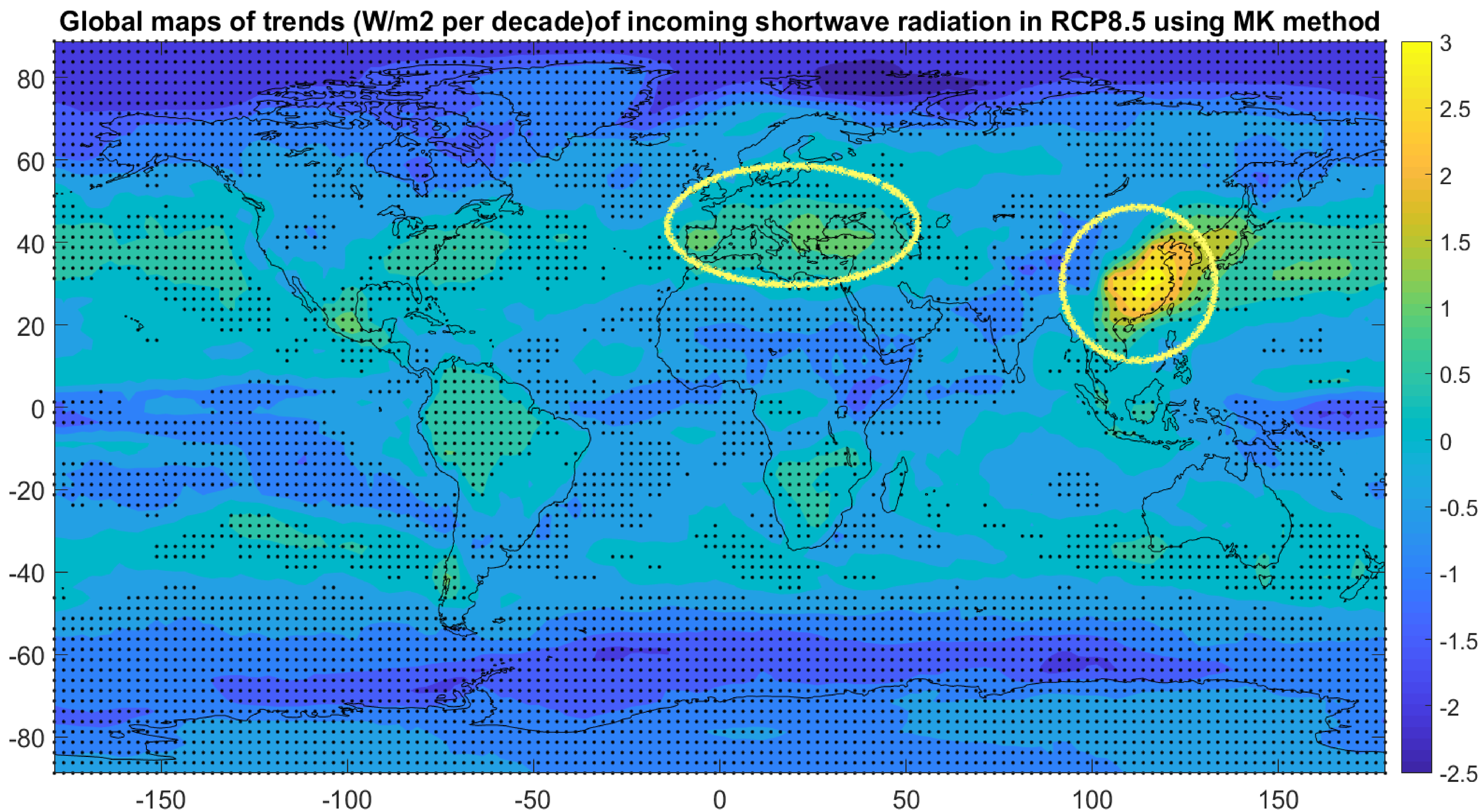
Global Trends Surface Irradiance 2020 - 2050 (RCP 4.5)



W m^{-1} $decade^{-1}$

Consequence of cleaner air?—note east Asia: aerosols!!!!

