Subseasonal forecast of surface water conditions in Chesapeake Bay using a hybrid approach

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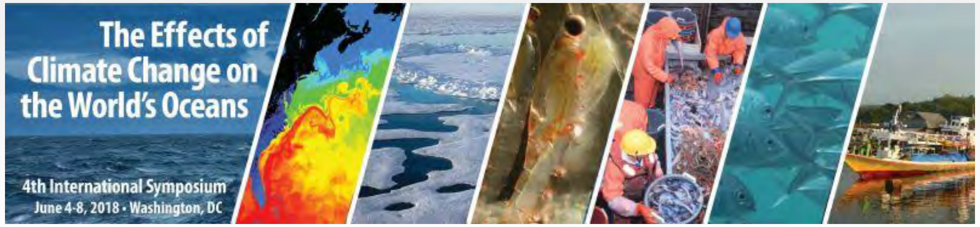
S2 - From prediction to projection: the role of seasonal to decadal forecasts in a changing climate



Estuarine ecosystems

Key ecosystem services but subject to important human impacts:

- nutrient cycling, food provision, cultural & recreational uses [~30K USD ha^{-1} yr^{-1}, rank 3rd]
- eutrophication, overexploitation and climate change

Challenging environment for resource managers

- multiple drivers and multiple sources of environmental variability
  - Streamflow (watershed), atmosphere, coastal ocean (tides)
- Scale markedly differs from target of Global Climate Models and Predictions

Can S2S2D improve management of transitional water bodies in a changing climate?

McLusky & Elliot 2004; Costanza et al 2014 Global Environ Change; Tommasi et al. 2017

Chesapeake Bay

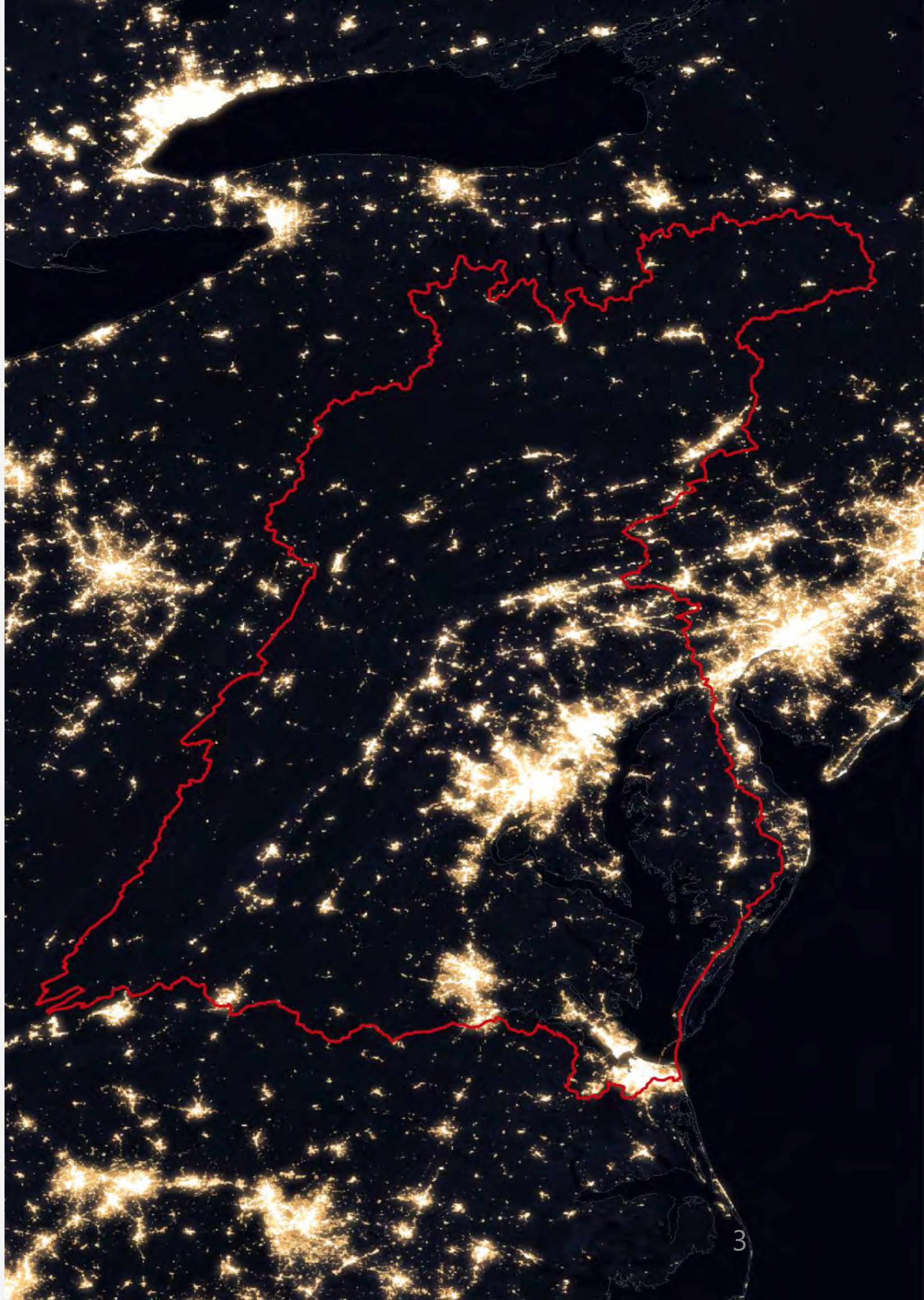
Northeast coast of USA

Huge watershed [~166534 km^2]

More than 18 million people living around

- Pollution (eutrophication)
- Climate change (sea level rise, warming)
- Overexploitation (fisheries and aquaculture)

Data for 2016, Chesapeake Bay Program



Chesapeake Bay

Northeast coast of USA

Huge watershed [~166534 km^2]

More than 18 million people living around

Area 11000 km^2

Volume 74.4 km^3

- More than 150 tributaries
- Total inflow ~2300 $m^3\ s^{-1}$
- Susquehanna river ~50%

Chesapeake Bay Program; USGS Water Services

Chesapeake Bay

Northeast coast of USA

Huge watershed [~166534 km^2]

More than 18 million people living around

Area 11000 km^2

Volume 74.4 km^3

- 300 km long
- 25 km wide [5-60 km]
- 6.5 m depth [up to 50 m in central channel]

