# A multi-year climate prediction system based on CESM2

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## Research Question

Is our earth system predictable on decadal time scales?
What are the sources for multi-year predictability?

## Introduction

- **Growing demands of initialized prediction systems**
- **Community Earth System Model 2 (CESM2)**
- **Seasonal-to-multi-year physical & ecosystem predictability and sources**

## Method

**[Uninitialized run] CESM2 Large Ensemble (LENS2)**

- Total 100 members
- 10 members for Initial condition for ASSM

**3-D Ocean Temperature & Salinity anomaly assimilation**

- 3 Observational T&S
- EN4.2.2 (Good et al., 2013)
- ProjD7.3 (*Ishii et al.*, 2017)
- ORAS4 (*Balmaseda et al.*, 2013)

**[Assimilated run] Initialization (ASSM)**

- **30 (10 * 3) Ensemble members**
- **10 members using EN4.2.2 (1950 ~ 2021)**
- **10 members using ProjD7.3 (1955 ~ 2020)**
- 10 members using ORAS4 (1958 ~ 2016)

**Initialization with ASSM, (1960~2021, Jan 1st) 5-year hindcast**

**[Initialized run] Hindcast & Forecast (HCST)**

- **20 Ensemble members** (EN4, ProjD7.3)
- **62 initialized years** (1960 ~ 2021)
- **6200 simulation years** (62*20*5)

Figure 1: The schematic of the CESM2 multi-year prediction system

**Potential Predictability (*PP*): Corr(ASSM and HCST)**
**PP driven by external forced response ($PP_{ext}$): Corr(ASSM and LENS2)**
**PP originated from internal variability ($PP_{int}$): Corr(ASSM and (HCST-LENS2))**
* 20 member annual ensemble mean was used.
* Lead Year 2 means every second year's hindcast result was used.

## Results

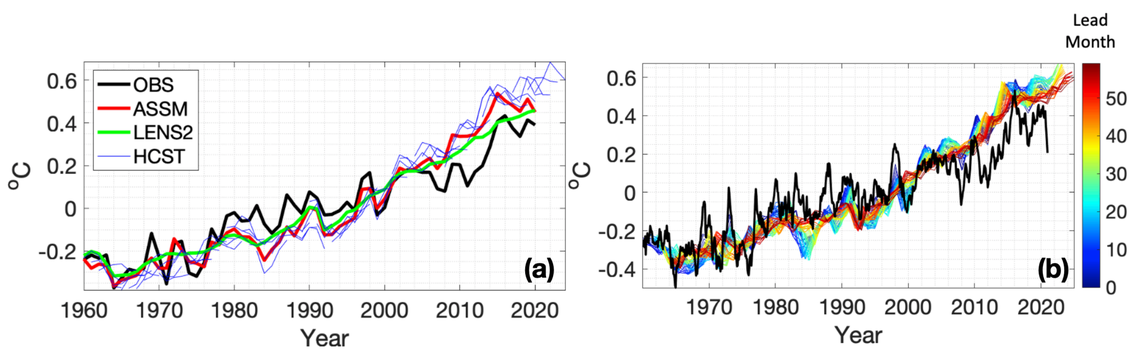


Figure 2. (a) Global mean sea surface temperature (GMSST) annual timeseries for ERSST (OBS), ASSM, LENS2 and HCST, respectively. Ensemble mean was used for all the model dataset. (b) Monthly timeseries of GMSST, black line denotes OBS and colored lines represent HCST result for the different lead month.

