Societally-Relevant Multi-Year Climate Predictions Workshop Mar 28, 2022

Seasonal-to-decadal variability and prediction of the Kuroshio Extension in the GFDL Coupled Ensemble Reanalysis and Forecasting system

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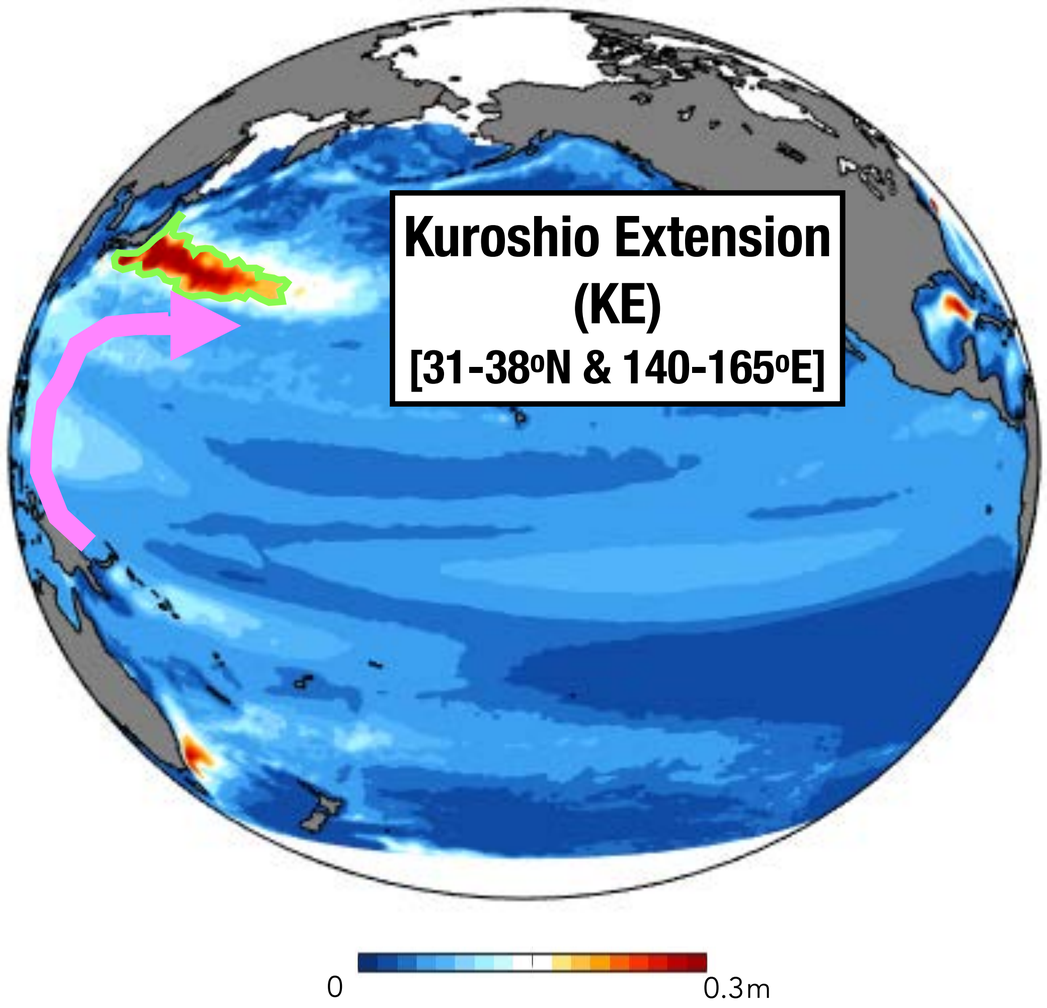
Geophysical Fluid Dynamics Laboratory
University Corporation for Atmospheric Research
Science Applications International Corporation