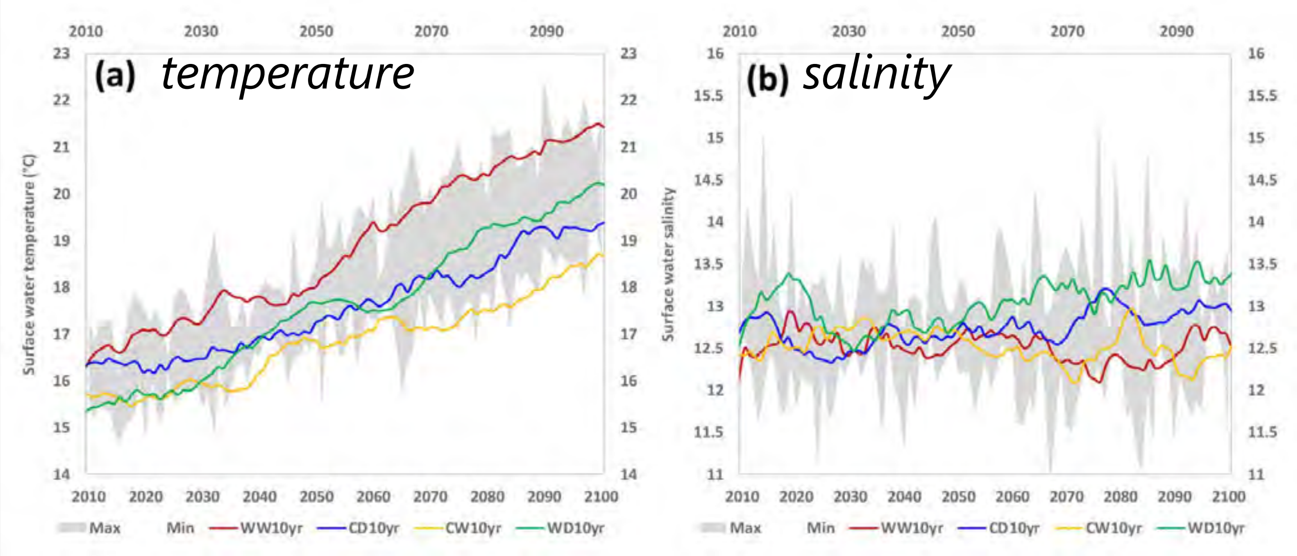
Chesapeake Bay Program; USGS Water Services

Background – decadal to century long

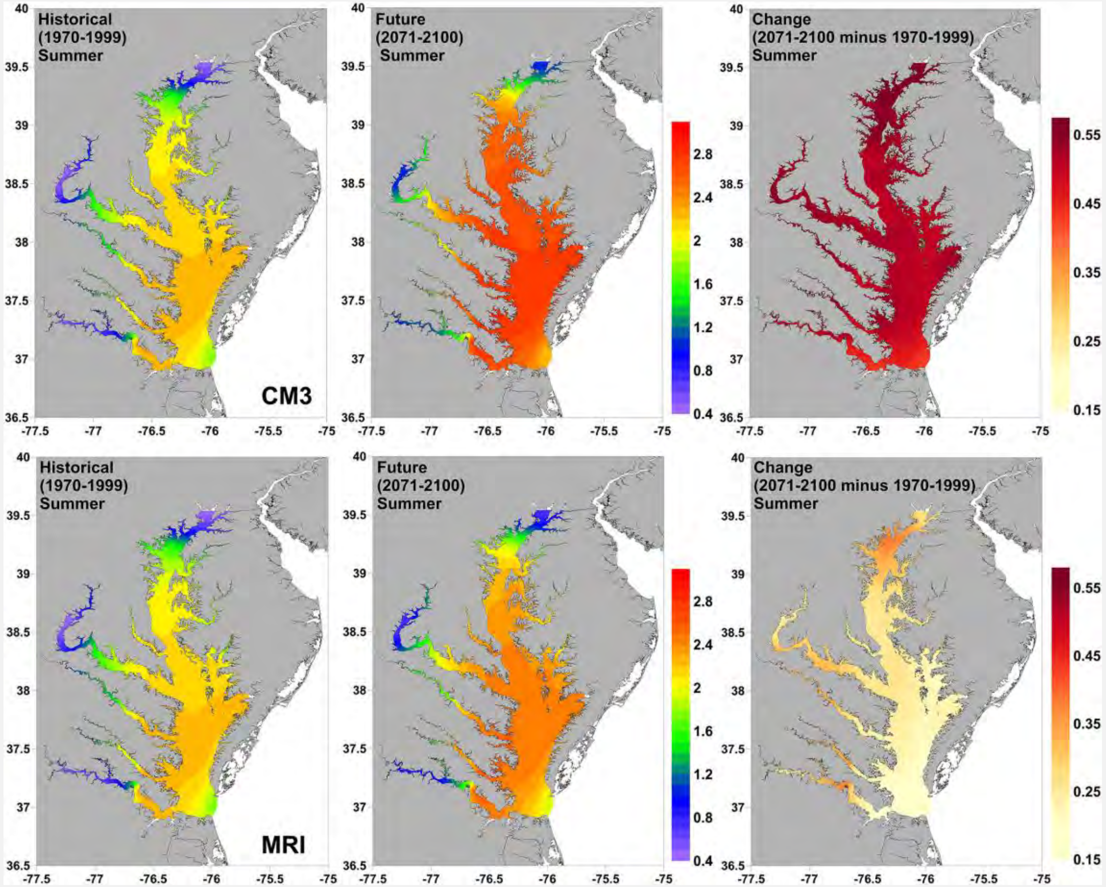
Projected increase in the mean concentration of *Vibrio parahaemolyticus* in oyster during summer

Long term changes associated with climate change

GCM atmospheric conditions
Statistical Downscaling (ESD)
Regression Trees



Projected changes in temperature and salinity in surface waters



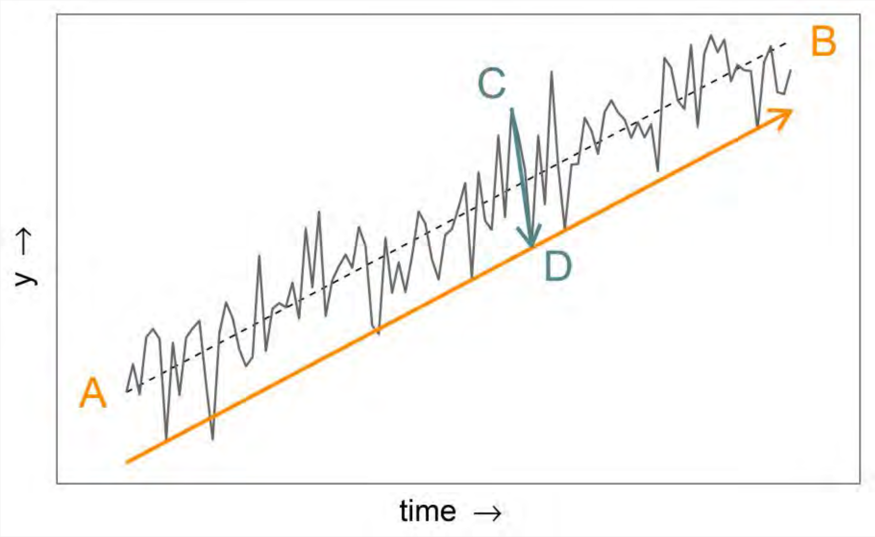
Muhling et al 2017 Estuaries and Coasts; Muhling et al 2017 GeoHealth