- **Dominant Anthropogenic warming signal** in GMSST
- **Minimized drift** and initialization shock due to the **anomaly assimilation**
- Early simulation period (**blue lines** in right panel)
  : driven by **internal** climate variability **from initial information**
- Late simulation period (**red lines** in right panel)
  : driven by **external boundary forcing** (GHG, aerosol, volcanic forcings)

**Evaluation of the ECMWF ocean reanalysis system ORAS4**, Balmaseda, M. A., Mogensen, K., & Weaver, A. T., *Quarterly journal of the royal meteorological society, vol. 139, 674* (2013)
**EN4: Quality controlled ocean temperature and salinity profiles and monthly objective analyses with uncertainty estimates**, Good, S. A., Martin, M. J., & Rayner, N. A., Sean Ulm & Corey J. A. Bradshaw, Journal of Geophysical Research: Oceans, vol. 118, 12 (2013)
**Accuracy of global upper ocean heat content estimation expected from present observational data sets**, Ishii, M., Fukuda, Y., Hirahara, S., Yasui, S., Suzuki, T., & Sato, K., *Sola*, vol. 13 (2017)
**Ubiquity of human-induced changes in climate variability.** Rodgers, K. B., Lee, S. S., Rosenbloom, N., Timmermann, A., Danabasoglu, G., Deser, C., ... & Yeager, S. G., *Earth System Dynamics*, vol. 12, 4 (2021)

## Results

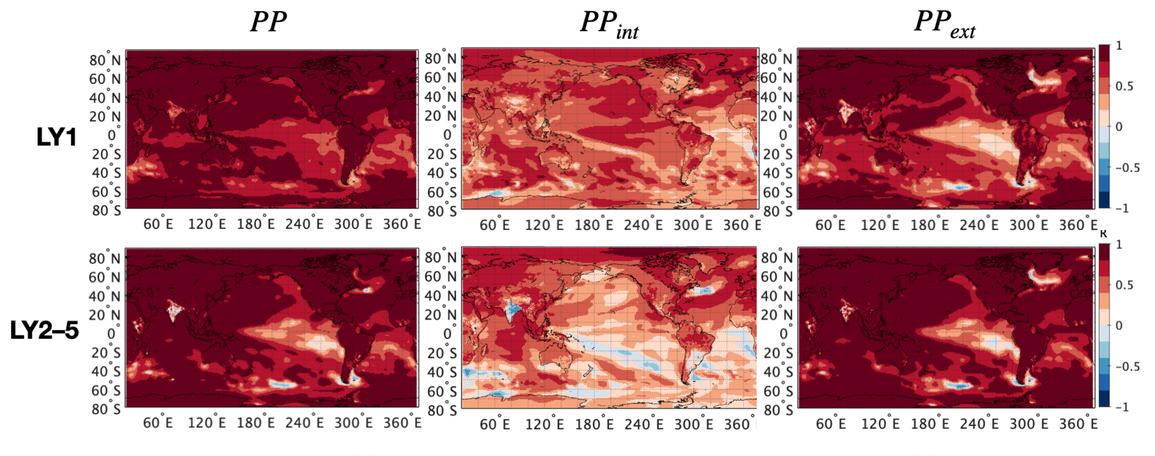


Figure 3. Potential predictability (*PP*) for surface air temperature. The first column shows *PP* as a function of lead year (1, 2~5). The second column represents $PP_{int}$ originated from initialized information and third column shows $PP_{ext}$ driven by external forcing

- **High predictability originated from antropogenic warming signal**
- **ENSO-driven predictability is dominant in Eastern Pacific**

