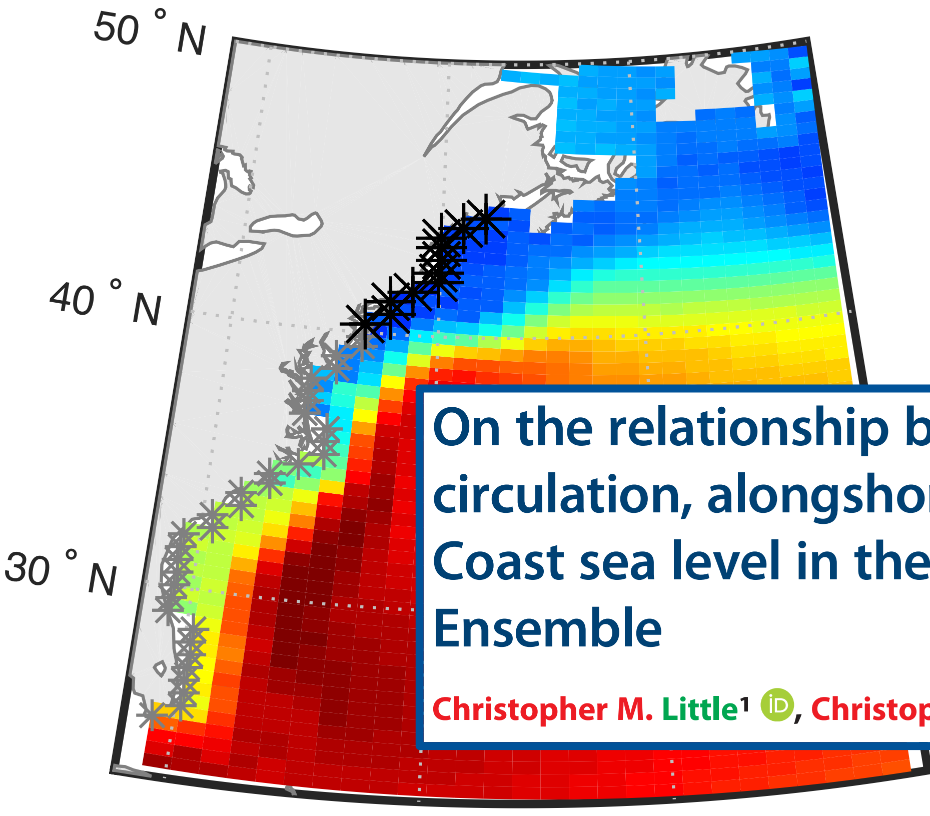

On the relationship between the meridional overturning circulation, alongshore wind stress, and United States East Coast sea level in the Community Earth System Model Large Ensemble

Christopher M. Little[1], Christopher G. Piecuch[1], and Rui M. Ponte[1]

[Little et al. (2017), *JGR-Oceans*]

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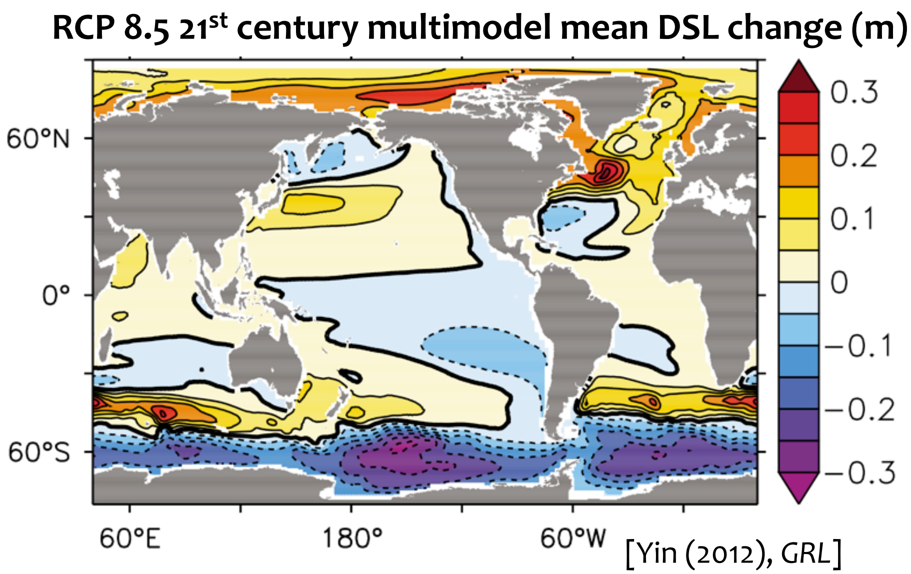
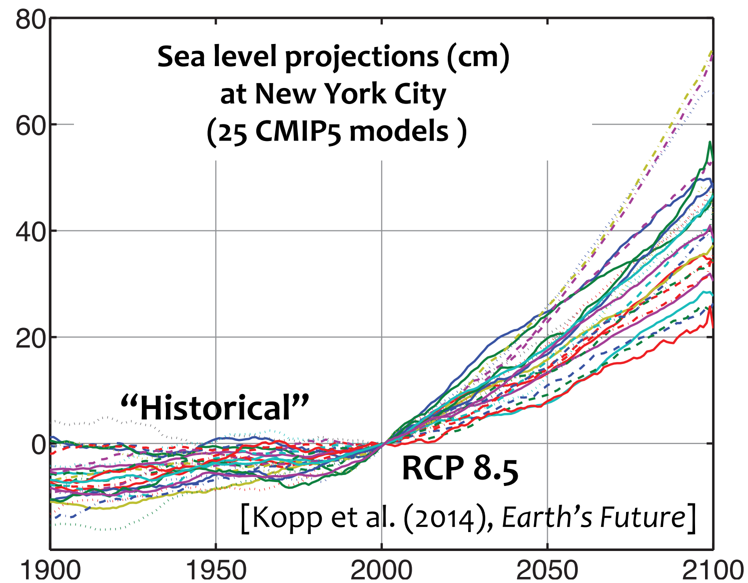
AMOC ST Meeting 2017

CMIP5 sea level projections





* **High mean AND wide spread in the NW Atlantic**
* **Dynamic sea level rise (DSL) is correlated with global mean across models**

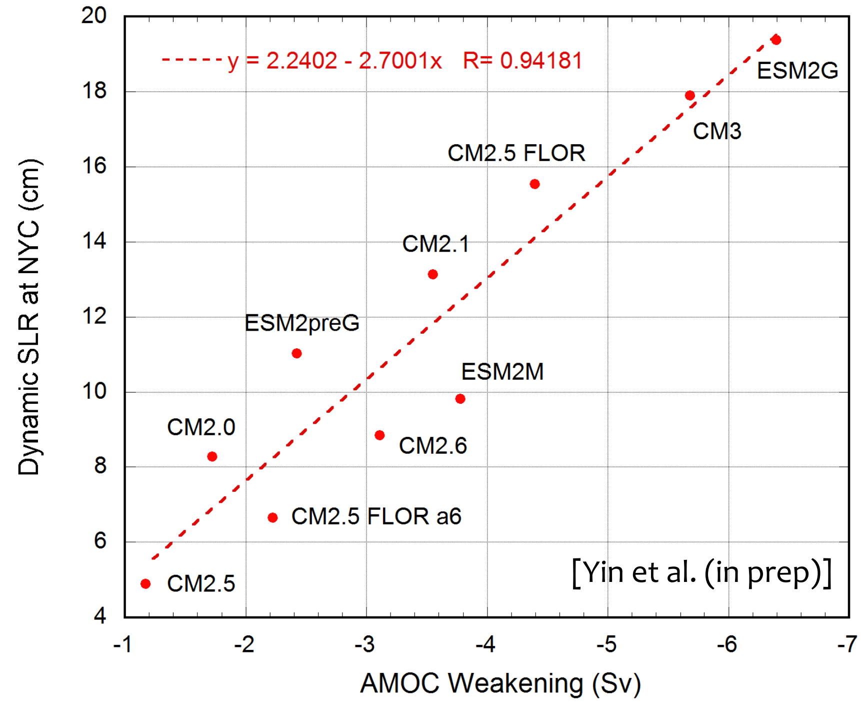
AMOC and DSL are closely coupled in models…

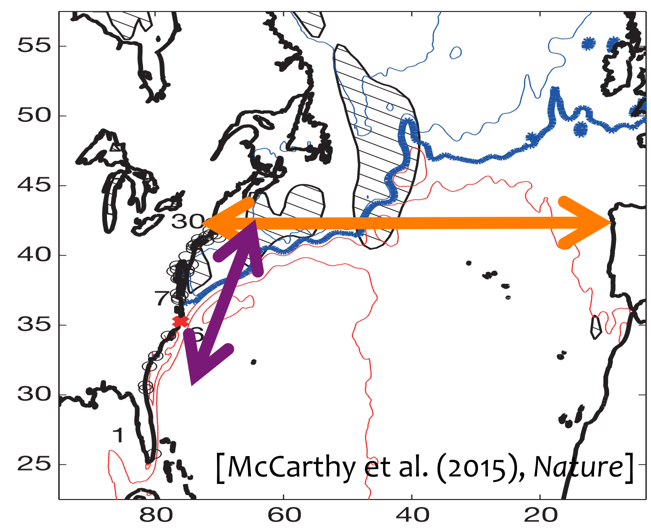
* **Future dynamic sea level rise is closely related to AMOC weakening…**

$$\vec{v} = \frac{g}{f}\vec{k} \times \nabla\vec{\eta}$$

* **And models suggest that DSL is a proxy of AMOC strength over the historical record (e.g. Bingham and Hughes 2009, McCarthy et al. 2015).**

70-year DSL change at New York City (10 GFDL models; 1%/yr CO_2 increase)



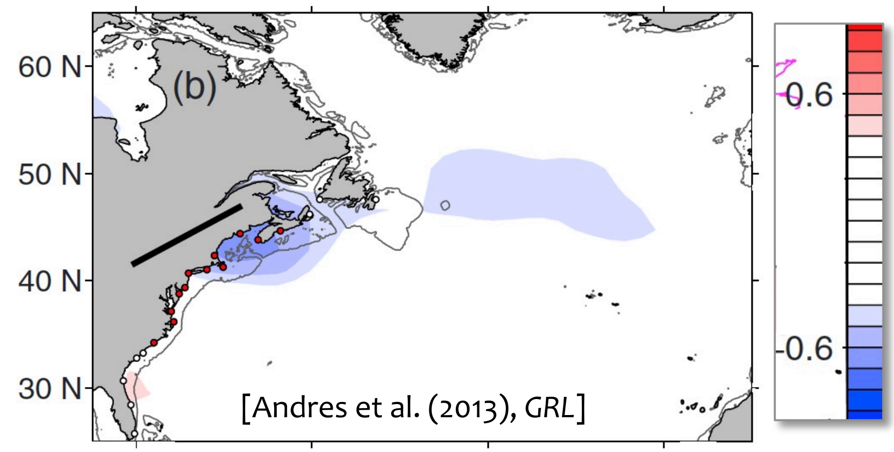


… but observations are dominated by local winds

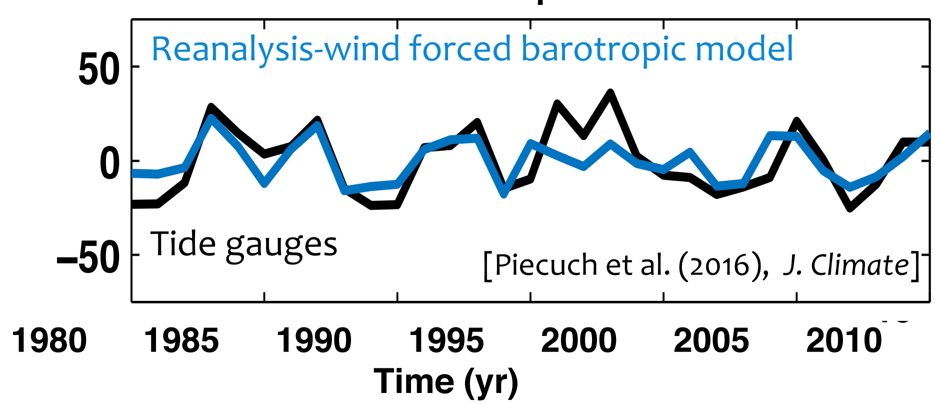
- Alongshore winds explain 50-60% of DSL variance north of Cape Hatteras

- Wither AMOC?