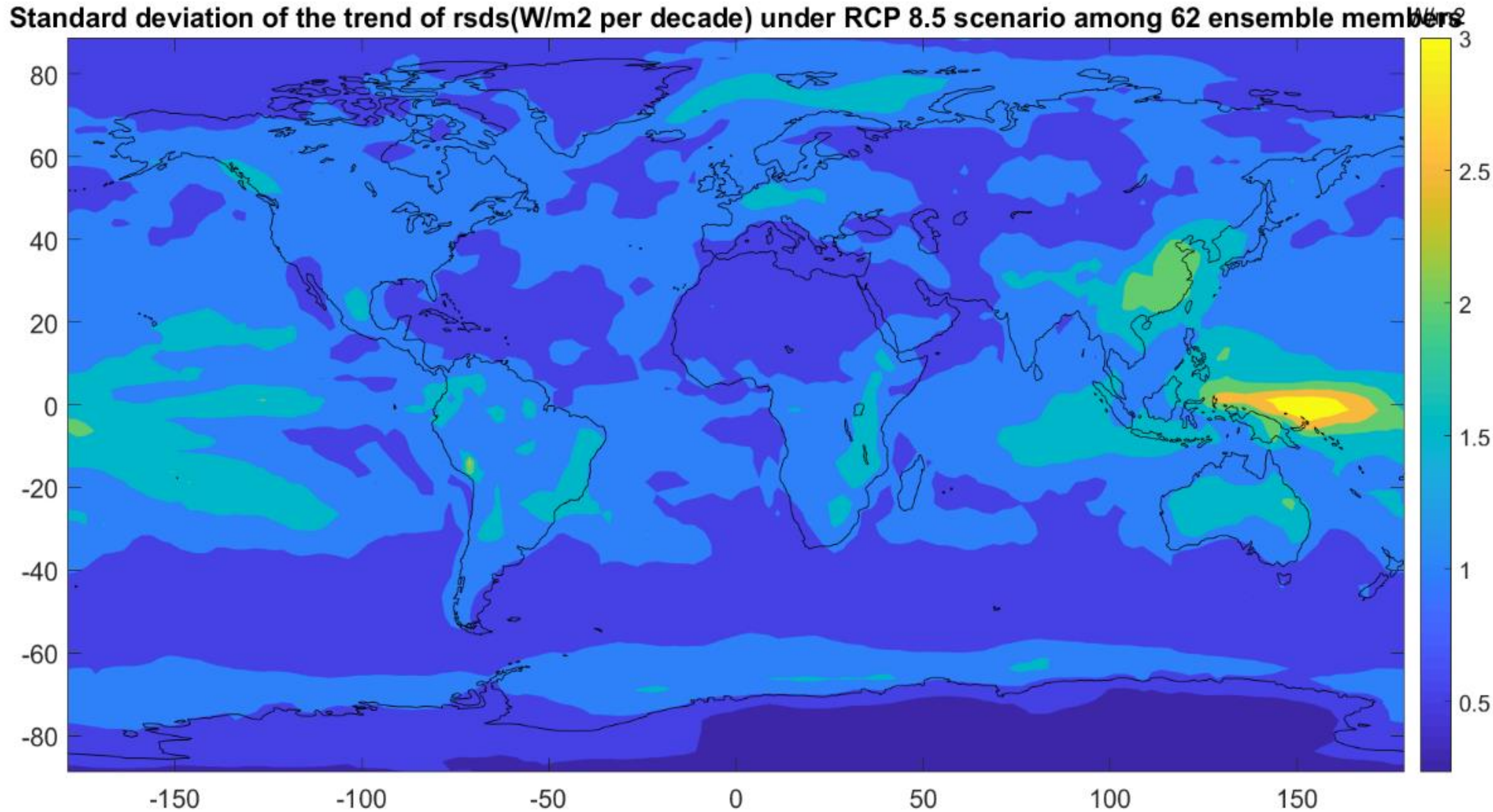
Global Trends Surface Irradiance 2020 - 2050 (RCP 8.5)



W m^{-1} $decade^{-1}$

Larger changes in general, slight increases where aerosols decrease (east Asia!)