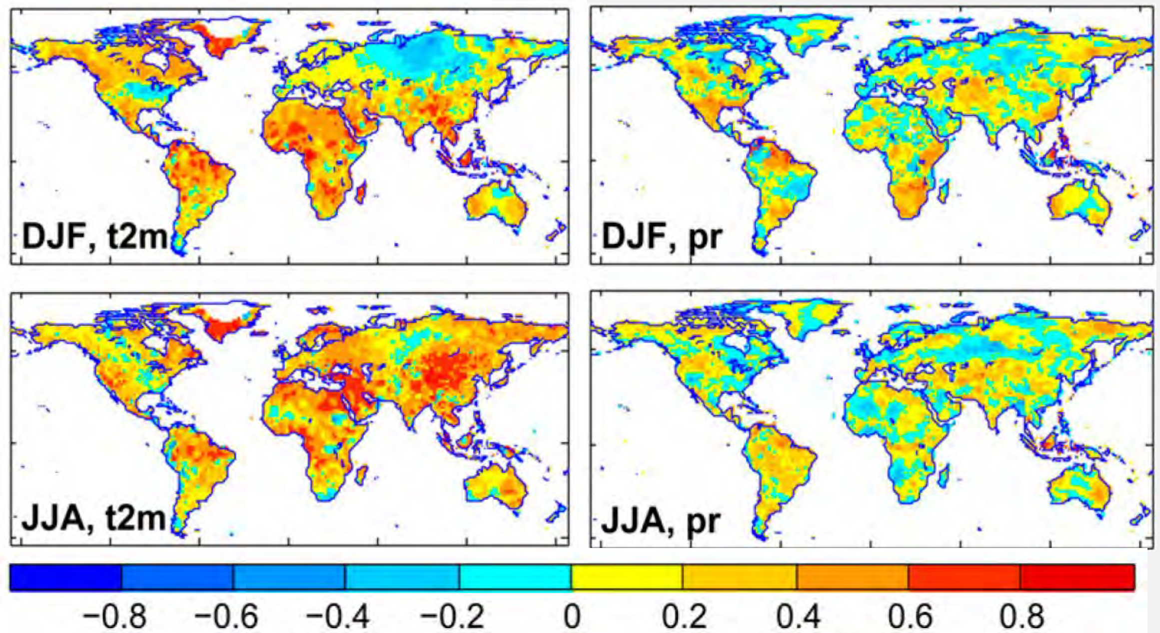
Subseasonal to Seasonal (S2S)

Initial *vs* boundary conditions

Adapted GCMs configurations

- Data assimilation
- Limitations [e.g. *precipitation*]





Skill for temperature and precipitation averaged for leads between 0 and 9 months using GFDL FLOR forecast system

Jiao et al 2015 J Clim

Data – 1986-2015 (30 years)

Thomas Point buoy *TPLM2*

National Data Buoy Center C-MAN station;

- More than 30 years of daily data
- Air temperature [*tas*] and sea surface temperature [*tos*]

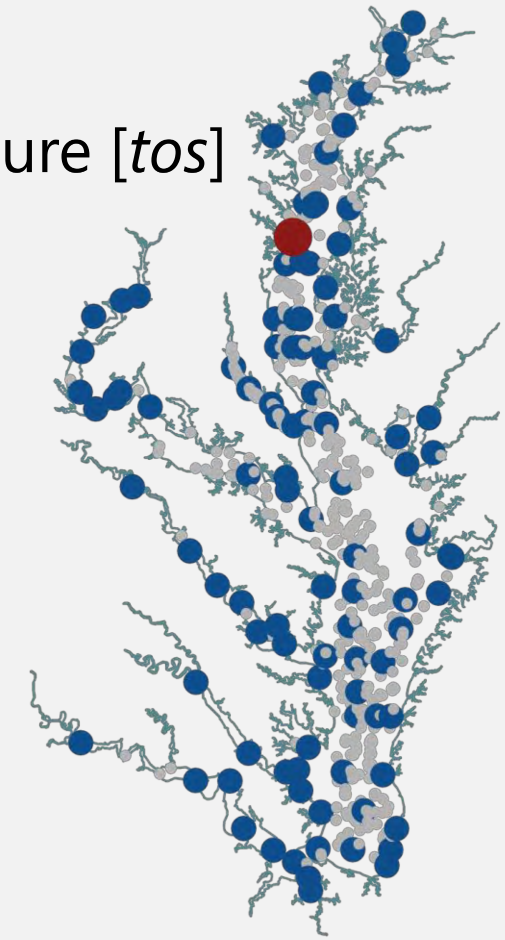
CTD data

Sparse but extensive [>40K obs]

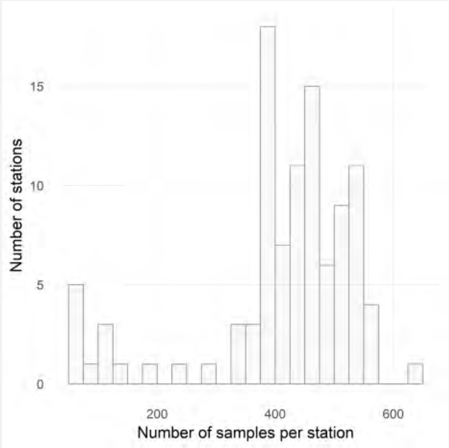
- 92 fixed stations, ~ fortnightly/monthly
- Sea surface temperature [*tos*] and salinity [*sos*]

Three main contributors;