1970-2012 observed annual mean sea level anomaly/alongshore wind correlation

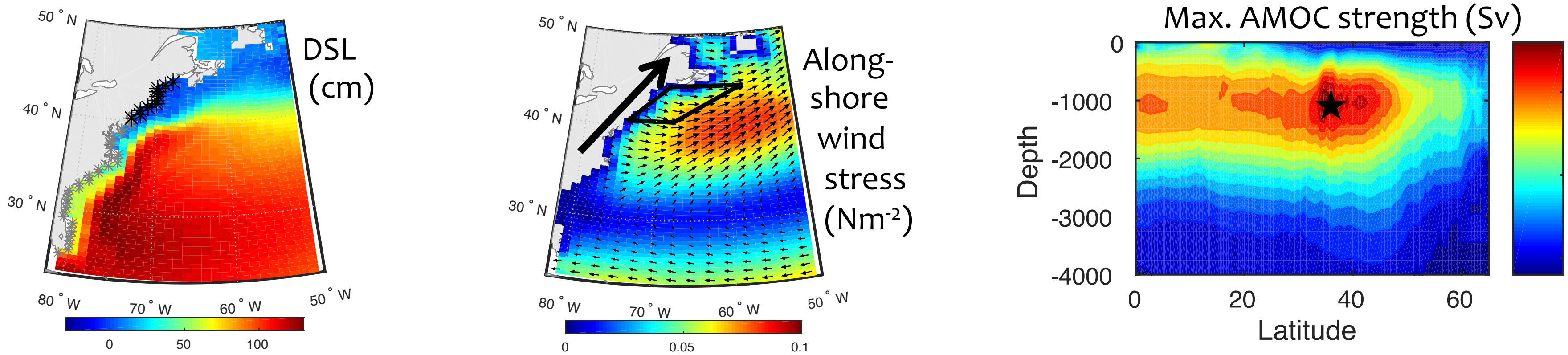


Annual mean detrended sea level anomaly (mm) North of Cape Hatteras

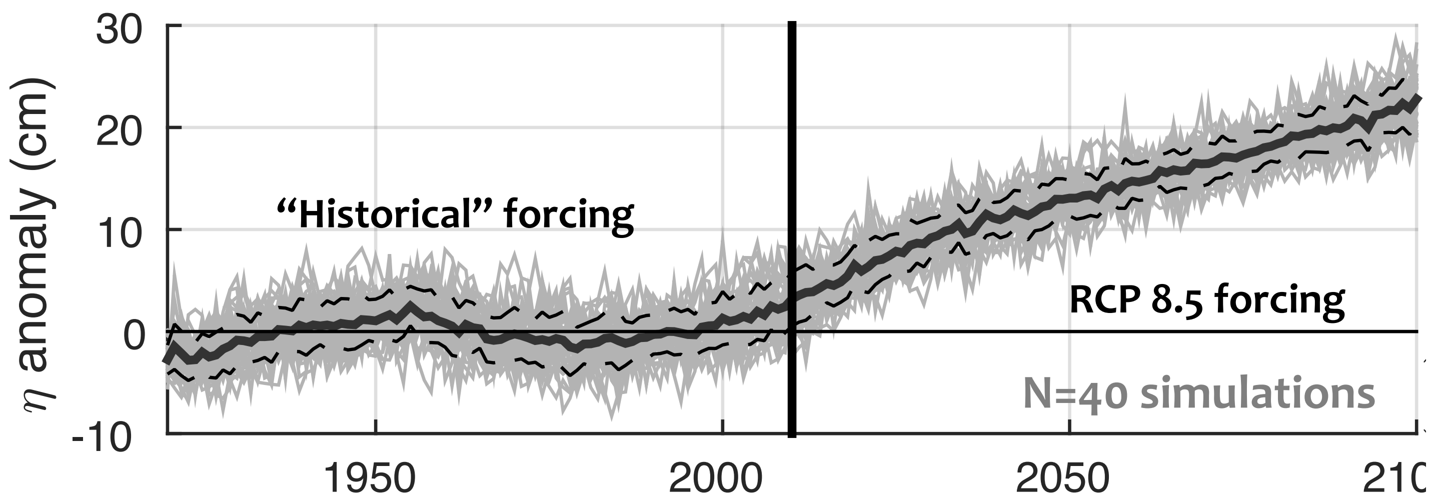


Community Earth System Model Large Ensemble
(CESM-LE; Kay et al. 2015)

1. Calculate scalars

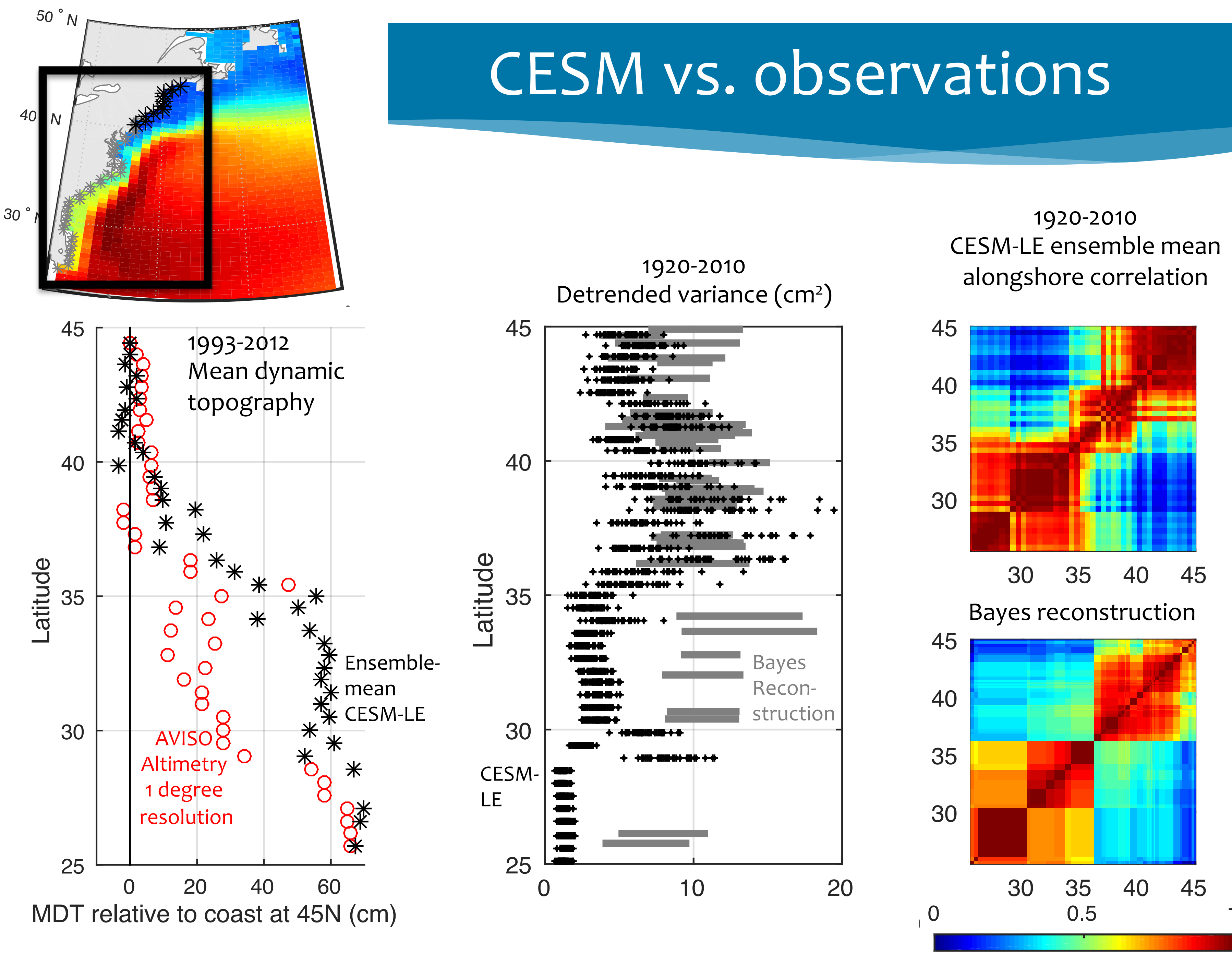


2. Partition externally-forced and internal components

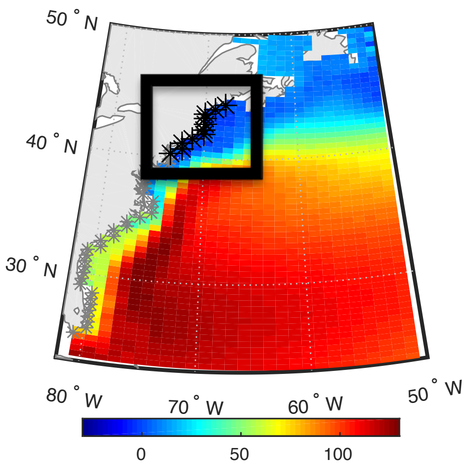


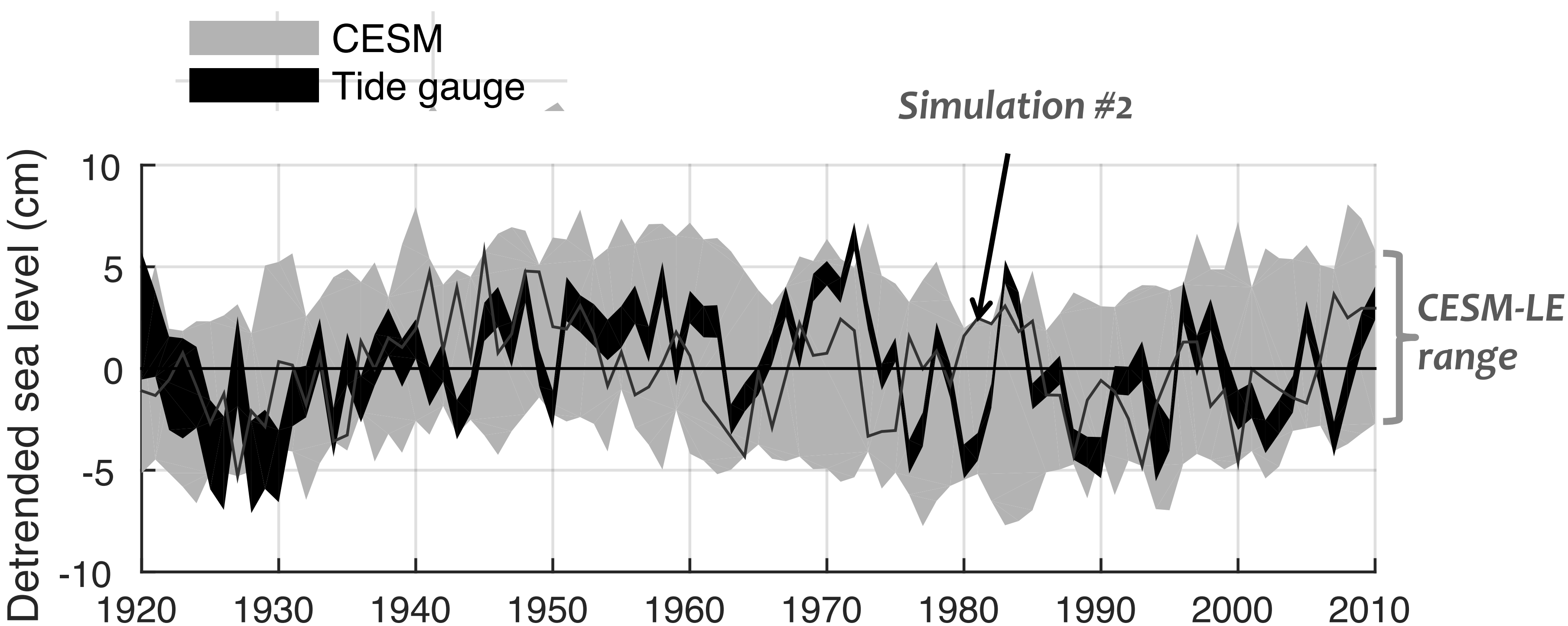
3. Compare to fully Bayesian (probabilistic) tide gauge reconstruction [Piecuch et al. (2017), JGRO]