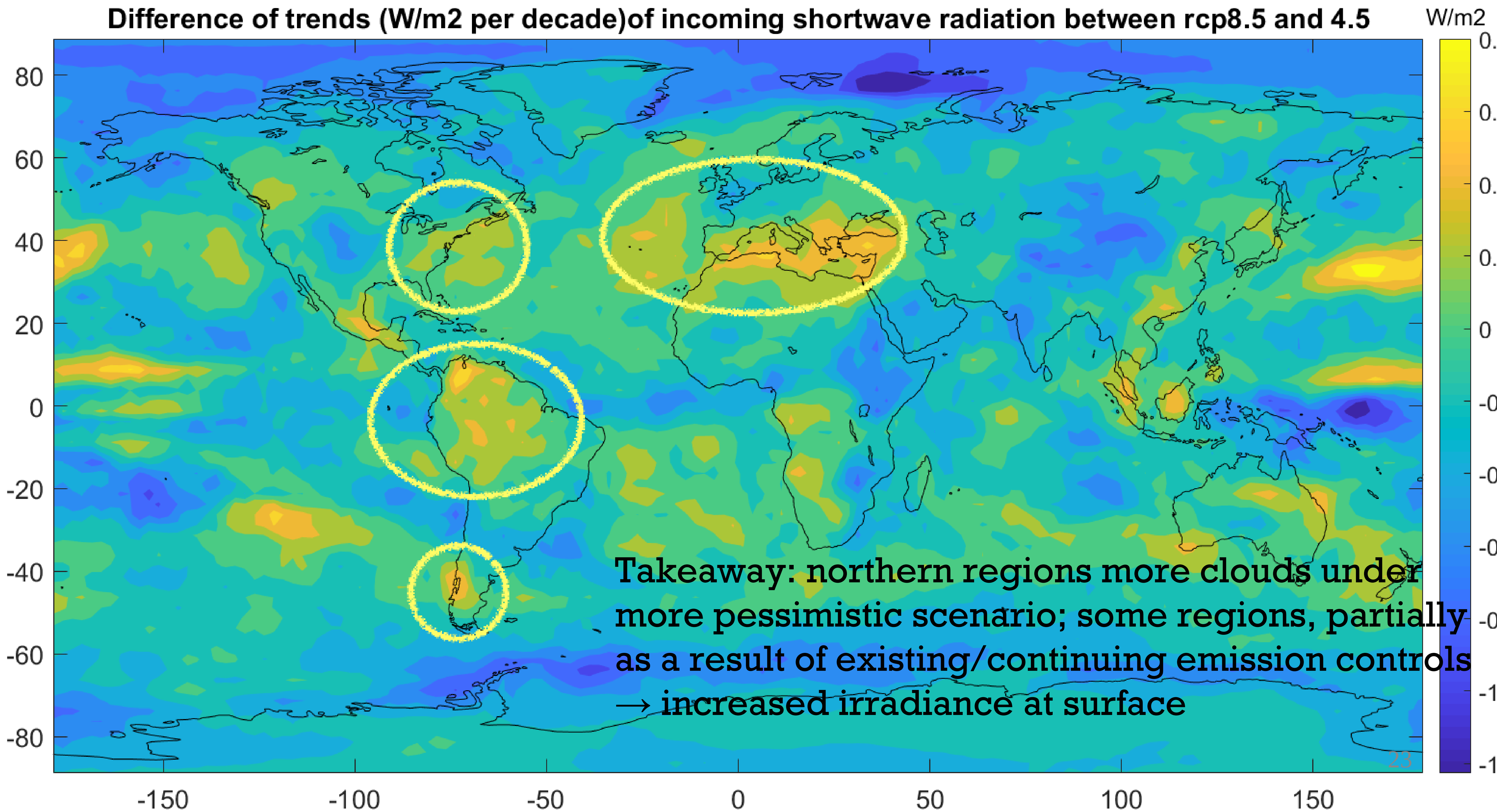
Standard deviation of the trend of incoming shortwave radiation: RCP8.5 2020-2050



W m^{-1} $decade^{-1}$

Standard deviation of the trends indicate the uncertainty (spread) of the *climate models predicting* the trends for a variable

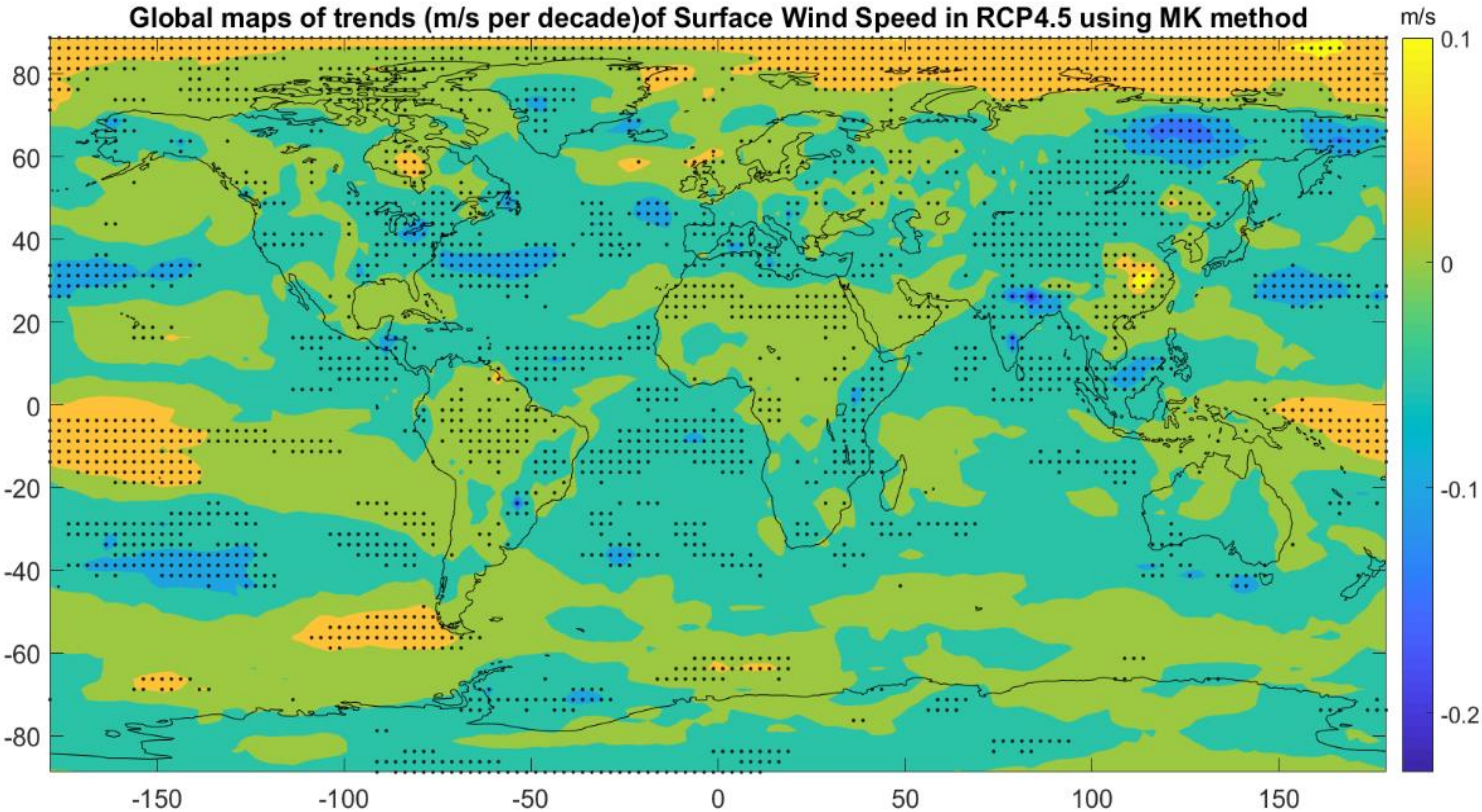
Difference of trends for irradiance RCP8.5 minus RCP4.5, from 2020 to 2050