Pacific Western Boundary Current (WBC) system



Sea Surface Height (SSH) standard deviation

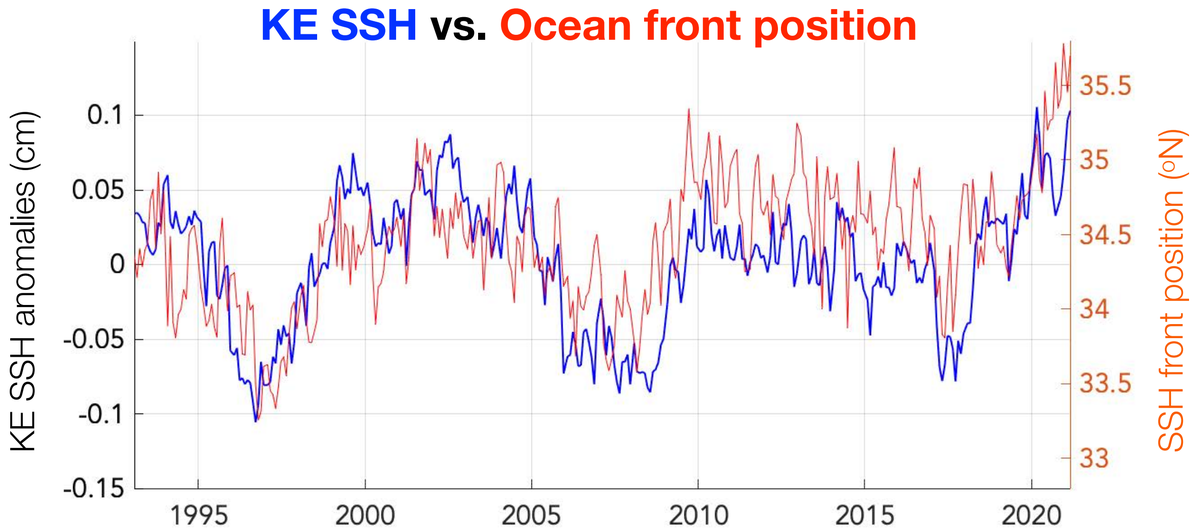
- Releases substantial heat to the atmosphere via turbulent fluxes of latent and sensible heat (Kuroshio-Oyashio Extension)

  Small et al. 2008, Taguchi et al. 2009

- Exhibits the **strongest SSH variability** due to oceanic current and mesoscale eddy activity

- Effective proxy for decadal modulations of the Pacific WBC system (e.g., eddy kinetic energy level, ocean front, recirculation gyre)

  Qiu et al. 2014 (JCLI)



Pacific Western Boundary Current (WBC) system

Motivations

KE variability plays a key role in modulating the Pacific decadal climate.

- Releases substantial heat to the atmosphere via turbulent fluxes of latent and sensible heat (Kuroshio-Oyashio Extension)
- Exhibits the **strongest SSH variability** due to oceanic current and mesoscale eddy activity
- Effective proxy for decadal modulations of the Pacific WBC system (e.g., eddy kinetic energy level, ocean front, recirculation gyre)
- Multi-year predictability associated with slow oceanic baroclinic adjustment that carries the wind-forced SSH signals into the KE region

GOAL

Exploring the representation and prediction skill of the KE SSH variability in GFDL SPEAR coupled climate model (reanalysis and forecast systems)

more details in Delworth et al. 2020

SPEAR (Seamless system for Prediction and EArth System Research)

:Next generation modeling system for seasonal to decadal prediction and projection at GFDL
AM4 atmosphere model + MOM6 ocean code + LM4 land model + SIS2 sea ice model

SPEAR_LES
Large-Ensemble

	SPEAR_LO	SPEAR_MED	SPEAR_HI	SPEAR_HI_25
atmosphere/land	100km	50km	25km	25km
ocean/sea ice	approximately 1° (with tropical refinement)			25km

Coupled Initialization Reanalysis

RS-ATMSST
Restoring atmospheric temp/winds & SST
No subsurface ocean observation

ODA
SST & subsurface ocean data assimilation
No atmospheric observation

Nudging-ATMSST
Nudging atmospheric temp/winds/humidity & SST
No subsurface ocean observation

GFDL SPEAR Forecast systems

Decadal Retrospective Forecast (DRF, SPEAR_LO)

Yang et al. 2021 (JAMES)

Seasonal Retrospective Forecast (SRF, SPEAR_MED)

Lu et al. 2020 (JAMES)