- Chesapeake Bay Program
- University of Maryland
- Smithsonian Institution

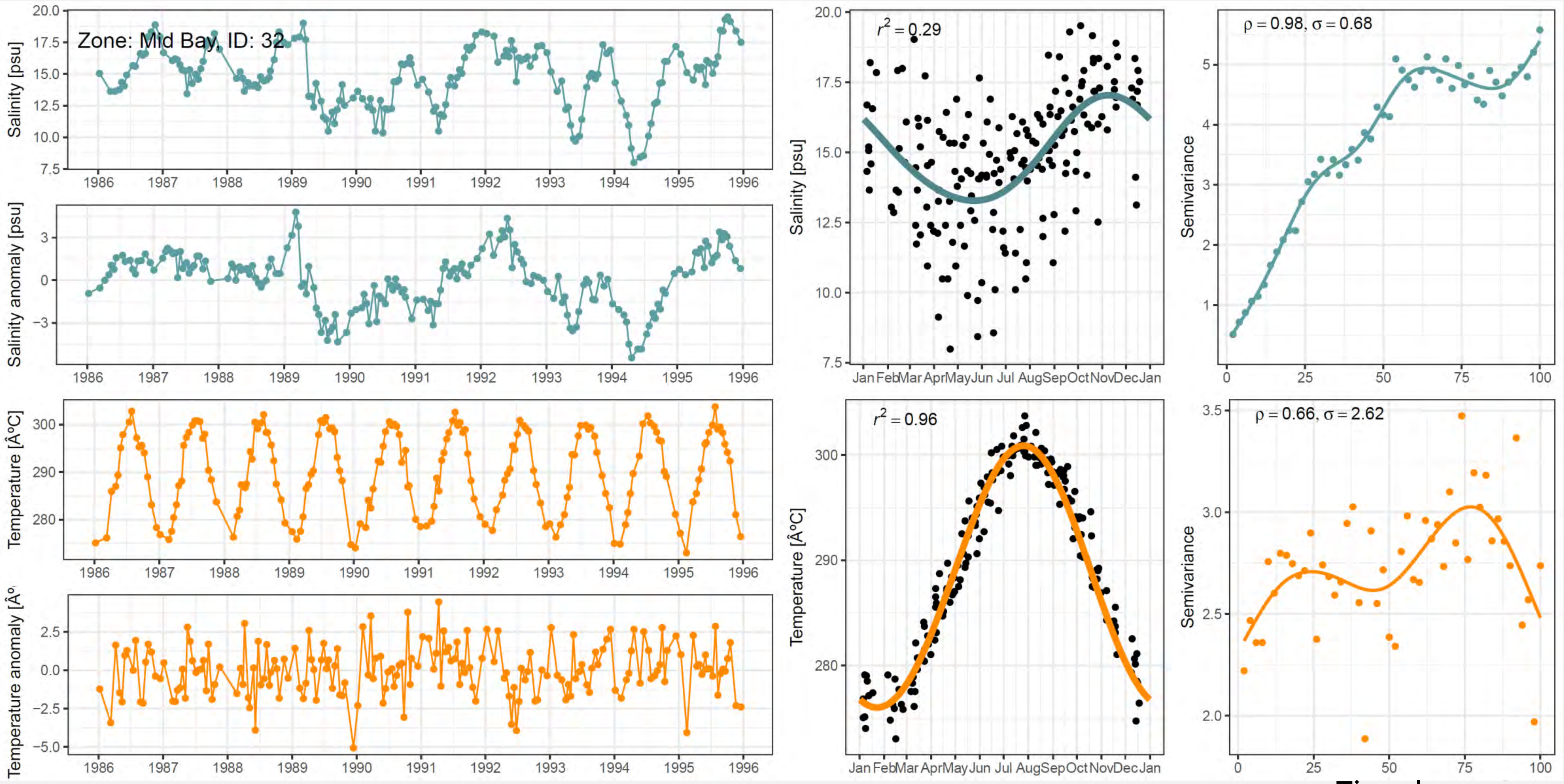


casual observations
fixed array
Thomas point



Station data

Raw and anomaly time series plots — *Seasonality* — *Variogram*



Time lag

Three component hybrid framework for S2S

1. Forecast-oriented Low Ocean Resolution (FLOR)
   - NOAA-GFDL Climate Model 2.5
   - Data assimilation + HR [50 km atmosphere]

2. Framework for Unified Downscaling of GCMs Empirically (NOAA-GFDL FUDGE)
   - Quantile mapping of FLOR forecasts

3. Hierarchical Bayesian spatiotemporal model (HBSTM)
   - Initial condition; reconstruct spatial *tos and sos* anomaly fields
   - Forecast anomaly evolution taking advantage of FLOR forecasts and covariates

Vecchi et al. 2015 J Clim; Dixon et al. 2017 Clim Change; Cressie & Wikle 2013

Framework for S2S – covariates

FLOR anomalies could improve tos forecasts

Downscaled [QMap] to match Thomas Point data and transformed to *tos* anomalies

Surface water temperature anomaly @ Thomas Point

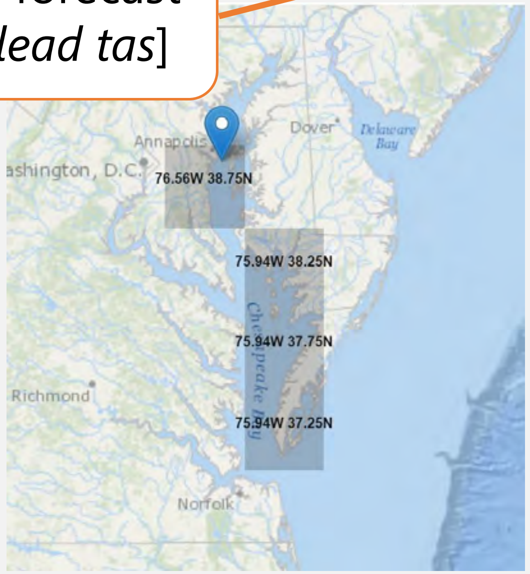
TPLM2 C-MAN
daily *tas*

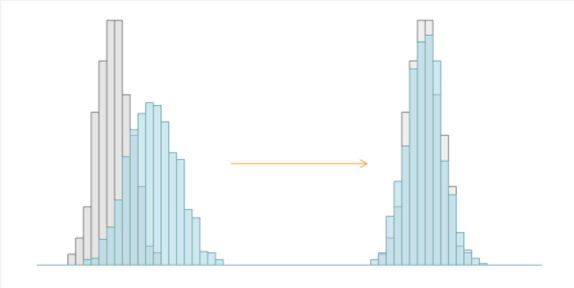
FLOR daily forecast
[*1 month lead tas*]