Takeaway: northern regions more clouds under more pessimistic scenario; some regions, partially as a result of existing/continuing emission controls → increased irradiance at surface

W m^{-1} $decade^{-1}$

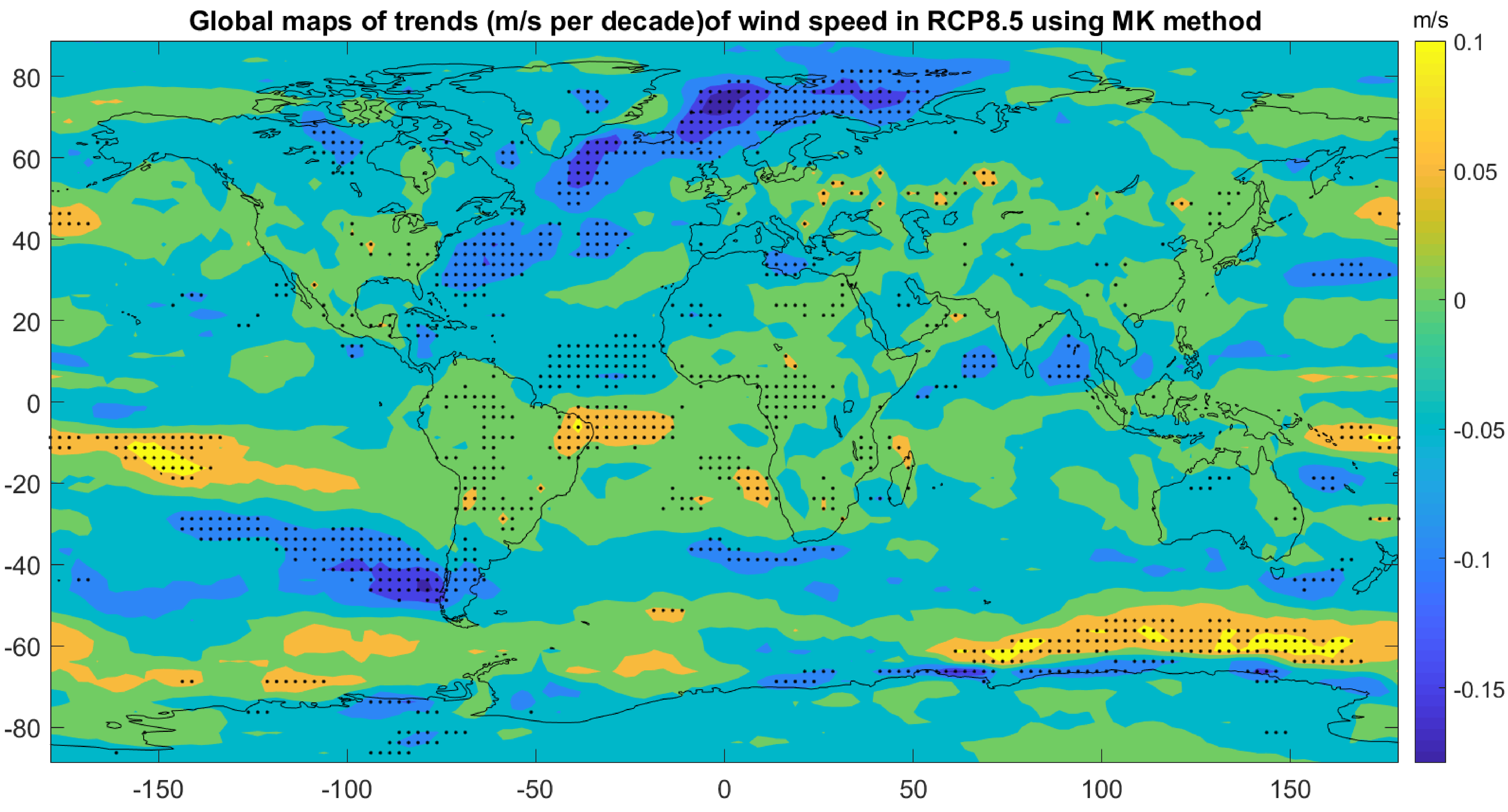
Global Trends 10 m Wind Speed (RCP 4.5)