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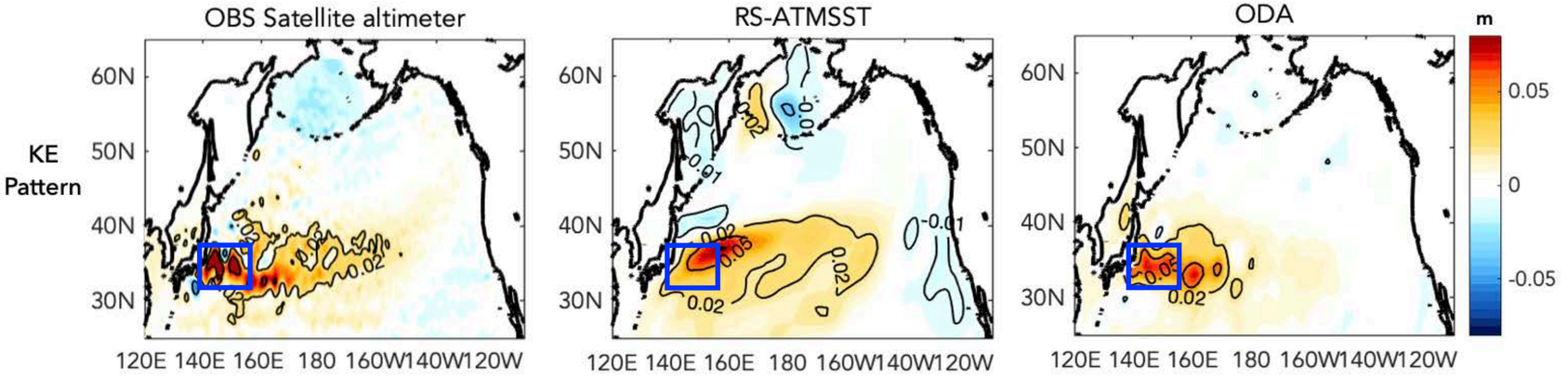