CESM vs. observations

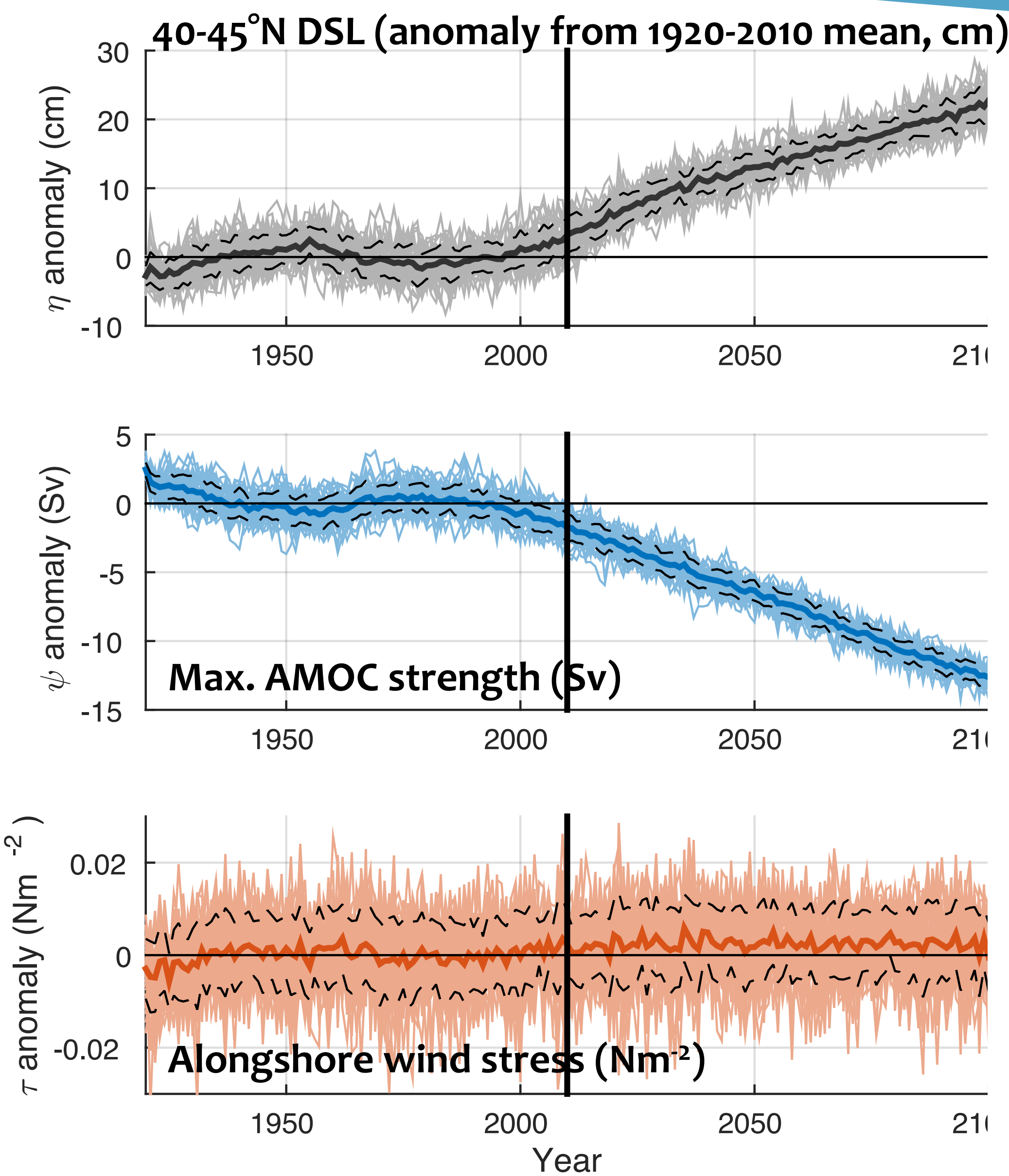


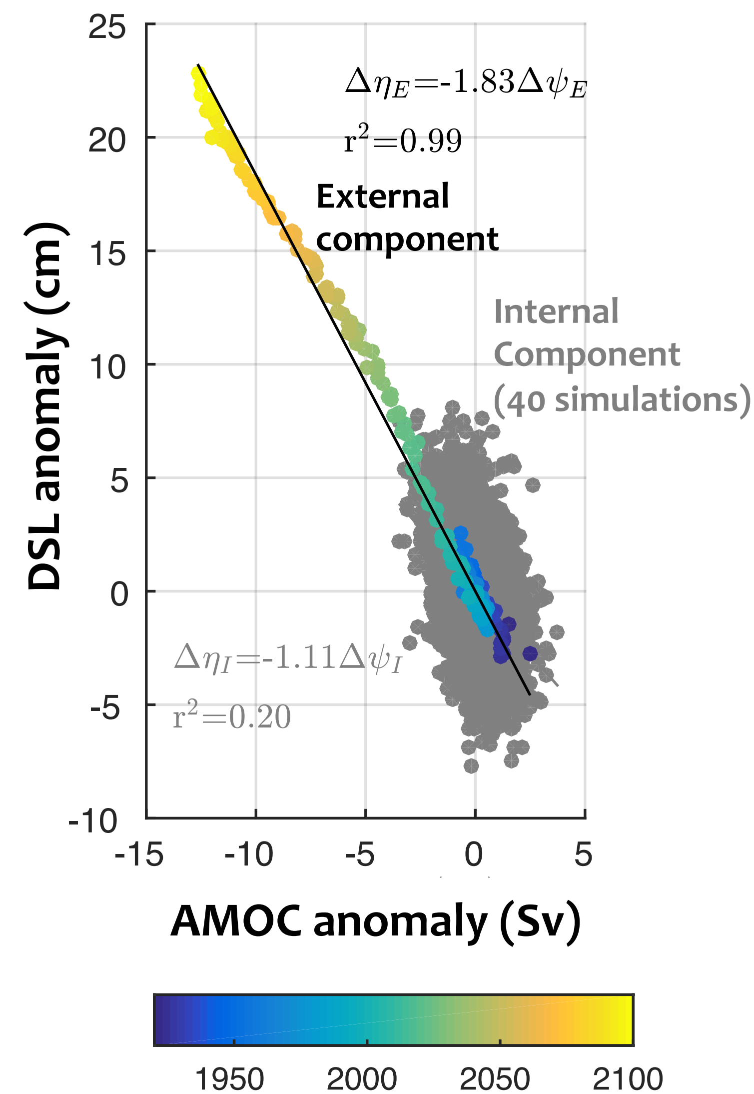
40-45°N model-data comparison



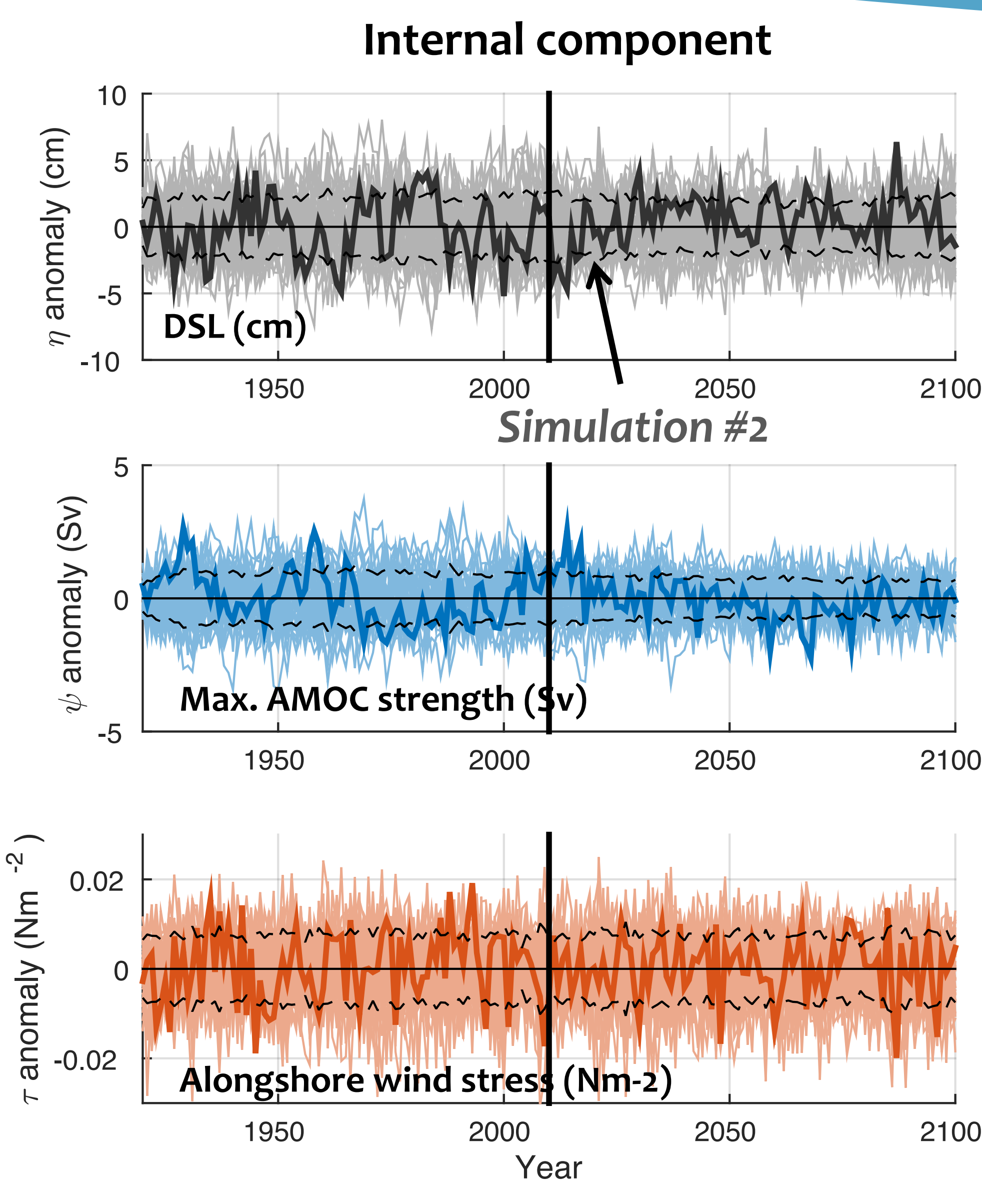


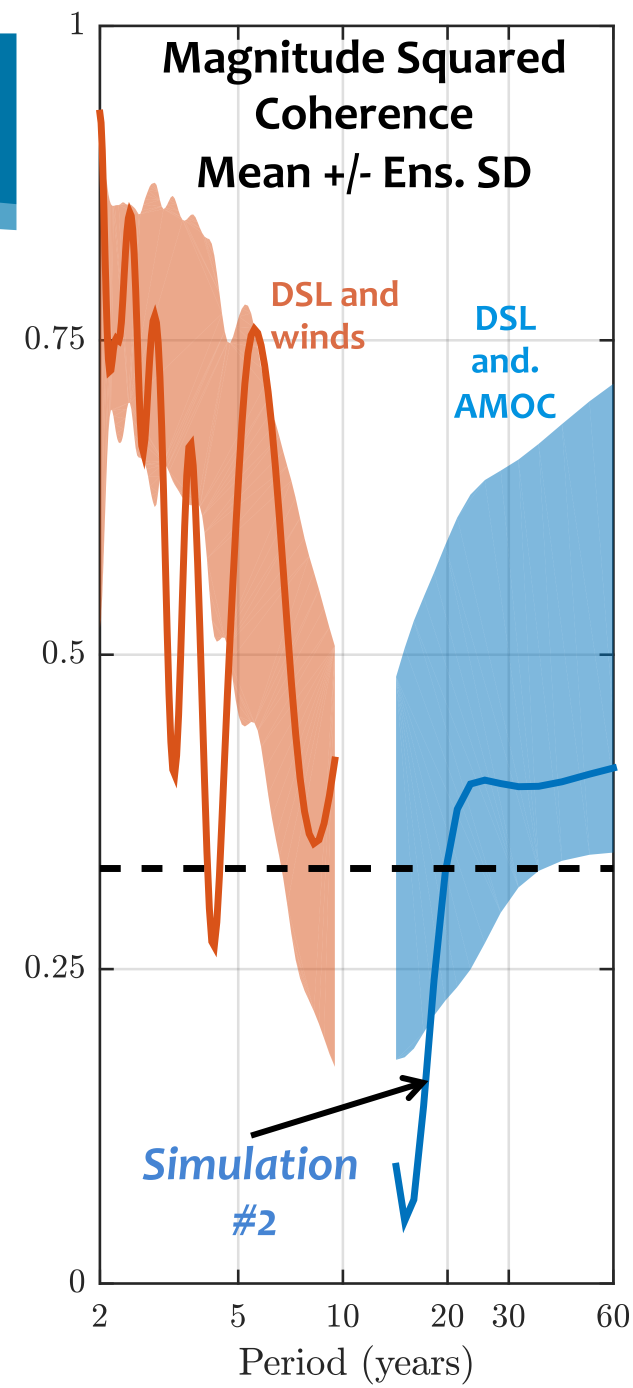
Partitioning forced and unforced variability





DSL coherence with wind and AMOC



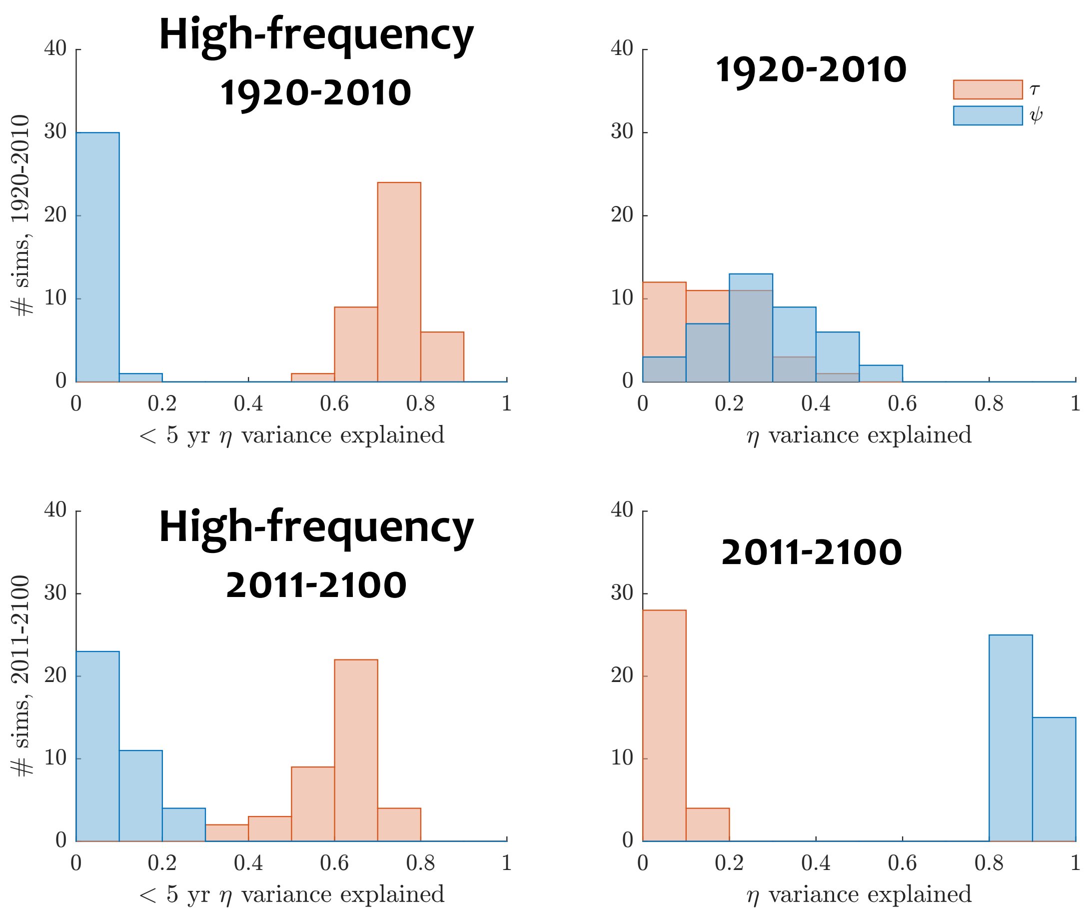


Partitioning winds and AMOC

$$\boxed{\eta^n} = \boxed{\alpha^n \tau^n} + \boxed{\beta^n \psi^n} + \varepsilon^n(t).$$

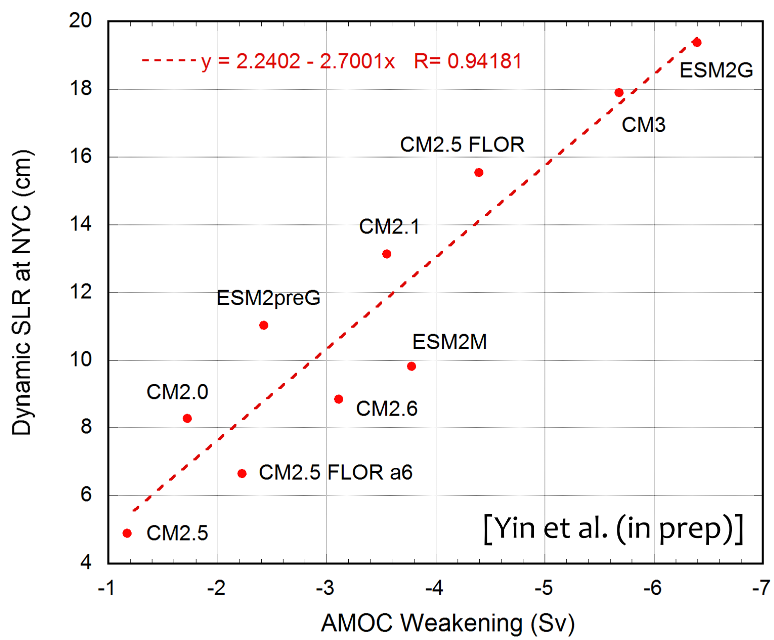
- Apply 5 year high pass filter

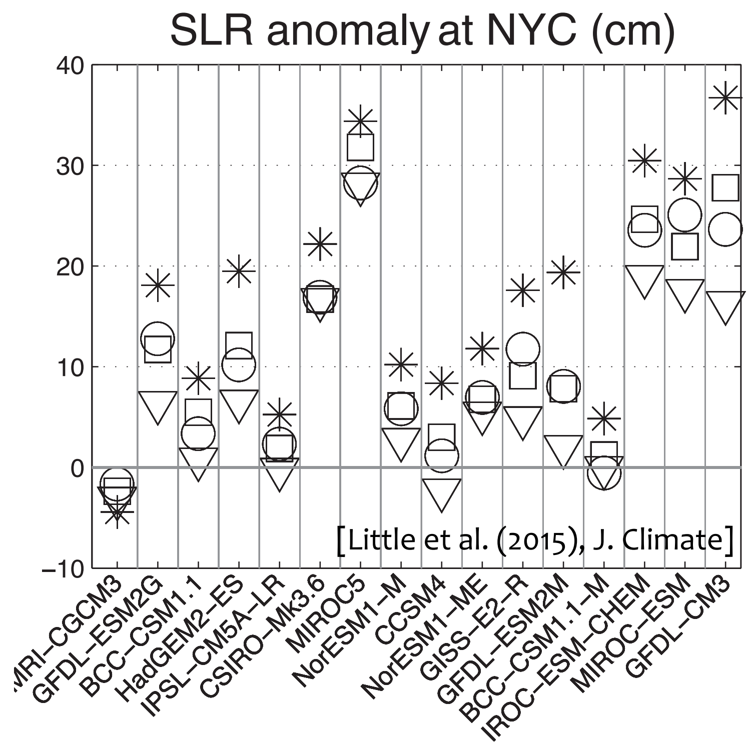
- Regress each simulation (*n*)



Future work

* Examine mechanisms underlying spread in climate model representation of: AMOC change **and** its coastal sea level expression