m s^{-1} $decade^{-1}$

Small increases over Arctic, central equatorial Pacific, west of southern S.A.; east of Indonesia

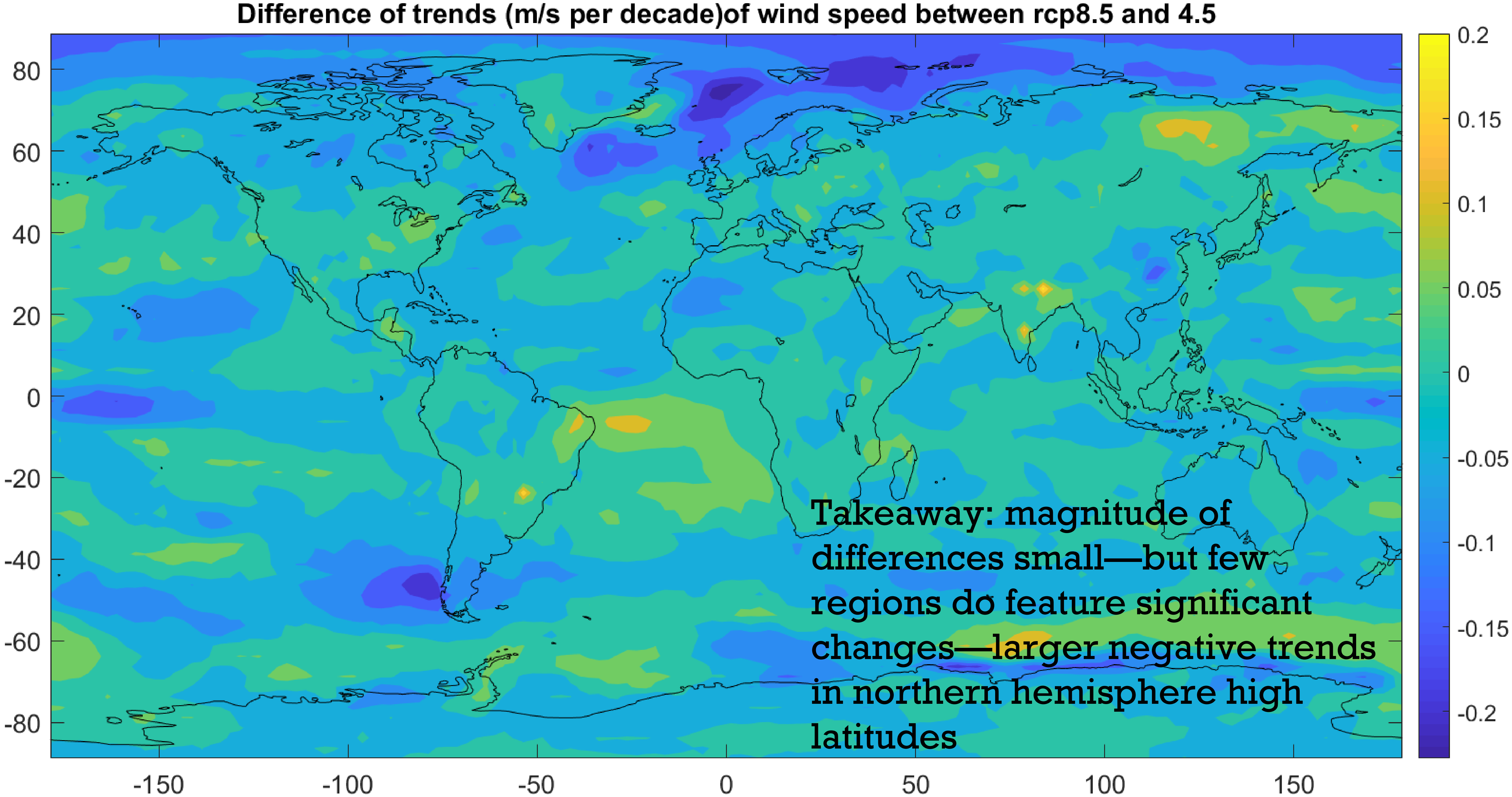
Global Trends 10 m Wind Speed (RCP 8.5)



m s^{-1} $decade^{-1}$

Overall decrease over NH— stronger where significant—note more negative along western/north Atlantic storm track