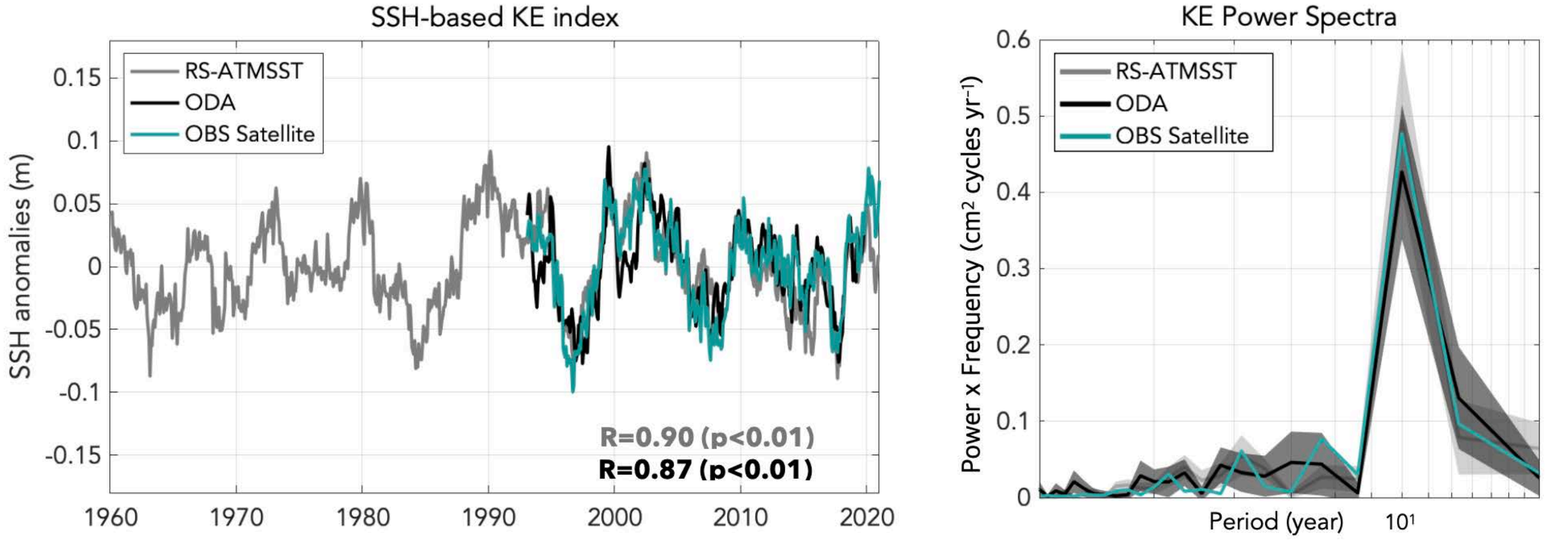
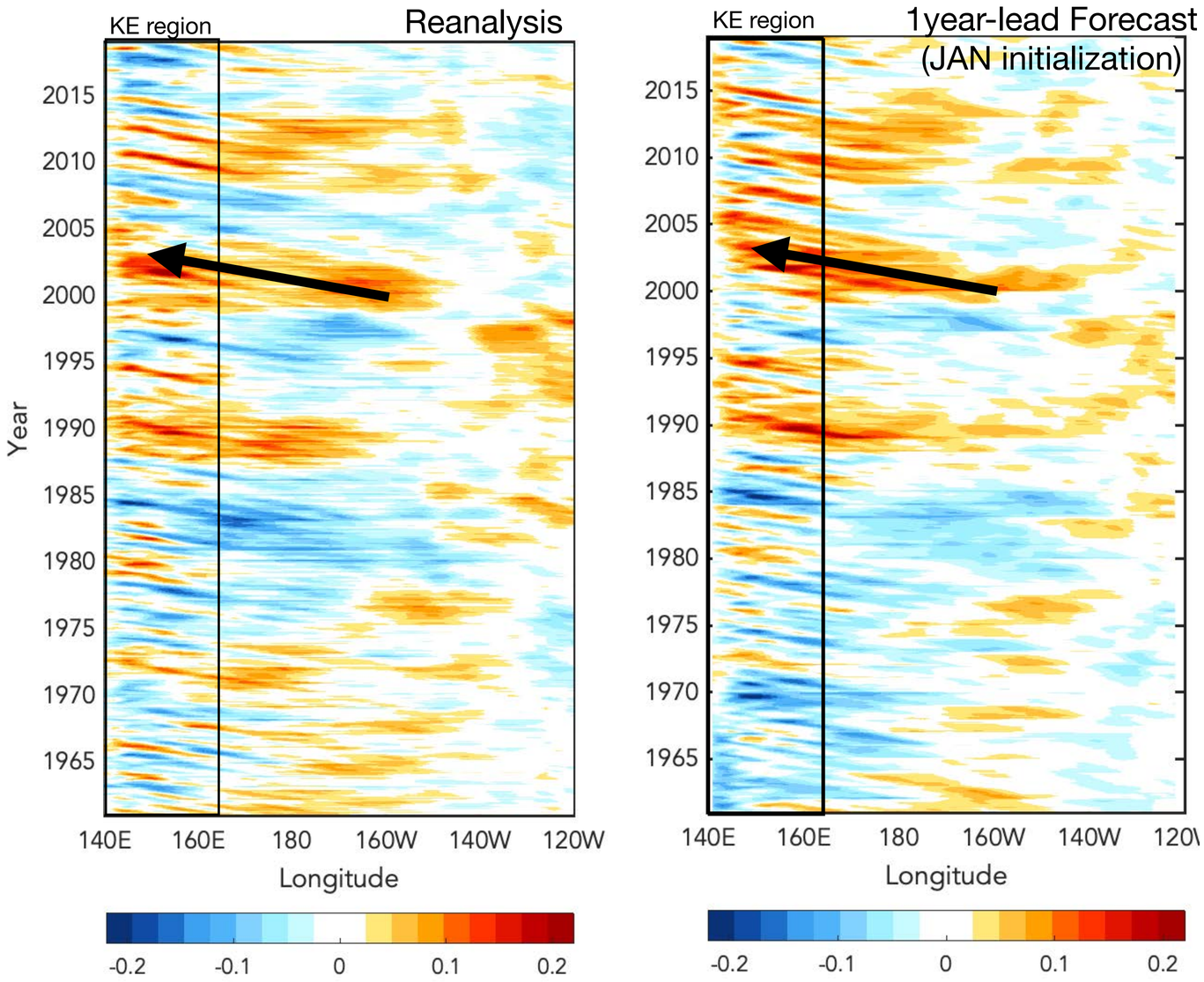