* Remove land motion and global mean sea level change by incorporating other data sources into Bayesian algorithm (e.g. GPS, altimetry)

Conclusions

* In CESM, Northeast US dynamic sea level changes can be partitioned into: 1) an interannual, internal, local wind-driven component and 2) a multidecadal-to-centennial, externally-forced, component that is tightly coupled to the overturning circulation
  * Externally forced AMOC/DSL scaling (~-1.8 cm/Sv) is stationary over the 1920-2100 period

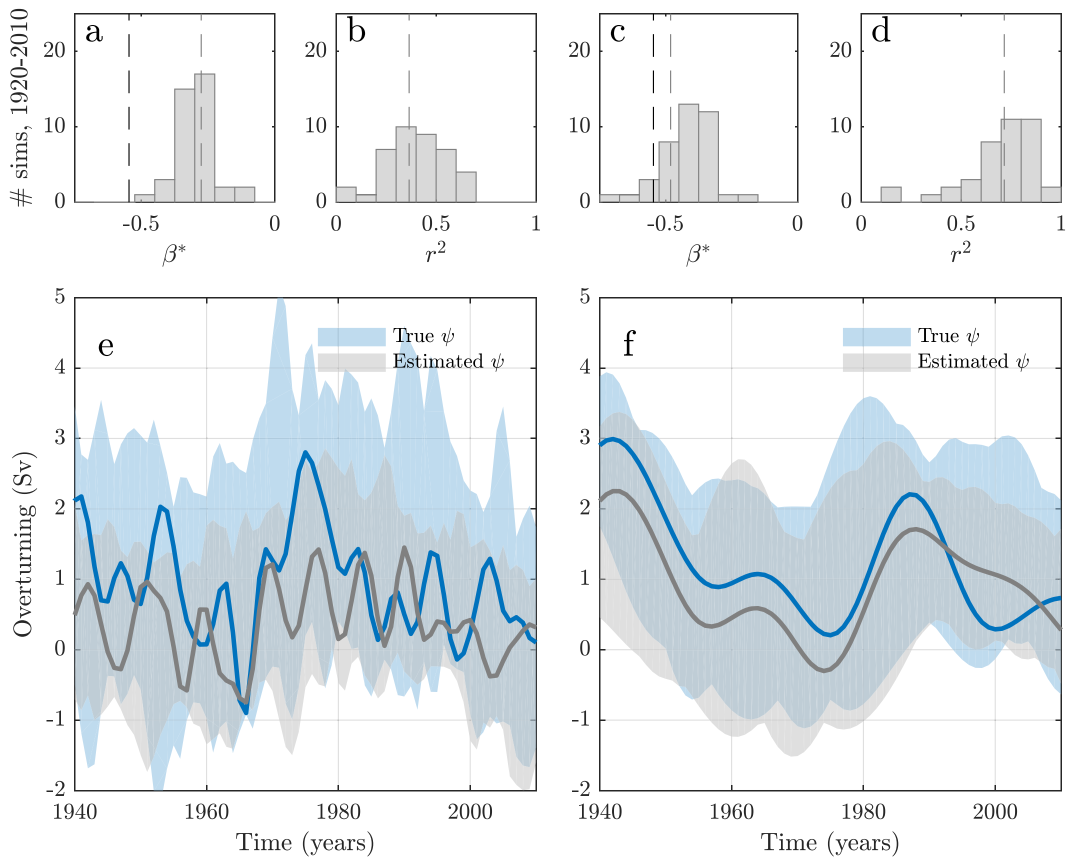
* Observation-based explanations highlighting the role of winds are not inconsistent with large 21st century, AMOC-coupled changes in climate models; robust linkages require more time to observe or stronger external forcing (see also Woodworth et al. 2014)