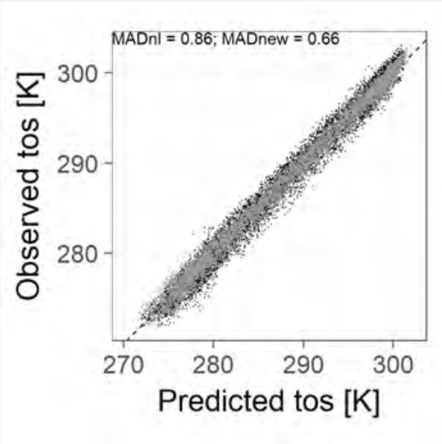
FUDGE
ESD-QM

1 month lead
ESD-FLOR
daily *tas*

1 month lead
ESD-FLOR
weekly *tos*







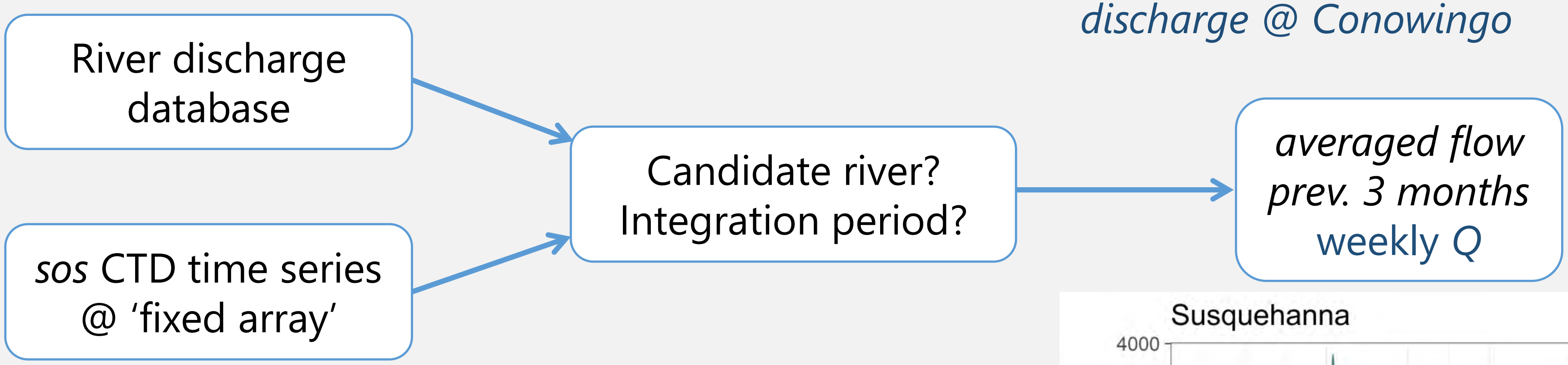
Framework for S2S – covariates

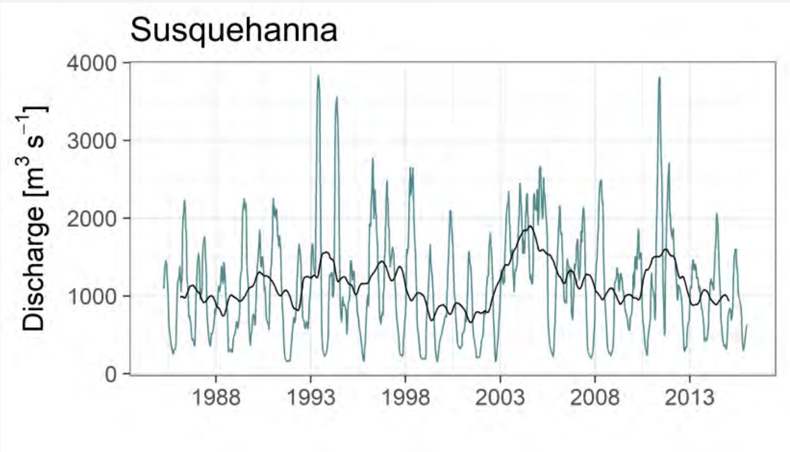
Past river discharge can inform changes in salinity

Inability to predict precipitation but mechanistically consistent

[residence time ~180 days]

Susquehanna river discharge @ Conowingo





Du & Shen 2016 J Mar Syst

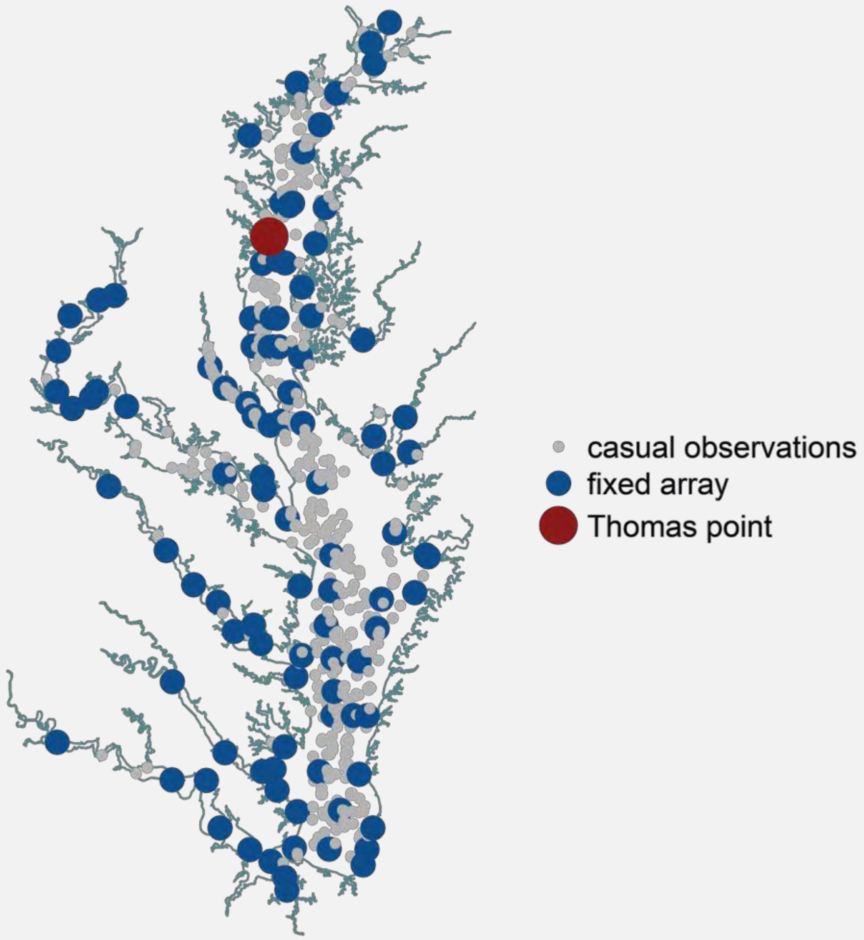
Framework for S2S – hierarchical model

Combine different data sources;

- Covariates provide info at a single point
- Target observations irregularly distributed