1. Subsurface ocean observation is essential to resolve an accurate position of the KE ocean front and eddy-associated oceanic dynamics (upstream KE).



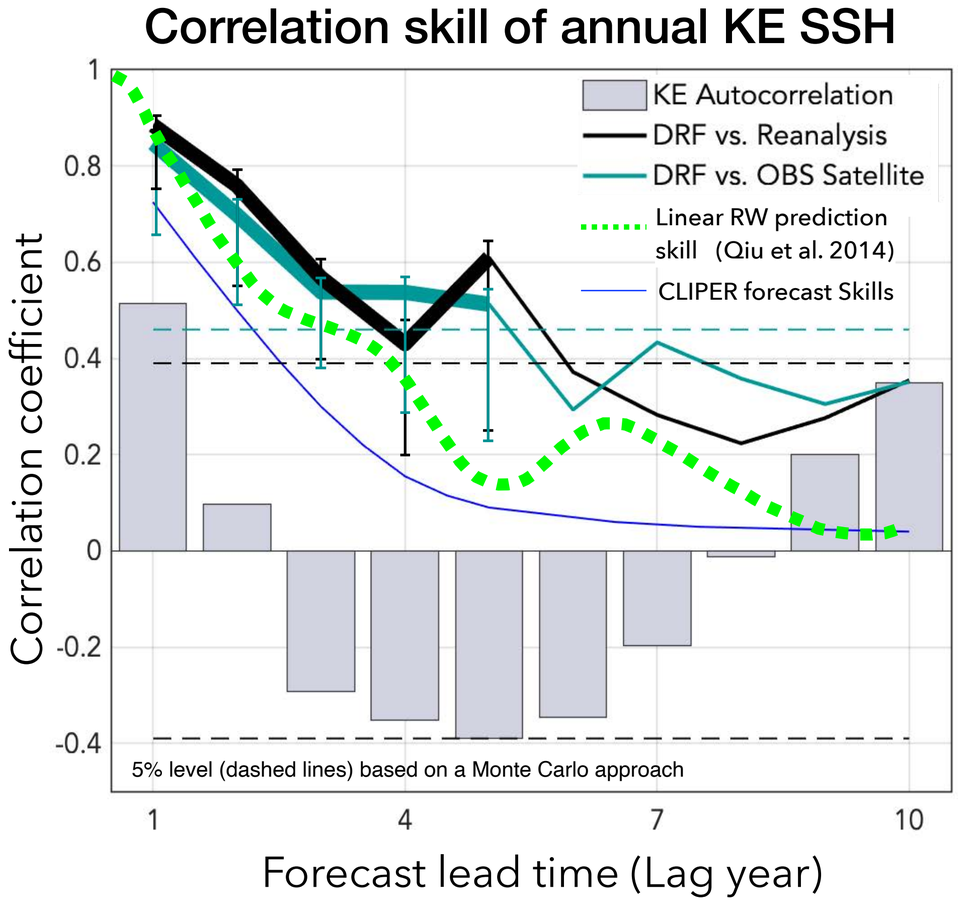
2. Both reanalysis systems detect reasonable KE SSH temporal evolutions comparable to Satellite including wind-forced decadal KE SSH variability (~10 year time scale).