* Northeast US sea level is a good metric of AMOC over multi-decadal timescales, especially in the presence of strong external forcing
  * Obscured over decadal timescales by local winds and unrelated internal variability; may be able to improve by filtering wind-forced interannual "noise"
  * Assessment of AMOC metrics that include locations south of Cape Hatteras are hindered by CESM's poor representation of South Atlantic Bight DSL

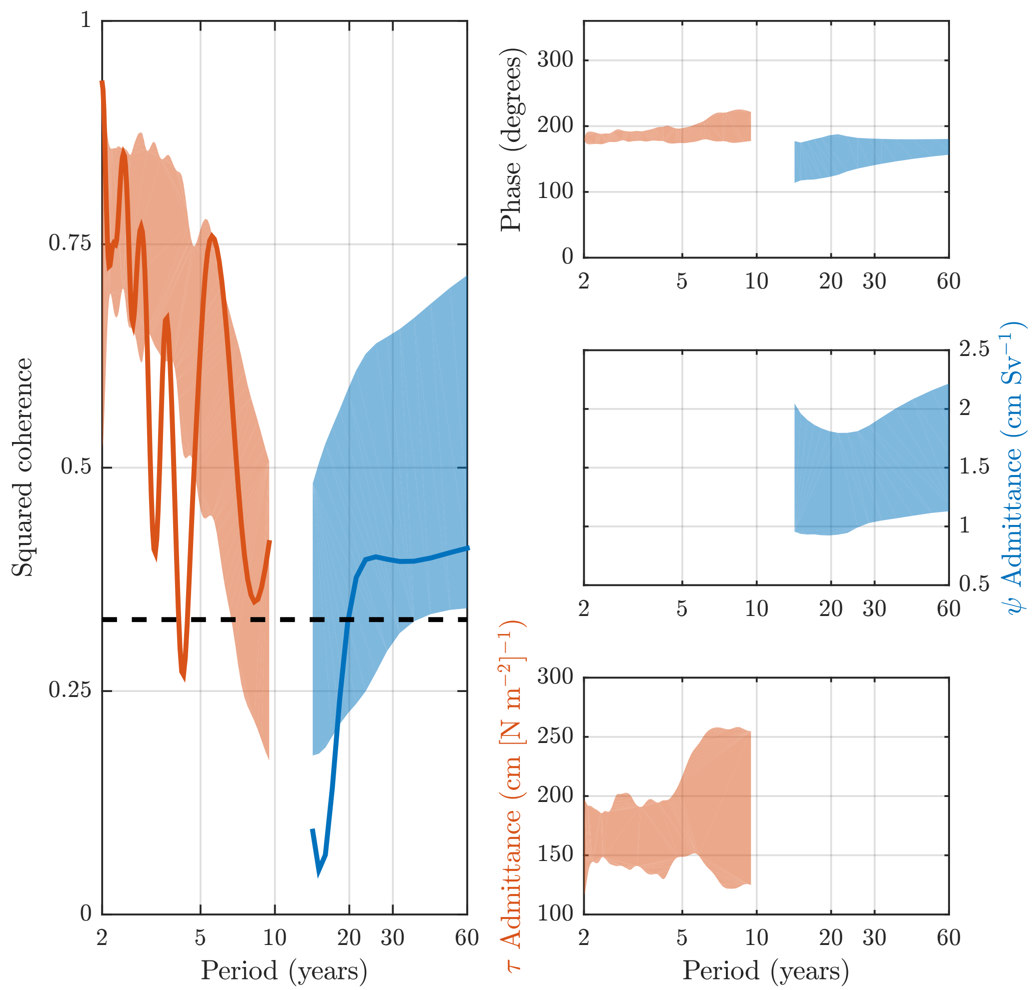
Thanks to:

* **NASA award #NNH16CT01C; NSF award #1558966**
* **Steve Yeager (NCAR), the CESM Large ensemble project and the NCAR ESG repository**
* **NOAA GFDL**

Extra

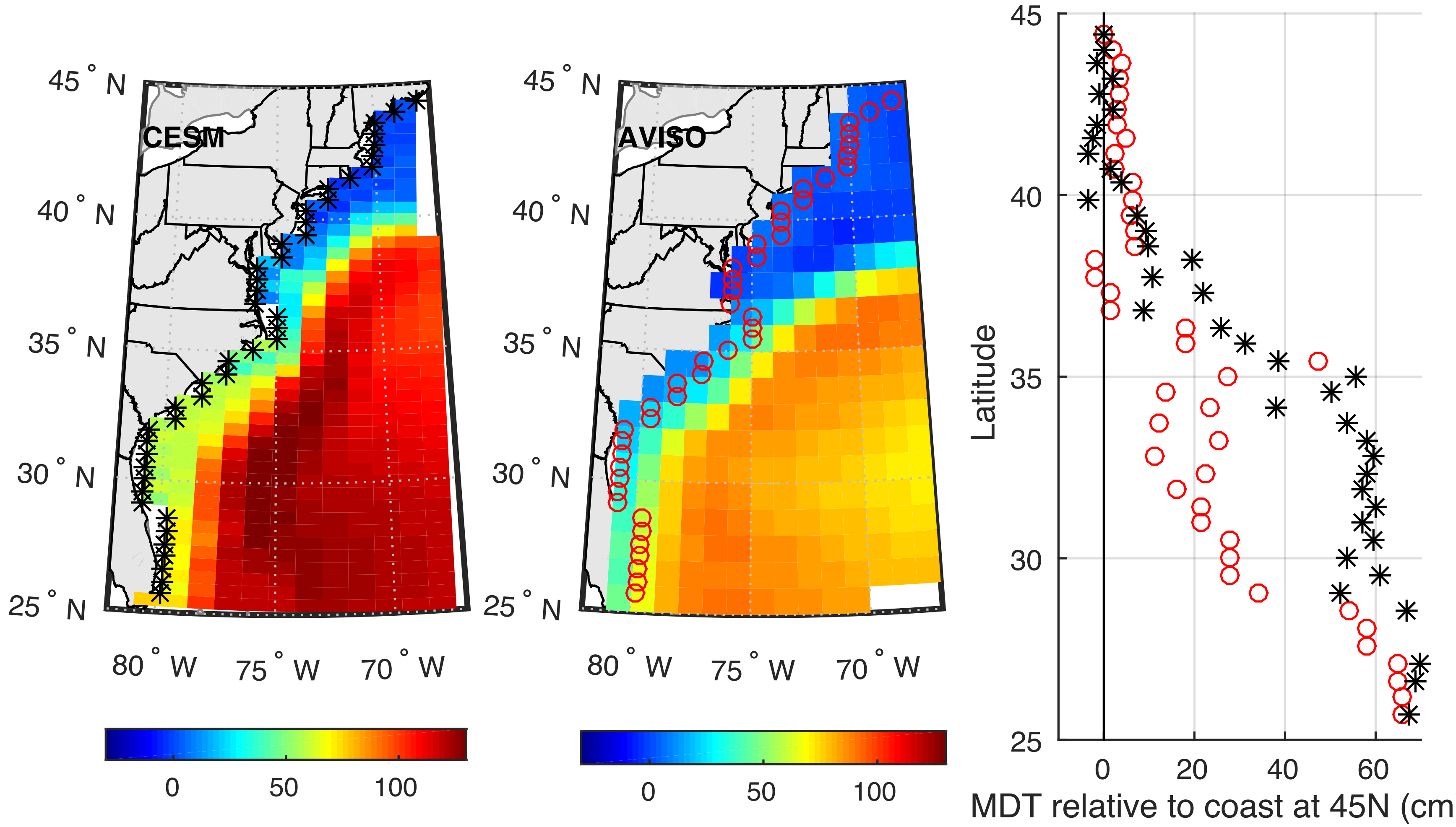


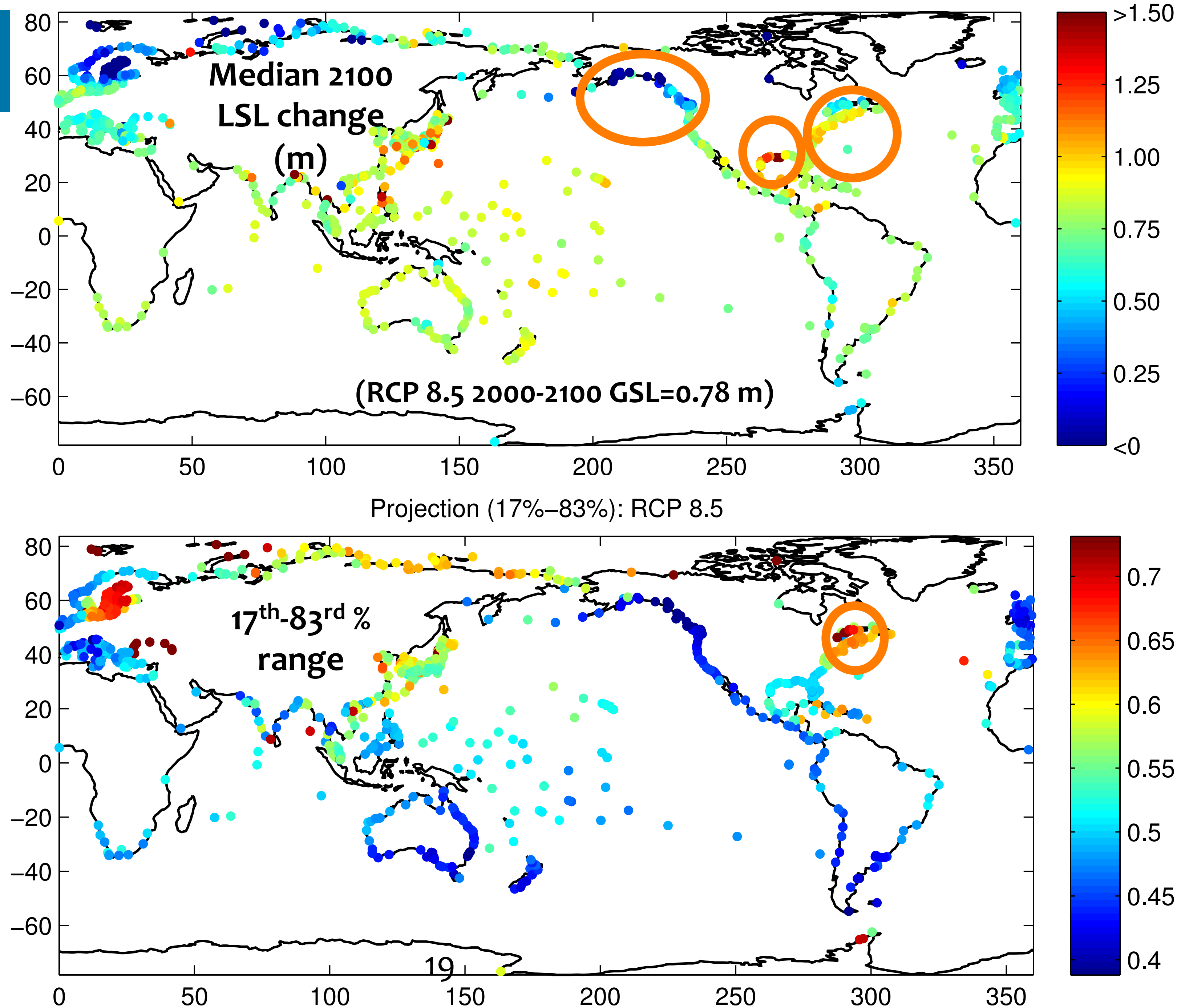
a
b
c
d
sims, 1920-2010
20
10
0
-0.5
0
0.5
1
β^*
r^2
e
f
True ψ
Estimated ψ
Overturning (Sv)
5
4
3
2
1
0
-1
-2
1940
1960
1980
2000
Time (years)