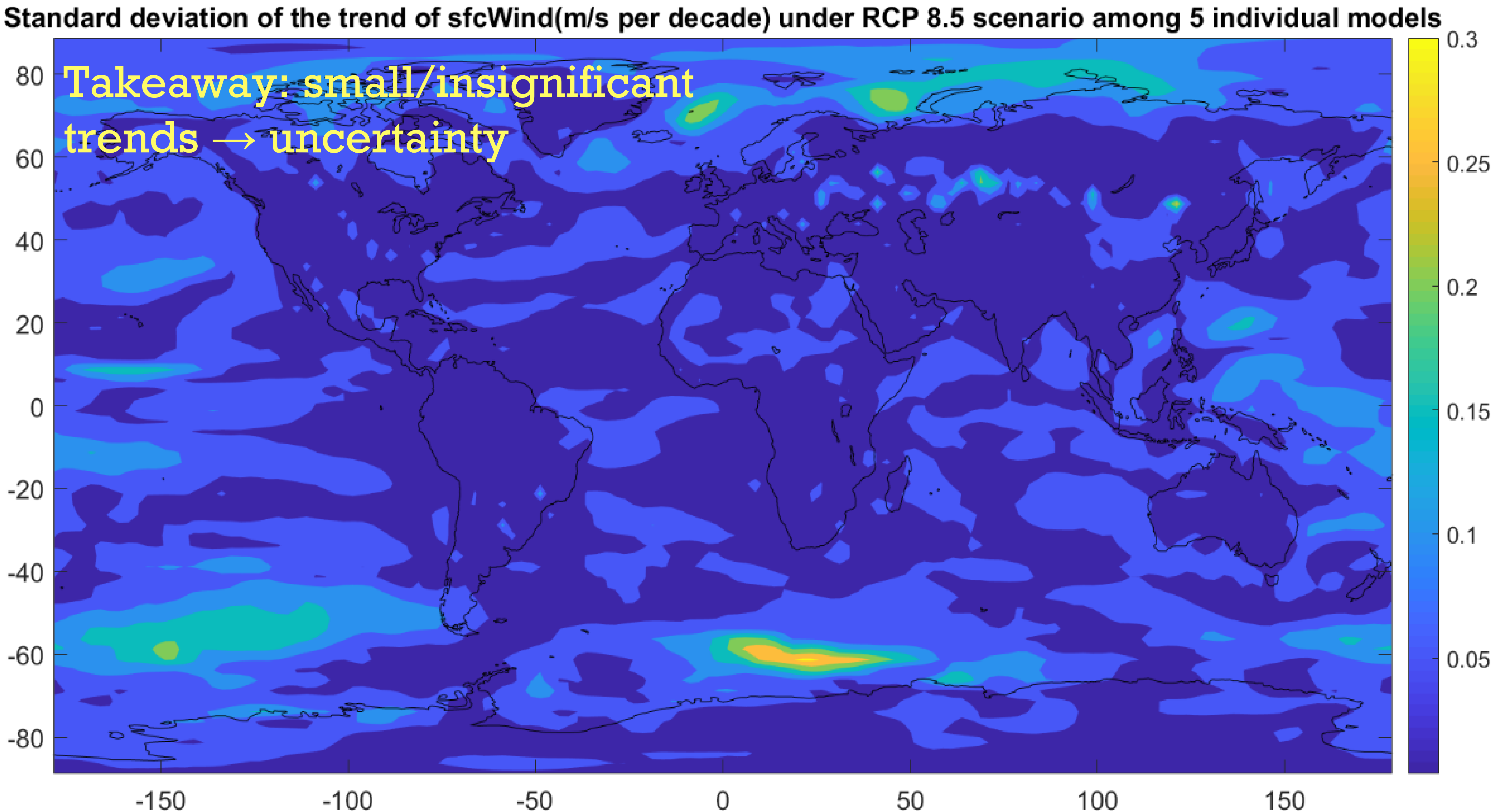
Difference in trends of surface wind speed, RCP8.5 minus RCP4.5, from 2020 to2050



Takeaway: magnitude of differences small—but few regions do feature significant changes—larger negative trends in northern hemisphere high latitudes

$m\ s^{-1}\ decade^{-1}$

Standard deviation of the trend of surface wind speed: RCP8.5 2020-2050



m s^{-1} $decade^{-1}$

Standard deviation of the trends indicate the uncertainty (spread) of the *climate models predicting* the trends for a variable.