Wind-induced KE SSH on longer time scales



Meridionally-averaged mid-latitude SSHa

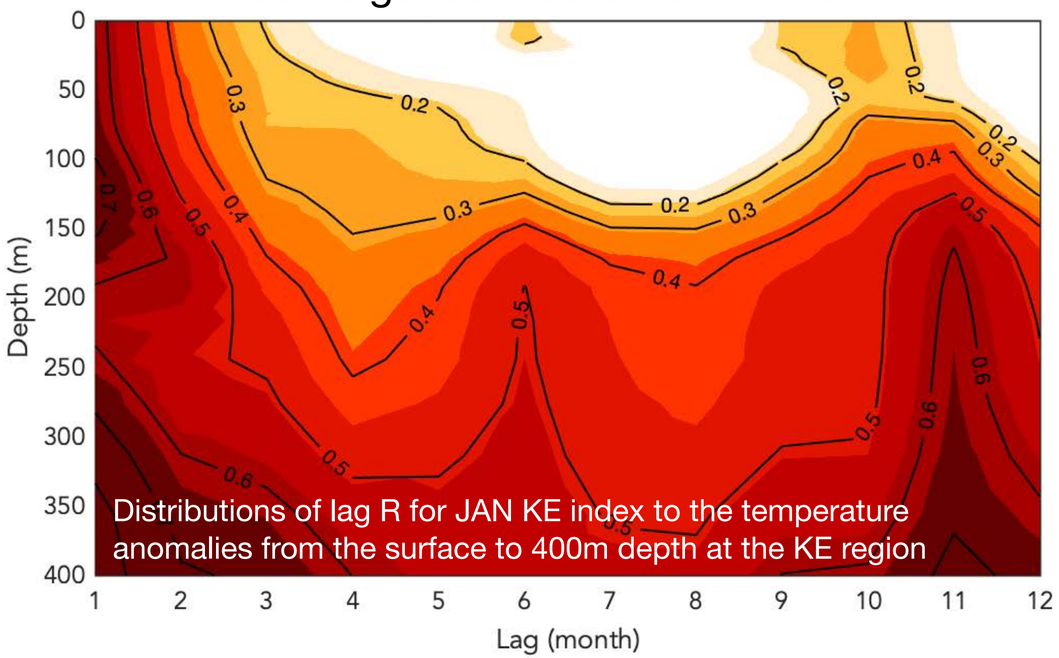
Decadal Retrospective Forecast (DRF)



Significant KE SSH forecast skill up to **5 yrs when using 20 member ENS mean**, **3 yrs when using individual model** in Decadal Retrospective Forecast system

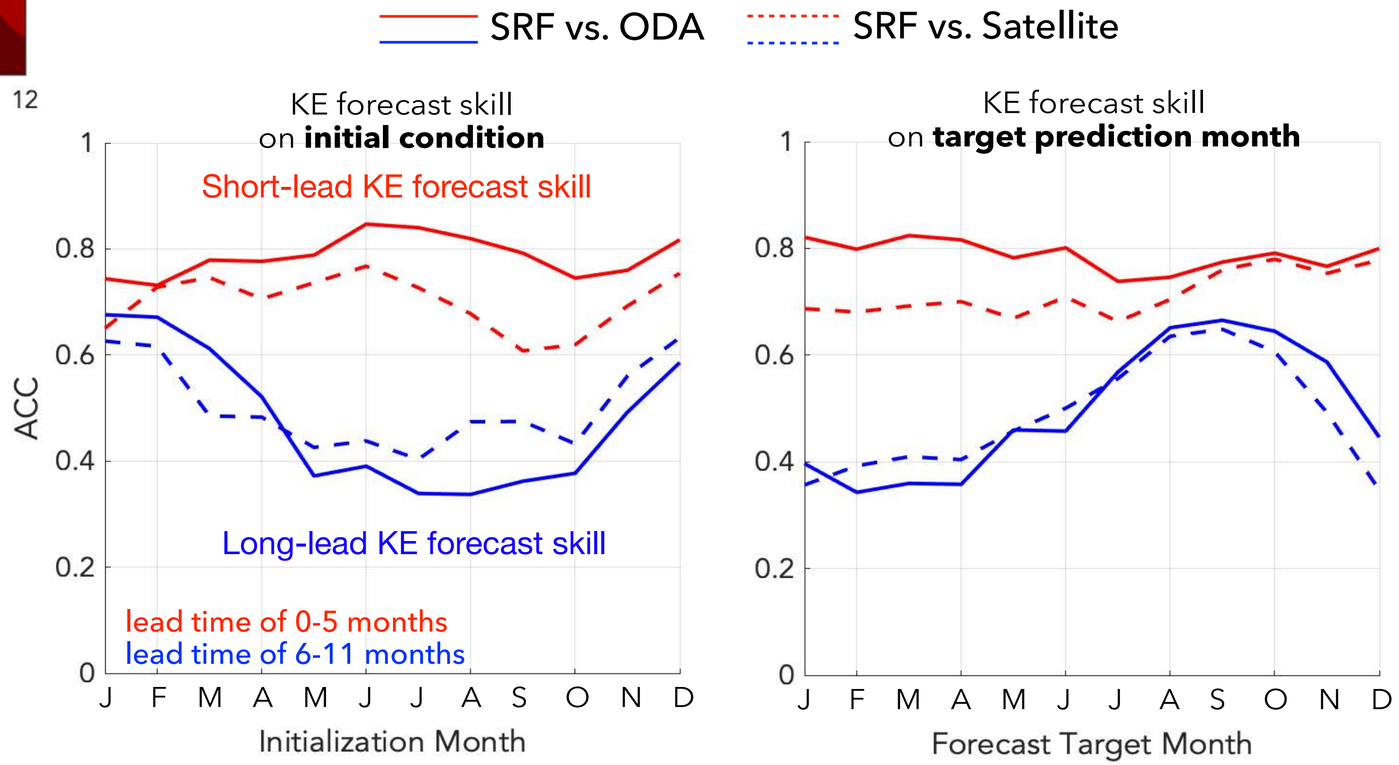
Seasonal Retrospective Forecast (SRF)