Squared coherence
1
0.75
0.5
0.25
0
2
5
10
20
30
60
Period (years)
Phase (degrees)
300
200
100
0
ψ Admittance (cm Sv^{-1})
2.5
2
1.5
1
0.5
τ Admittance (cm [N m^{-2}]$^{-1}$)
250
150

MDT CESM/AVISO




Median 2100
LSL change
(m)
(RCP 8.5 2000-2100 GSL=0.78 m)
>1.50
1.25
1.00
0.75
0.50
0.25
<0
Projection (17%–83%): RCP 8.5
17th-83rd %
range
0.7
0.65
0.6
0.55
0.5
0.45
0.4

Mean sea level drivers

Local mean sea level (LSL)
"COMPONENTS"

Oceanographic

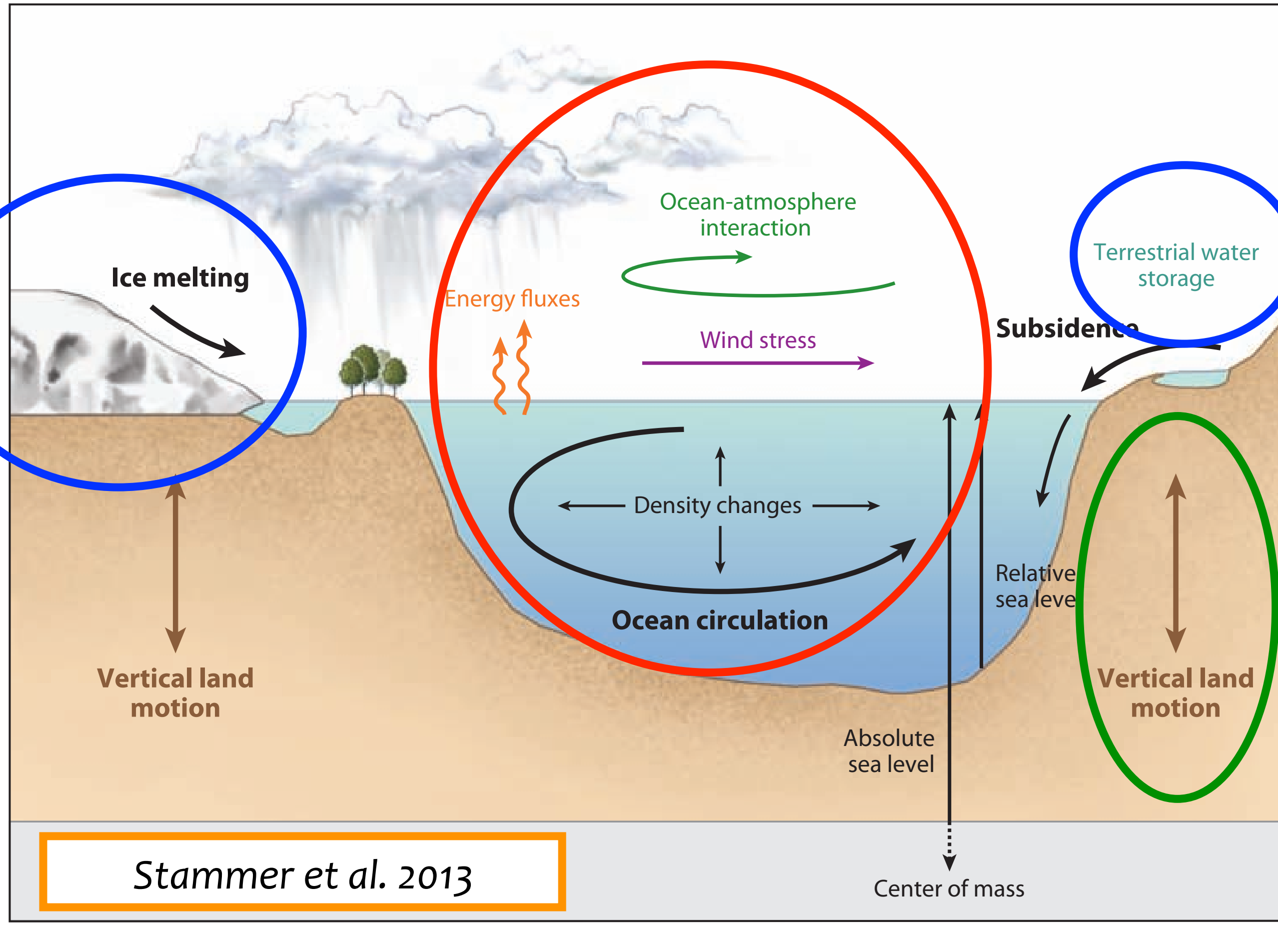
* Density changes
* Mass rearrangements

Mass exchange

* Ice sheet mass change
* Glacier mass change
* Land water storage

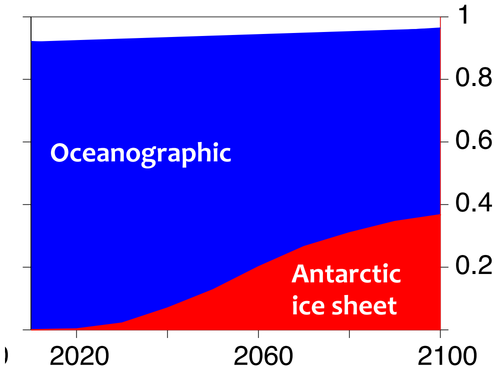
Solid-earth

* Isostatic adjustment
* Subsidence

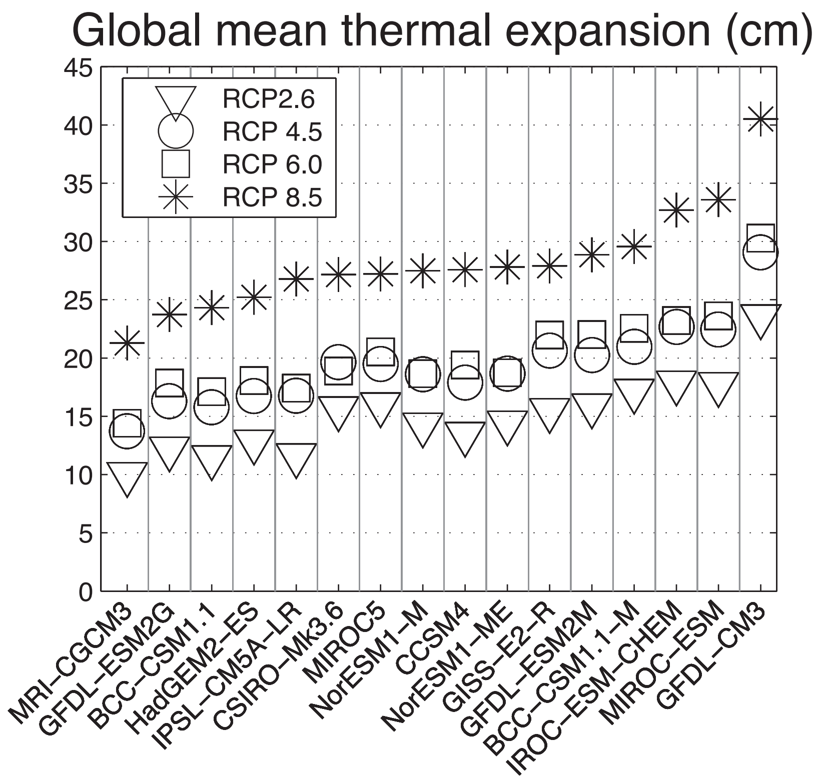


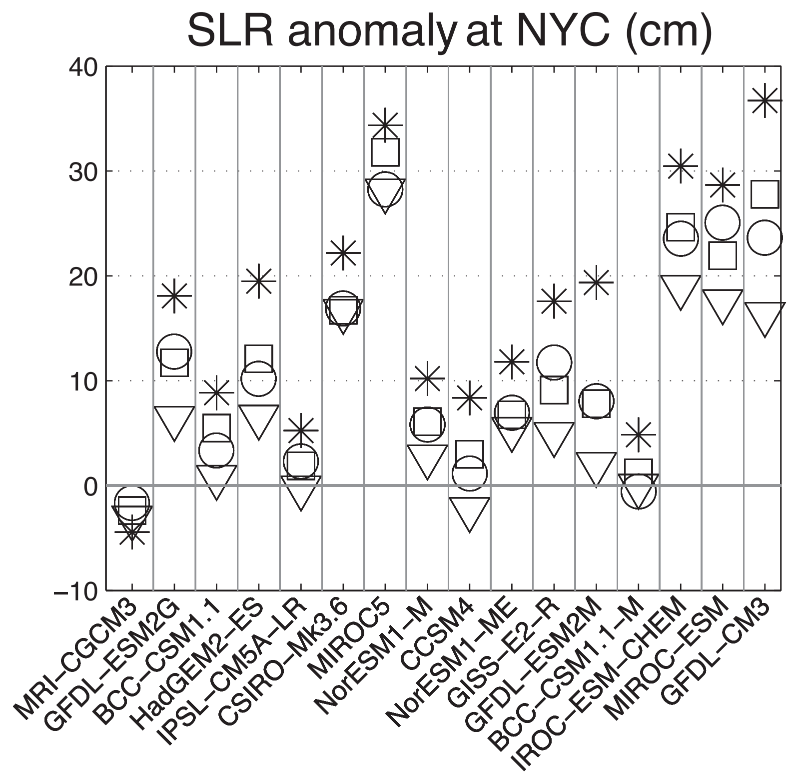
Stammer et al. 2013

16 CMIP5 model projections (2090-1990)

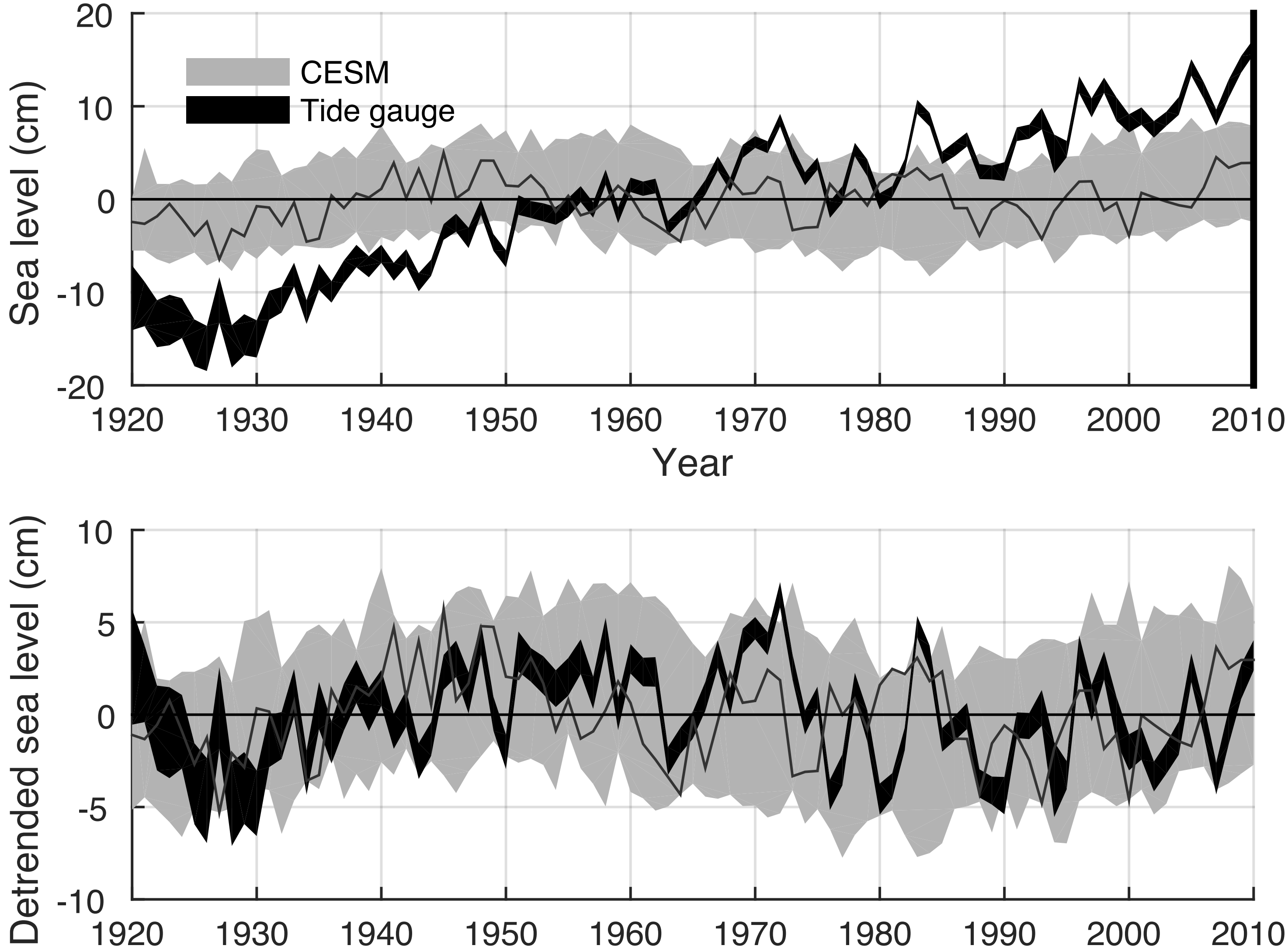


DYNAMIC SEA LEVEL





Little et al. 2015


CESM
Tide gauge
Sea level (cm)
20
10
0
-10
-20
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year
Detrended sea level (cm)
10
5
0
-5
-10
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Reconciling models and data: difficulties

* Three key issues:

* Tide gauge record quality/length
  * Use probabilistic, gap-filling reconstruction