Hierarchical spatiotemporal model;

- Based on Wikle et al. 1999 *Environ Stats*
- Reconstruct underlying field
- Project short term evolution

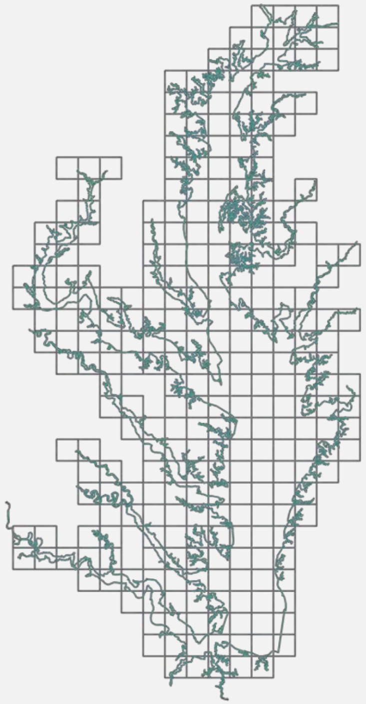


Cressie & Wikle 2013

Framework for S2S – hierarchical model

1. Weekly evolution of *tos* or *sos* in a 10 km grid
2. Space-time decomposition based on spatially varying;
    a. Mean [$\mu(s)$]
    b. Seasonal cycle [$S(s,t)$]
    c. Covariate effect [$\nu(s)\ N(t)$]: *none, FLOR or Susquehanna*
    d. Local decay and (fixed) neighbor effects (VAR) [$X(s,t)$]
3. Spatial smoothness constrain (Gaussian random fields)
4. Assessment based on sequential fitting (2011-2015)

and one-step ahead forecasts (1 month lead)



$$Z(s,t) \sim Normal(M\ Y(s,t), \sigma_\epsilon)$$

$$Y(s,t) = \mu(s) + S(s,t) + \nu(s)\ N(t) + X(s,t)$$

$$X(s,t) = H\ X(s_{NN}, t-1) + \gamma_{t-1},$$

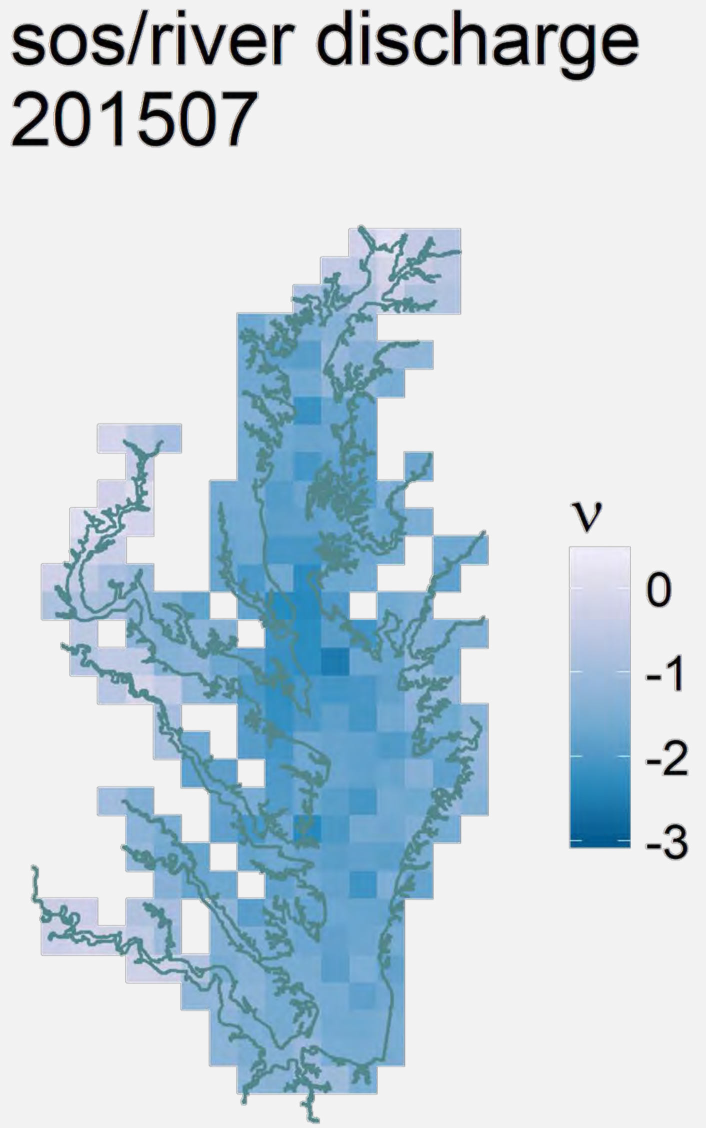
$$\gamma_t \sim Normal(0, \sigma_\gamma)$$

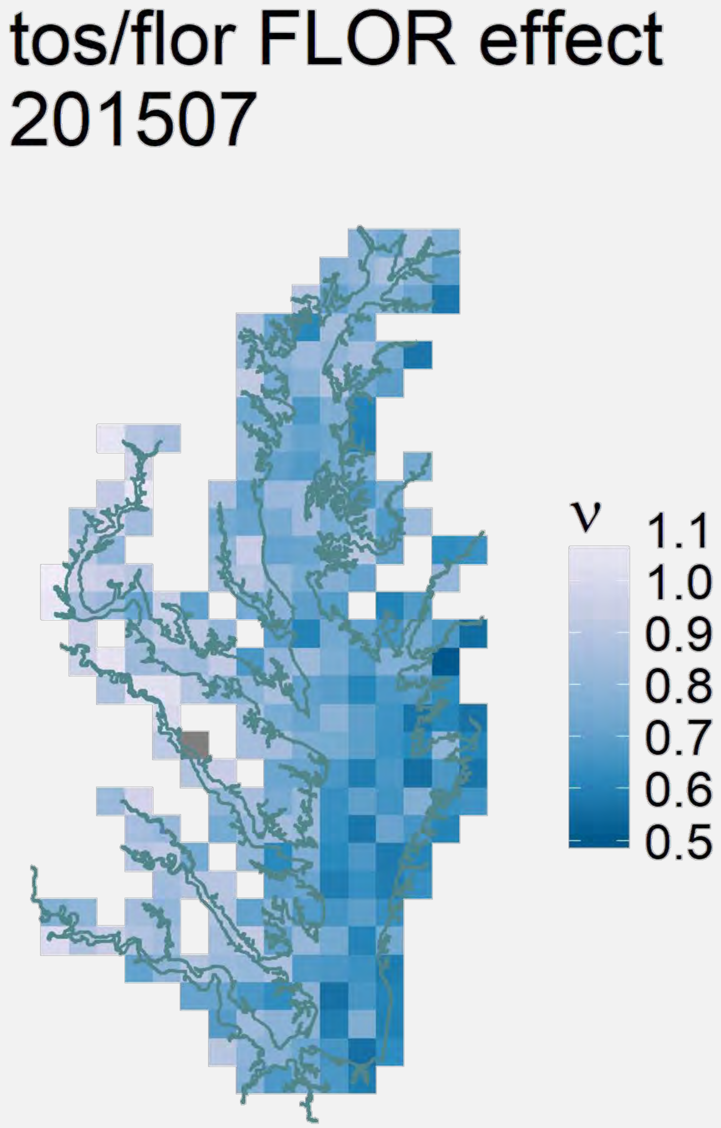
Cressie & Wikle 2013; Wikle et al. 1999 *Environ Stats*