"Effects of Climate Change on Renewable Energy Distribution in New York State"

Sponsored by the New York State Energy Research and Development Authority
Agreement #105161

Jeff Freedman and Richard Perez, Jason Covert and Shengzhe Chen (grad students), UAlbany, Atmospheric Sciences Research Center

Aiguo Dai, UAlbany Department of Atmospheric and Environmental Sciences

Philippe Beaucage and Dan Kirk-Davidoff, UL- AWS Truepower

John Manobianco, Mano NanoTechnologies, Inc.

Objective

The primary objective of this work is to develop a quantified, probability-based study of the redistribution of the renewable energy resources (wind, solar, and hydropower) that will provide a clearer path for adaptation strategies necessary for New York State to ensure energy resiliency in the midst of a changing climate

High Resolution Climate Modeling Results coming soon (end of the year)

Perform **dynamic downscaling** of the selected (6 "representative") CMIP5 models in WRF for 3 periods:

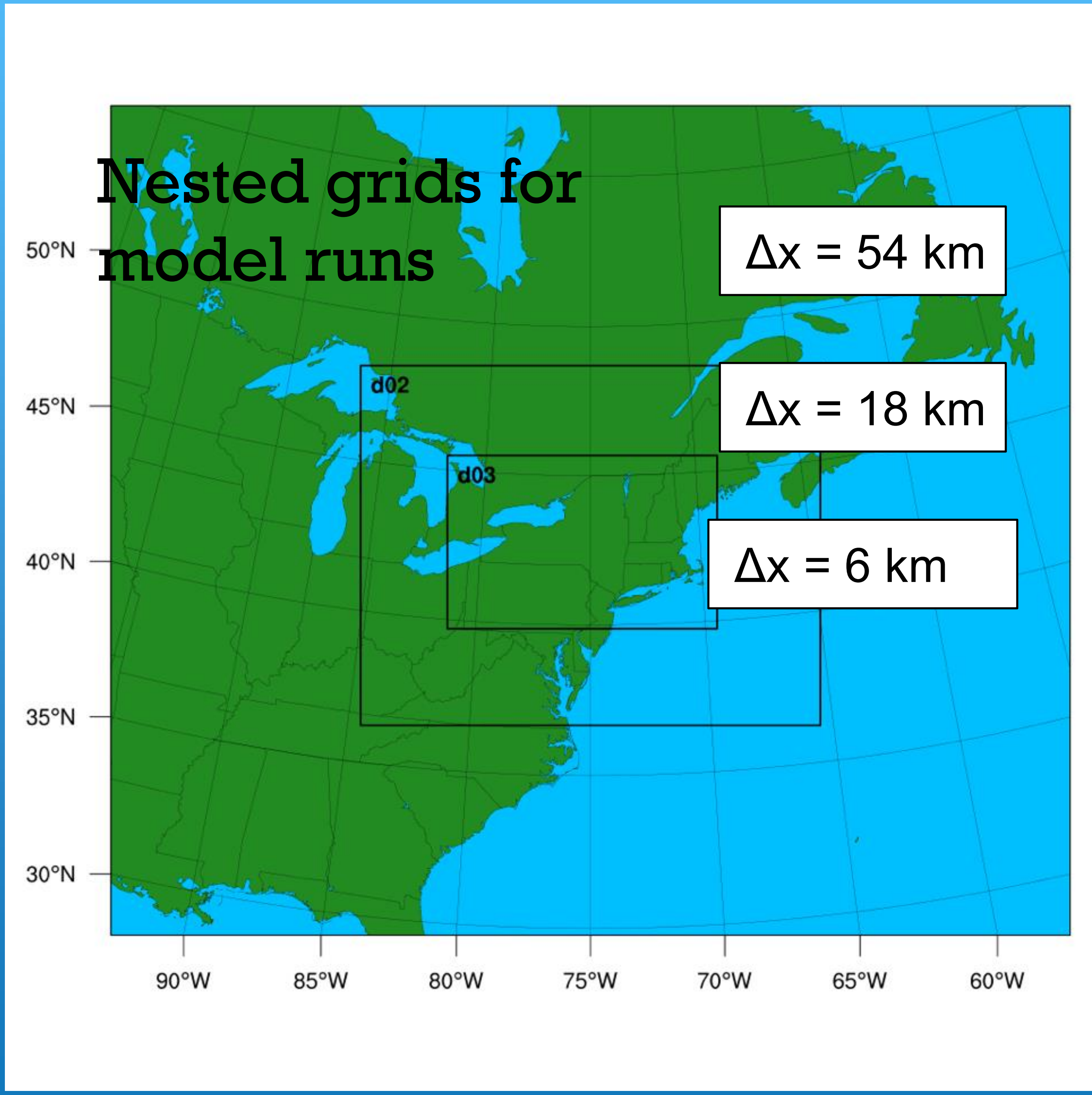
1. historical (1998 -2017)
2. near-future (2018 - 2035)
3. mid-future (2036 - 2055)