* Tide gauge records include other processes
  * Compare detrended alongshore averages

* Internal variability
  * Use climate model ensemble

Bayesian tide gauge reconstruction

PROCESS LEVEL—

$$\boldsymbol{y}_k - \boldsymbol{b}t_k = r\left(\boldsymbol{y}_{k-1} - \boldsymbol{b}t_{k-1}\right) + \boldsymbol{e}_k$$

$$\boldsymbol{e}_k \sim \mathcal{N}\left(\boldsymbol{0}_N, \Sigma\right), \Sigma_{ij} = \sigma^2 \mathrm{e}^{-\varphi|\boldsymbol{x}_i - \boldsymbol{x}_j|}$$

$$\boldsymbol{b} \sim \mathcal{N}\left(\mu \boldsymbol{1}_N, \pi^2 \mathsf{I}_N\right)$$

OBSERVATION LEVEL—

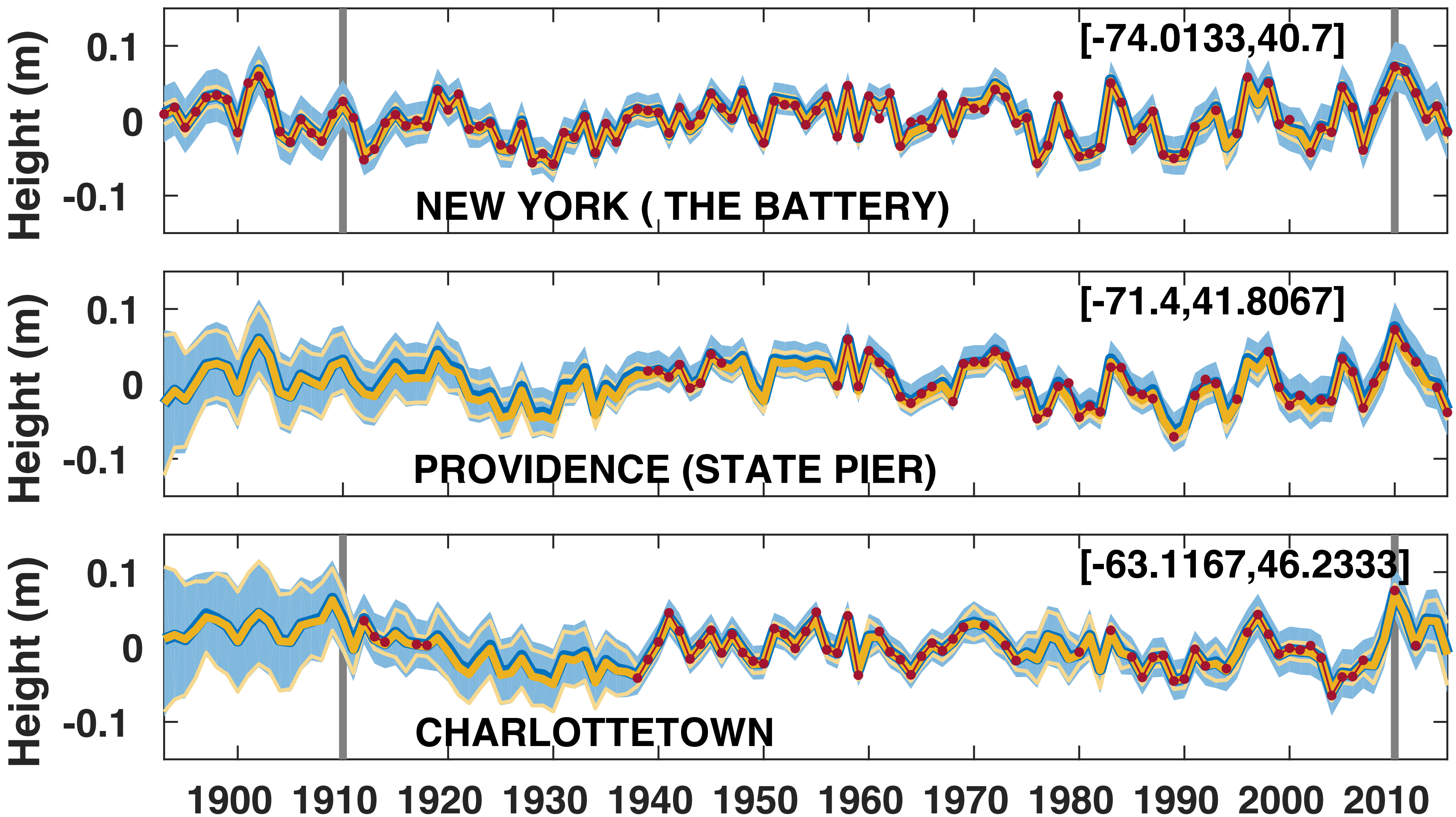
$$\boldsymbol{z}_k = \mathsf{H}_k \boldsymbol{y}_k + \boldsymbol{d}_k + \mathsf{F}_k \boldsymbol{\ell}$$

$$\boldsymbol{d}_k \sim \mathcal{N}\left(\boldsymbol{0}_{M_k}, \delta^2 \mathsf{I}_{M_k}\right)$$

$$\boldsymbol{\ell} \sim \mathcal{N}\left(\nu \boldsymbol{1}_M, \tau^2 \mathsf{I}_M\right)$$

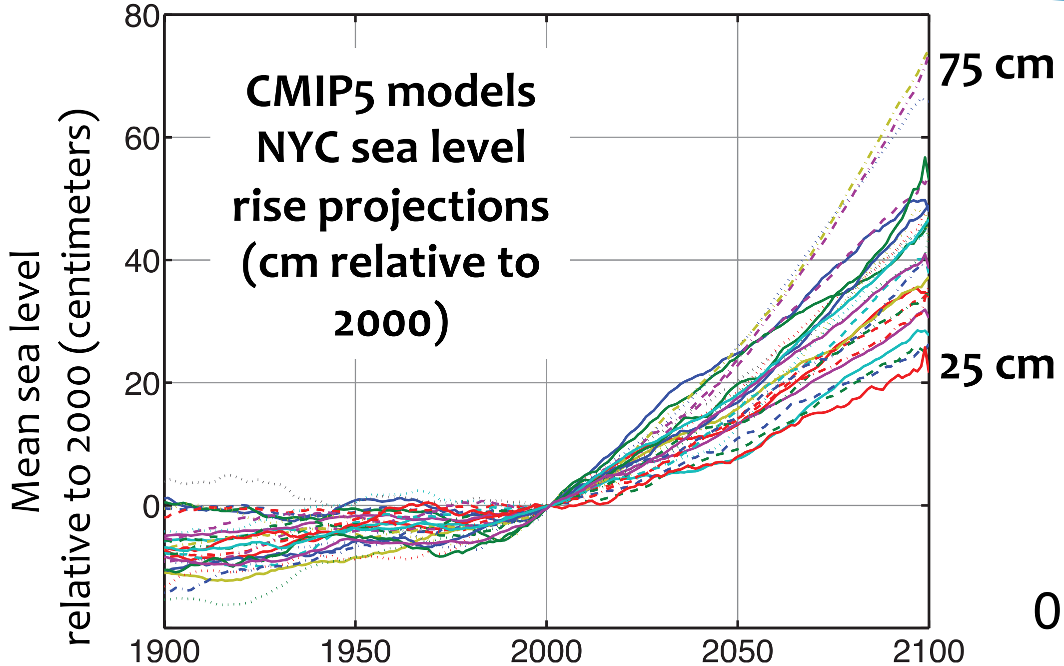
APPLY BAYES' RULE—

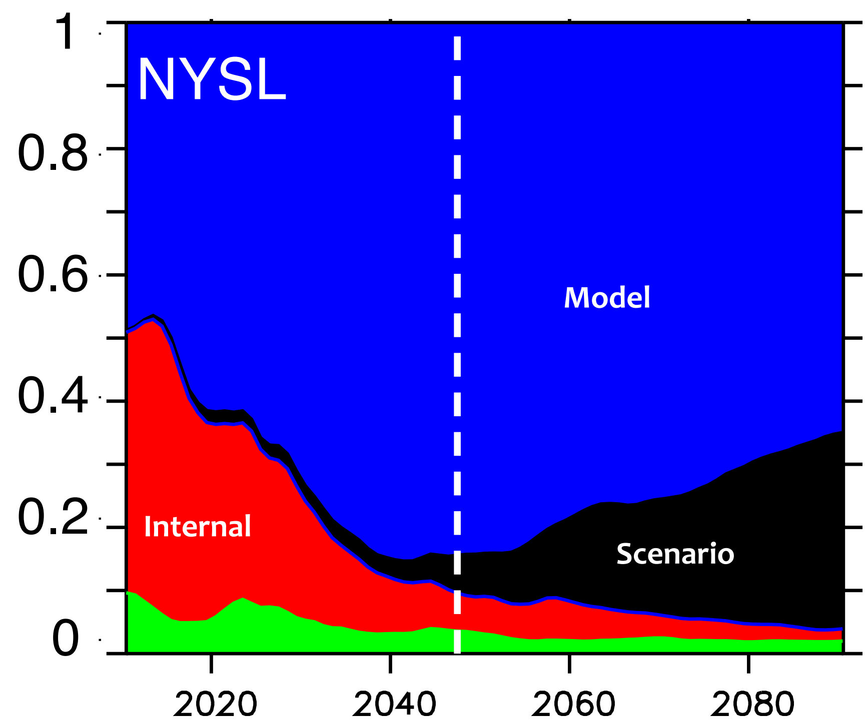
$$p\left(\boldsymbol{y}, \Theta \middle| \boldsymbol{z}\right) \propto p\left(\boldsymbol{z} \middle| \boldsymbol{y}, \Theta\right) \cdot p\left(\boldsymbol{y} \middle| \Theta\right) \cdot p\left(\Theta\right)$$