Reemergence mechanism in the KE

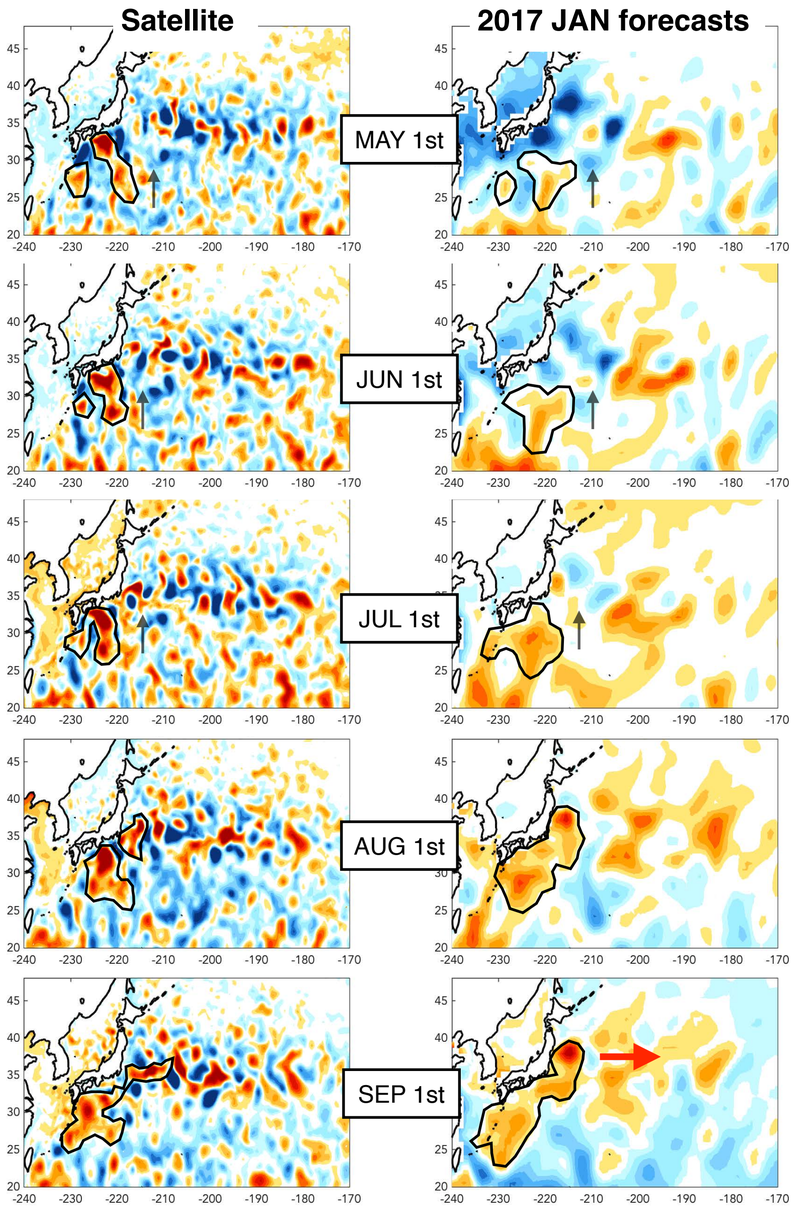


“Initialization & lead time dependent” KE prediction skill

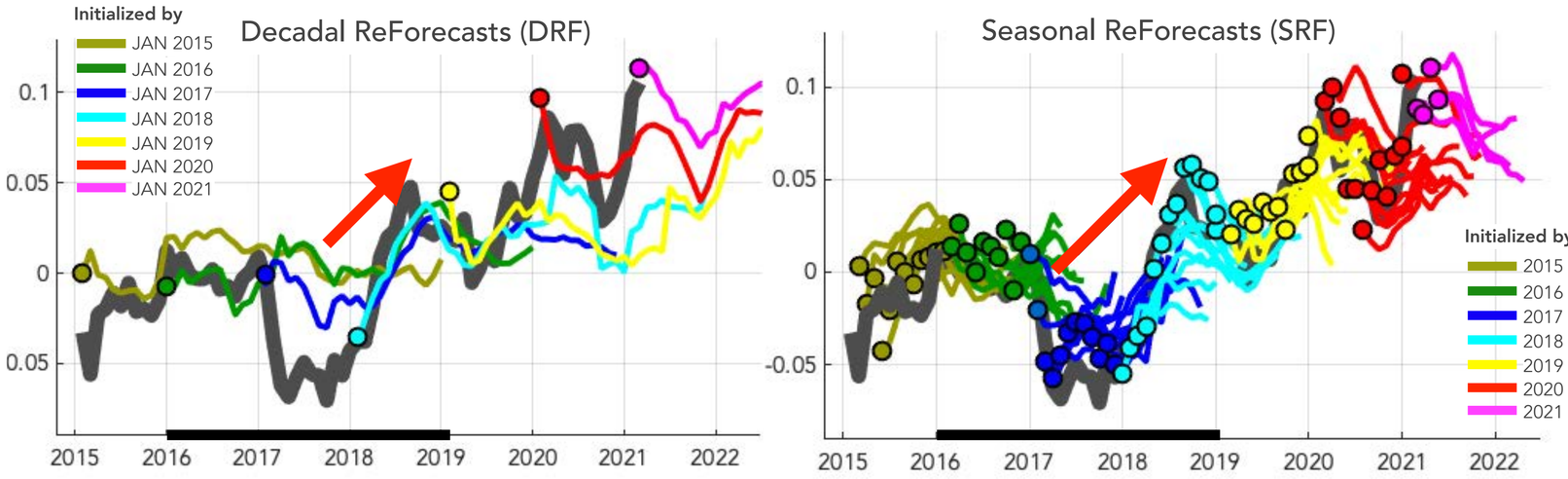
Best forecast skill: **using Winter initialization targeting Autumn KE SSH**



2017-2018 KE phase transition induced by the large meander episode



Observed (black) and predicted (colored) recent KE index



Higher multi-year prediction skill of dynamical model forecasts compared to that of linear RW forecasts?

Existence of strong air-sea coupling and coherent atmosphere and ocean fluctuations in coupled dynamical models, contributing to detect more accurate and comprehensive KE dynamics → a potential of real-time KE prediction