Variables of interest:

Surface (10 m) and hub height (80m, 100 m, and 120 m) wind speed and direction

surface irradiance

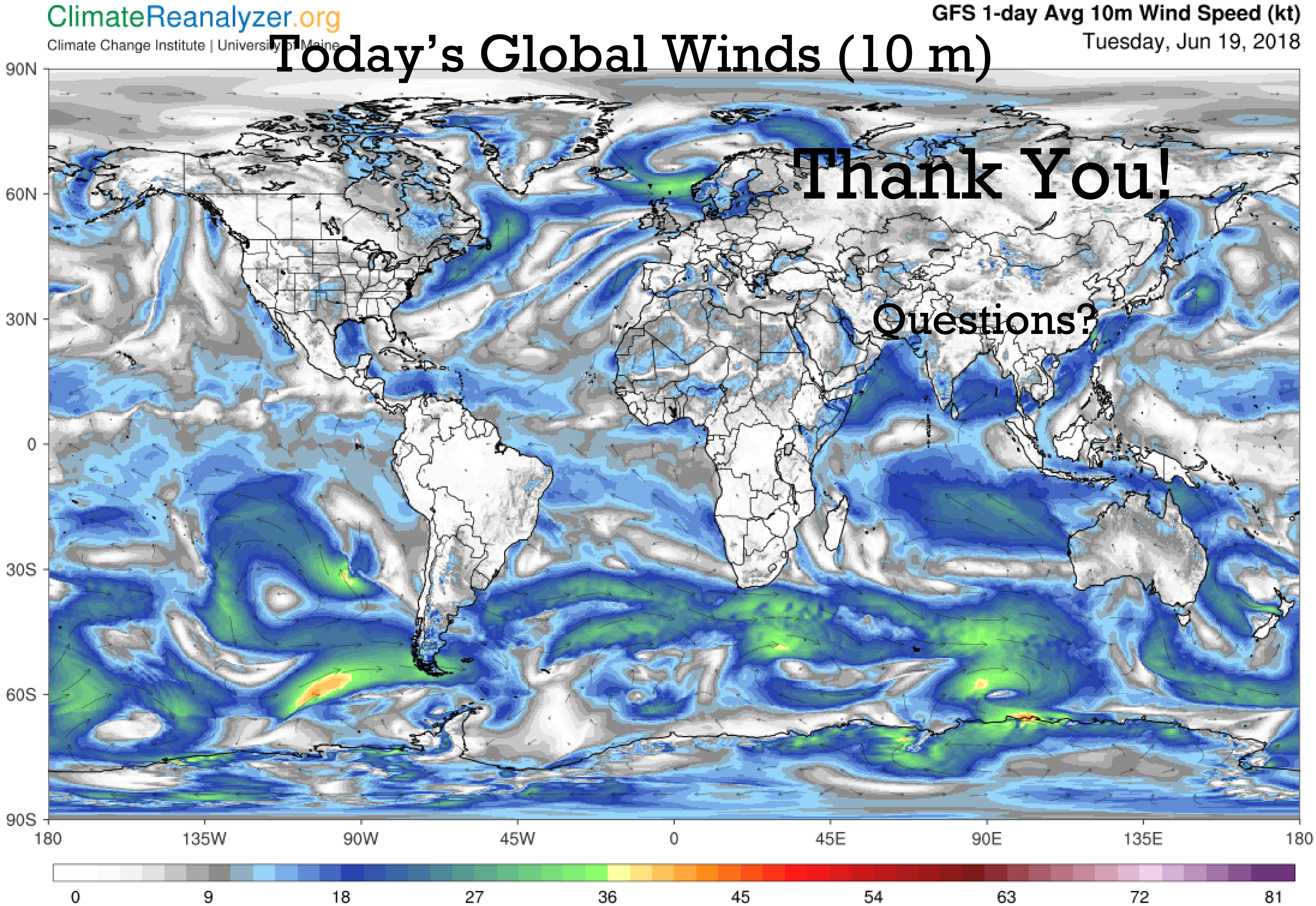
precipitation



So what does this mean for forecasting in a changing climate?

1. More robust trends (increasing in population centers) in irradiance
2. Less clear regarding surface winds (really indeterminate)
3. Some modest, not so modest differences between scenarios
4. Northern latitudes in N.H., from ensemble means, SD, susceptible to more significant changes (increase in irradiance, decrease in WS).
5. Load forecasting will be more challenging due to increased variability (timescales!)(?)
6. It will really come down to downscaling results—region by region

Today's Global Winds (10 m)



Thank You!

Questions?