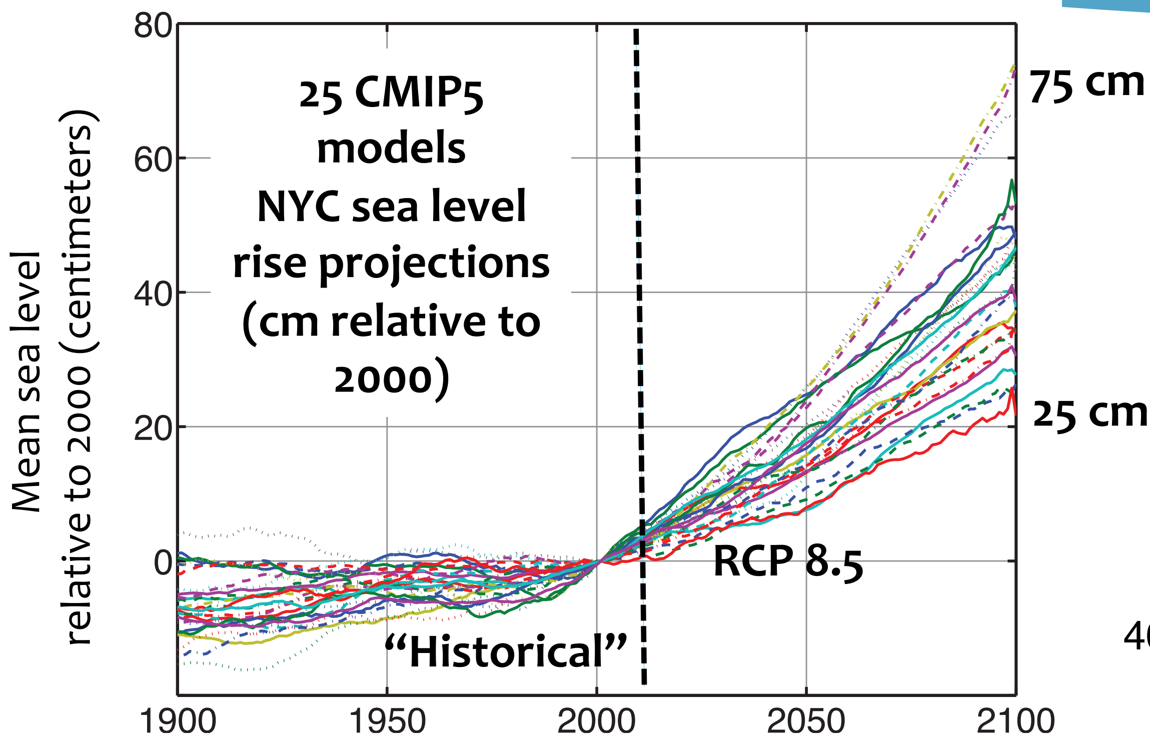
Height (m)
0.1
0
-0.1
[-74.0133,40.7]
NEW YORK (THE BATTERY)
[-71.4,41.8067]
PROVIDENCE (STATE PIER)
[-63.1167,46.2333]
CHARLOTTETOWN
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

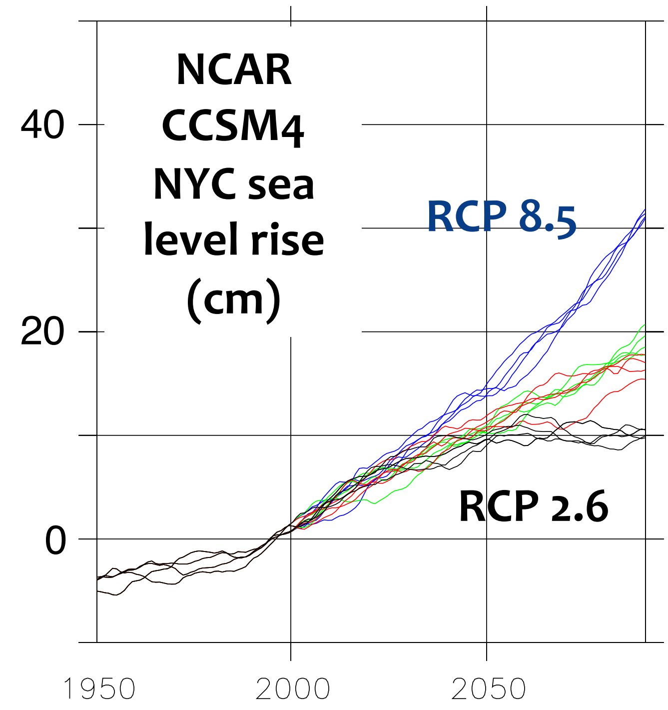
"Oceanographic" sea level rise uncertainty at New York City



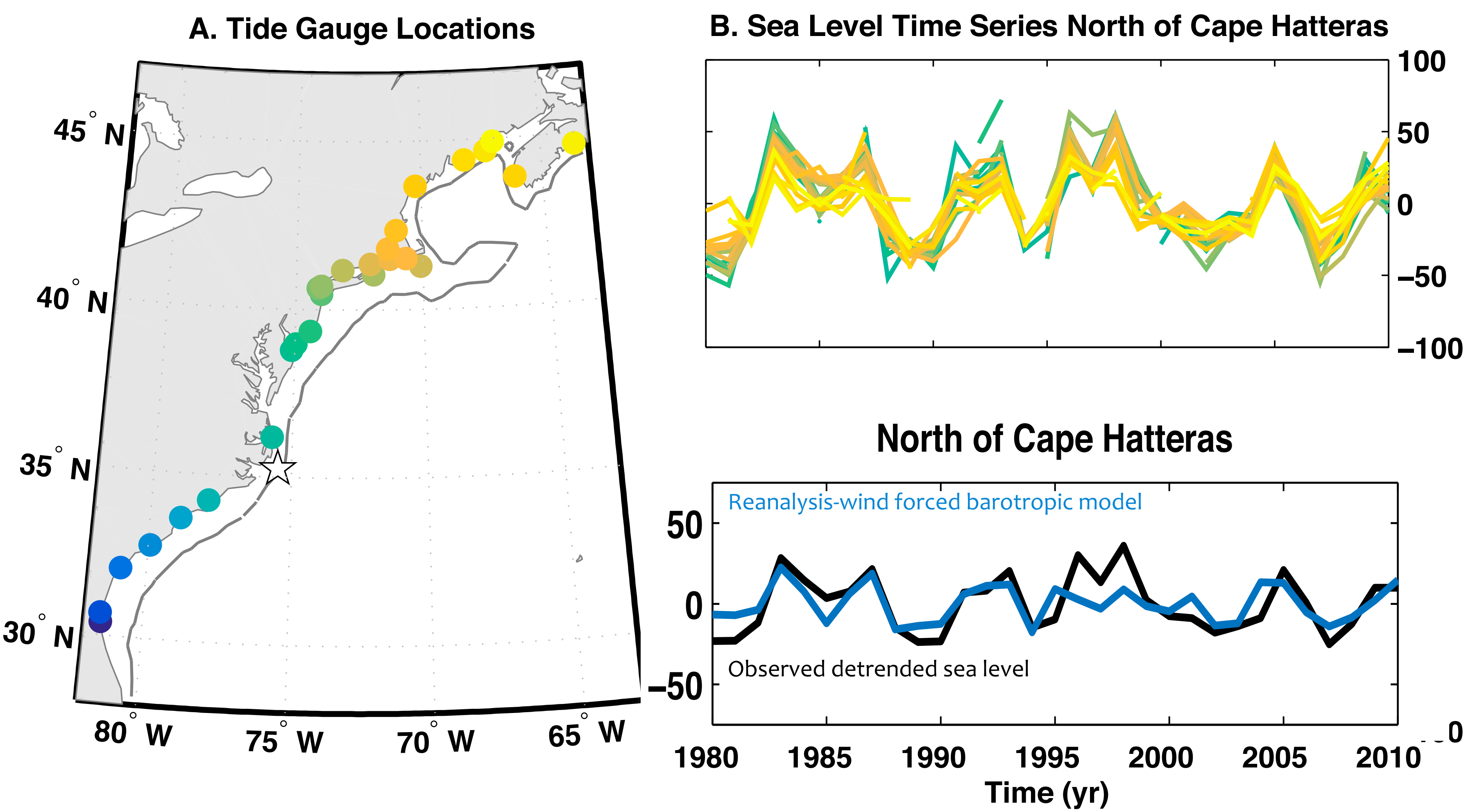


CMIP5 local sea level uncertainty



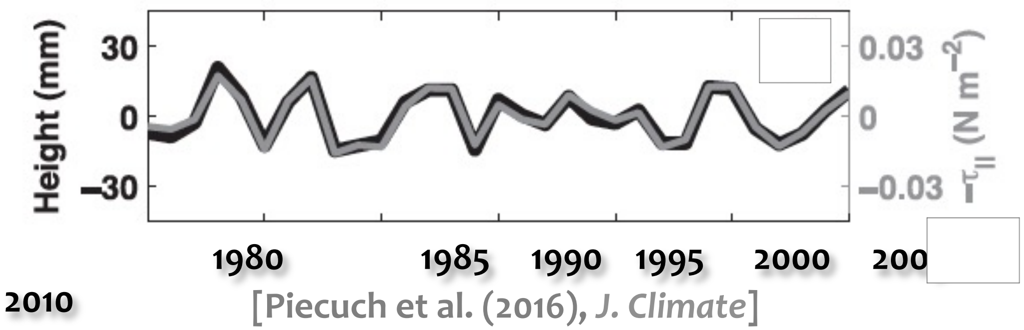


… but observations are dominated by local winds



II. Wind effects on regional sea level

* Strong anti-correlation between SL in SHAL & local alongshore winds
* Physical framework—



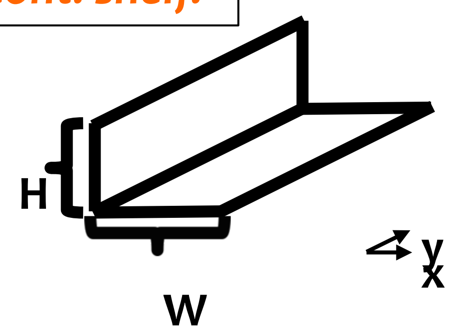
[Piecuch et al. (2016), *J. Climate*]

$$\vec{v} = \frac{g}{f}\vec{k} \times \nabla\vec{\eta}$$

$$\frac{\tau}{\rho H} = 2\frac{A}{H}v,$$

$$\Delta\eta = \frac{fW}{2A\rho g}\tau$$

Across cont. shelf!



[Piecuch et al. (2016), *J. Climate*]