Summary and Discussion

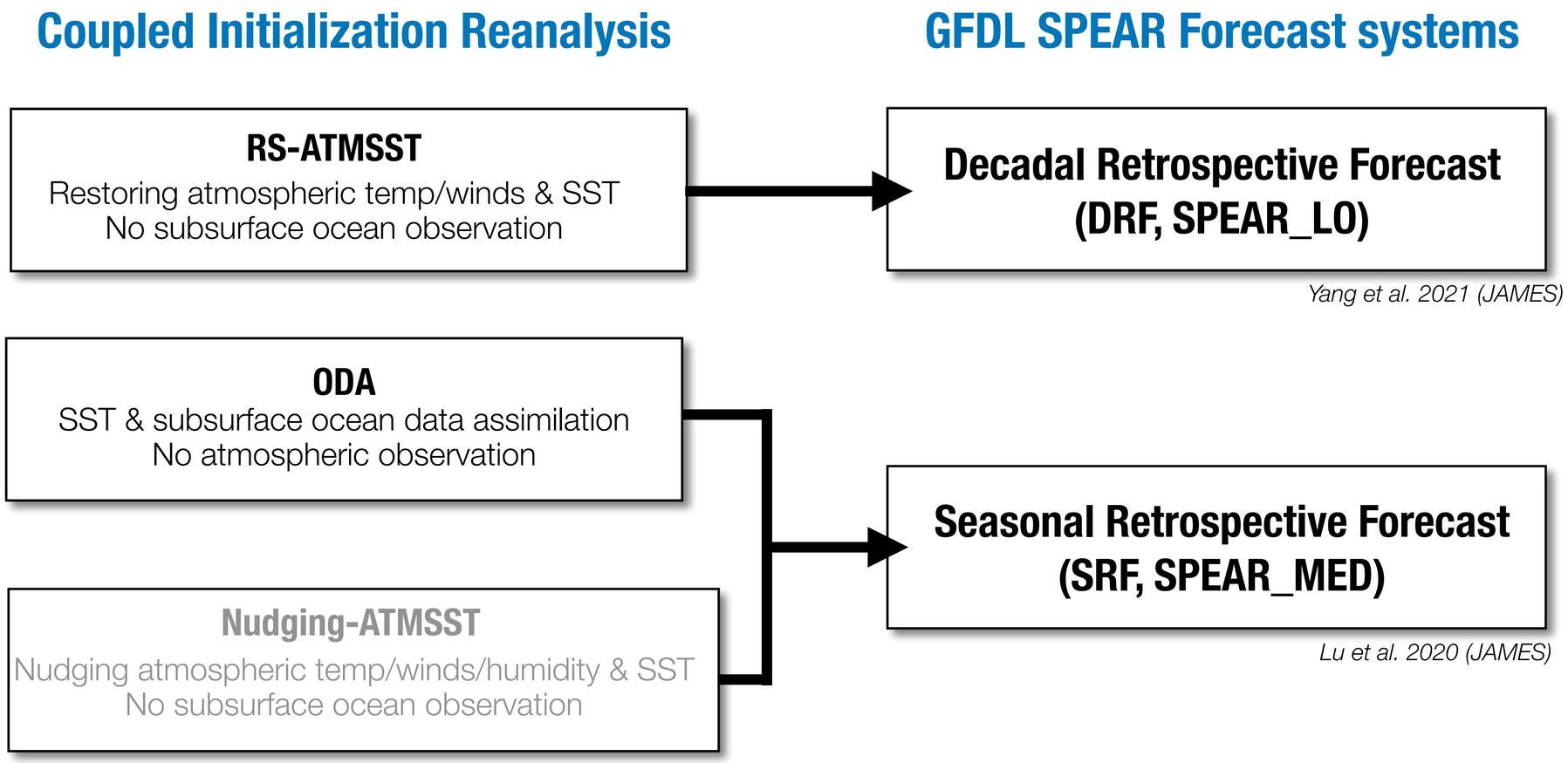
- Significant multi-year prediction skill of KE SSH up to 5 years in decadal forecasts and 1 year in seasonal forecasts
- Winter initialization contributes to long-lead prediction skill with longer inertial memory to the upper ocean by supporting reemergence mechanism and enhanced oceanic Rossby waves.
- Dynamical model prediction reveals higher KE forecast skill compared to linear RW model prediction by detecting strong air-sea couplings (e.g., wind-related large meanders) over the WBC system.

Challenges

- Important role of subsurface ocean observation in simulating realistic KE spatial structure (e.g., ocean front)
- High dependency of short-lead (1-3 months lead) KE SSH prediction skill on ocean horizontal grids

Joh et al. 2022 Seasonal-to-decadal variability and prediction of the Kuroshio Extension in the GFDL Coupled Ensemble Reanalysis and Forecasting system. Journal of Climate, in press

Methods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Coupled initializations for prediction systems

RS-ATMSST

Restoring ATM. temp/winds to JRA reanalysis (every 6 hrs)
Restoring SST to ERSST (every 5 days),
No subsurface ocean assimilation
SPEAR_LO (30 ensemble members)
1958-2020

ODA

Surface & subsurface **Ocean Data Assimilations** (daily)
-OISSTv2, Argo, XBT, and tropical moorings
No atmospheric restoring
SPEAR_LO (30 ensemble members)
1990-2019

Decadal Forecast system

RS-ATMSST

Restoring ATM. temp/winds to JRA reanalysis (every 6 hrs)
Restoring SST to ERSST (every 5 days),
No subsurface ocean assimilation
1958-2020
30 ensemble members

Decadal Retrospective Forecast (DRF)

Yang et al. 2021 (JAMES)

Model	SPEAR LO model (100km for atmosphere/land &1^{o} for ocean & sea ice components)
Atmos/land/ ocean/sea-ice Initialization	from RS-ATMSST (no subsurface ocean assimilation)
Initialization month	1st of January every year
Forecast length	10 years
Time period	1961-2021
Ensemble member	20

more details of SPEAR models in Delworth et al. 2020

Seasonal Forecast system

SPEAR_MED_nudged

Nudging ATM. temp/winds/humidity of CFSR (every 6 hrs)
Nudging SST to OISST (daily)

1990-2021
15 ensemble members

ODA

No atmospheric restoring
Surface & subsurface **Ocean Data Assimilations** (daily)
-OISSTv2, Argo, XBT, and tropical moorings
1990-2019
30 ensemble members

Seasonal Retrospective Forecast (SRF)

Lu et al. 2020 (JAMES)

Model	SPEAR_MED model (50km for atmosphere/land &1° for ocean & sea ice components)
Atmos/land/sea-ice initial conditions	from SPEAR_MED_nudged
Ocean initial condition	from ODA
Initialization month	1st of each month
Forecast length	1 year
Time period	1992-2021
Ensemble member	15

more details of SPEAR models in Delworth et al. 2020