Results – covariate effects

River discharge decreases salinity in lower bay but nil in upper bay [always fresh]

Temperature anomalies are more similar to ESD-FLOR close to TPLM2

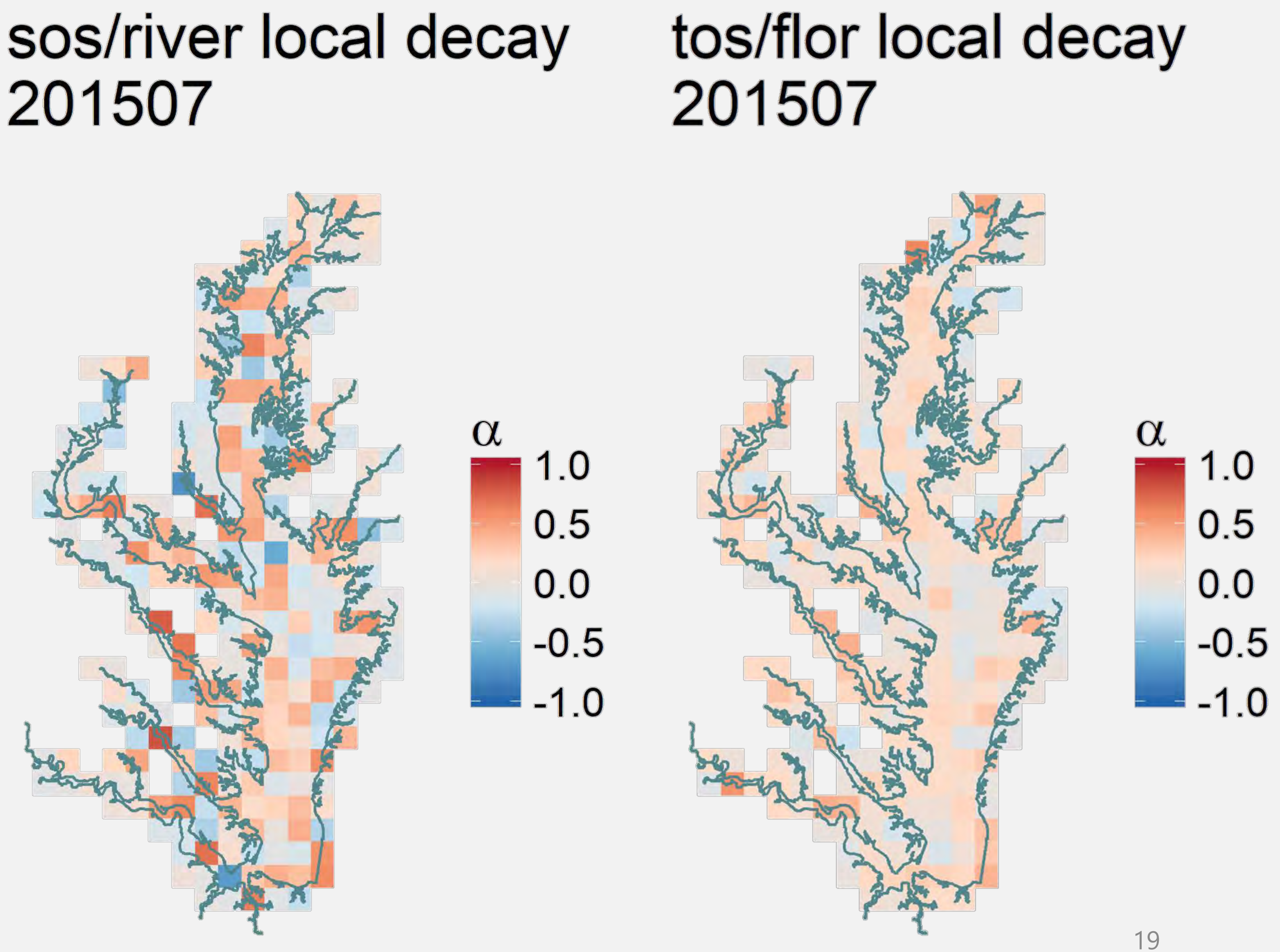




Results – persistence

Reinforces the notion that river anomalies are more persistent

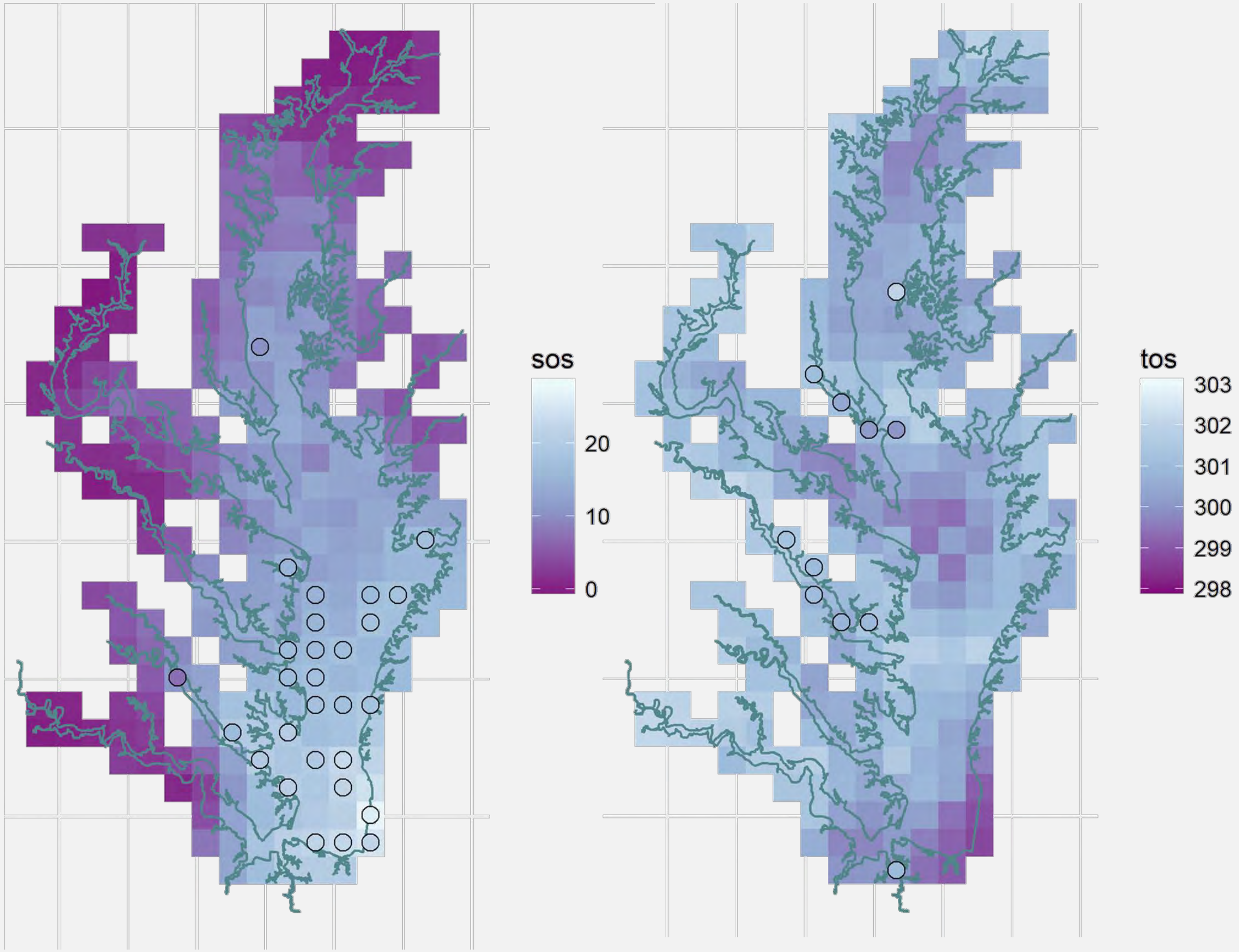
(note that the model includes the covariate effect)



Results – example predictions

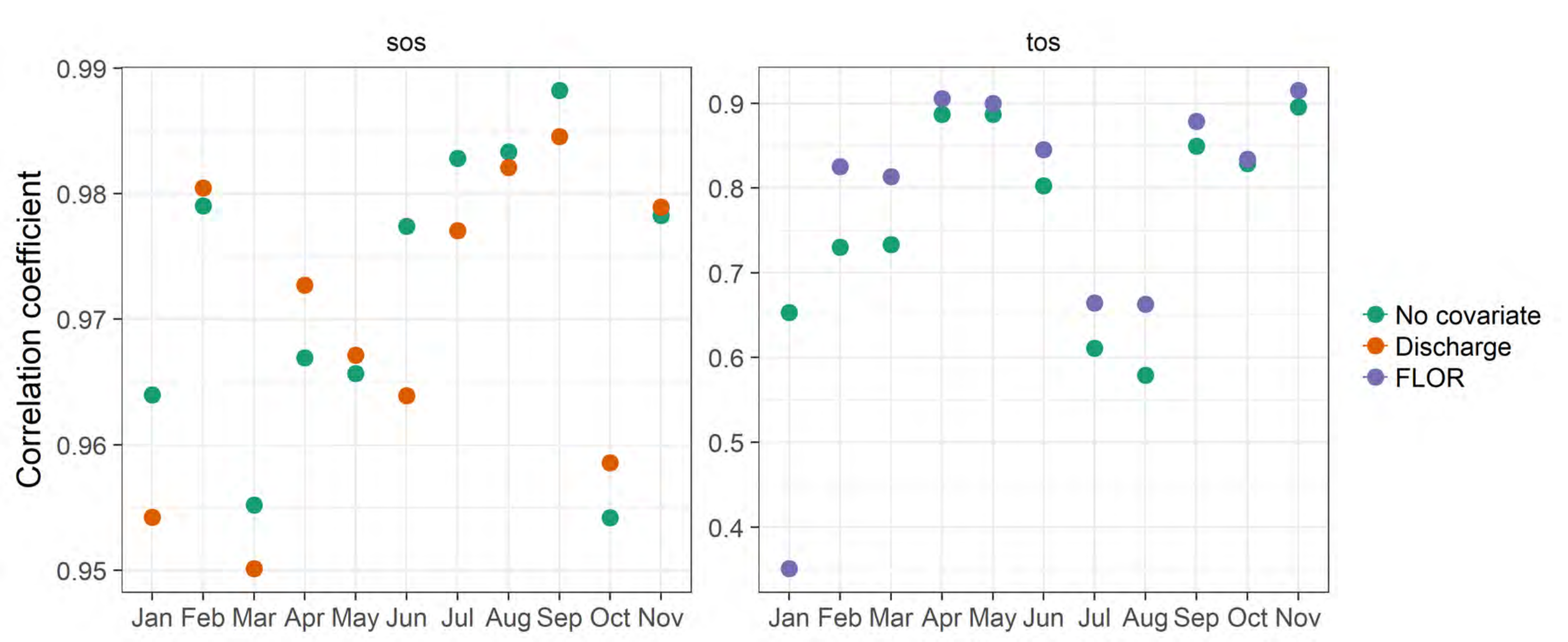
Works relative well in many cases …

[… others not!]



Results – monthly correlation skill

Correlation between predictions and observations, different months for 2015



NOTE the change of scale between *sos* and *tos* panels

Summary and prospects

Hybrid approach improves predictability wrt either approach independently (statistical or dynamic); *take the best of the two worlds*

Downscaling highlighted again as key approach to solve the change of support problem and to account for model biases

Potential applications towards decreasing the impacts associated with

- marine pathogens (*Vibrio*) and jellyfish blooms
- eutrophication and anoxia

Explore potential extension to other transitional water bodies

With special thanks to
Carlos Gaitán [Arable Labs]
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Xiaosong Yang [NOAA GFDL/UCAR]

Data sources
CTD Monitoring [*tos & sos*]
Chesapeake Bay Program
Univ Maryland Chesapeake Biological Lab
Smithsonian Environmental Research Center

Thomas Point [TPLM2 C-MAN] – NOAA NBDC

River discharge - USGS Water Services

Bathymetry - NOAA NCEI

GIS & Satellite imagery
Natural Earth
Chesapeake Bay Program
NASA EOSDIS Worldview
NASA Visible Earth