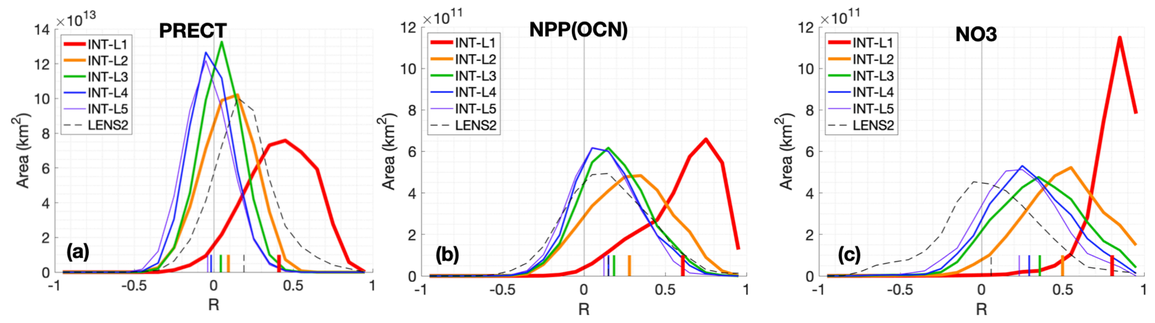


Figure 4. Density of $PP_{int}$ in tropical to subpolar region (60°S ~ 60°N). (a) Total precipitation, (b) Net Primary Productivity (NPP) in ocean, (c) Nitrate. Ocean variables are integrated from surface to 100m.

- **Low predictability for chaotic atmosphere variables**
- **High predictability for ocean variables due to the slow ocean dynamics**

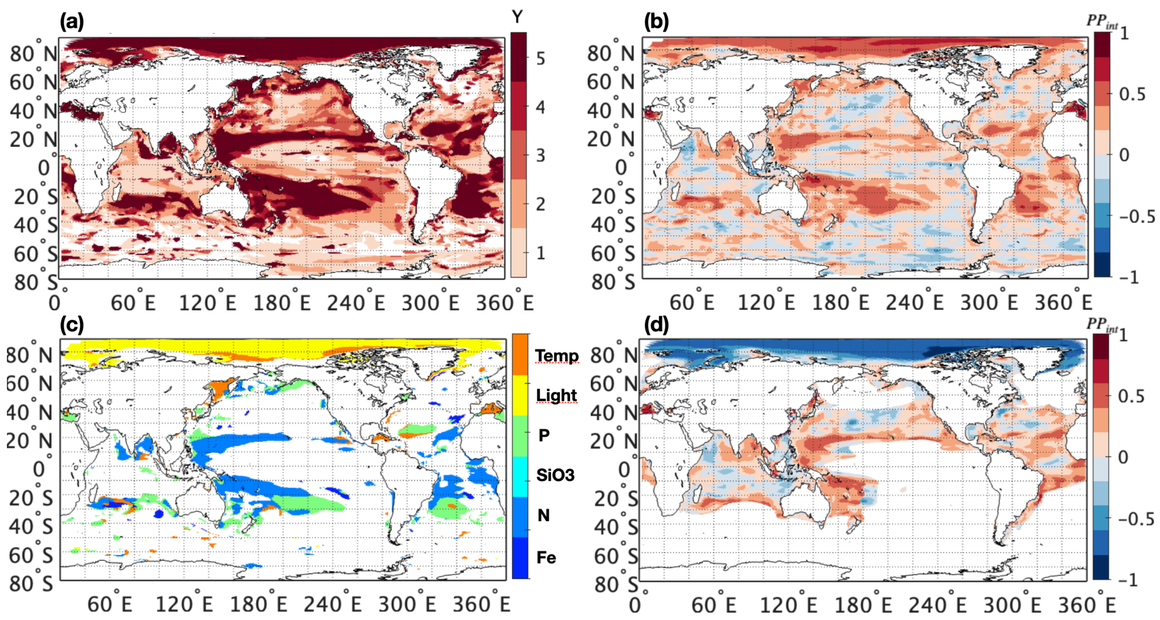


Figure 5. (a) Predictability time horizon map of NPP. The value is defined by longest predictable year when positive PP is higher than significance level (90%). (b) $PP_{int}$ of NPP for lead year 5. (c) Highest correlated NPP (by small phyto.) source terms such like temperature and limiting factors (Light, Phosphorus, Silicate, Nitrogen and Iron). (d) Nitrogen-driving $PP_{int}$ over the world for lead year 5.

- **Long-term predictable NPP, even for lead year 5**
- **Nutrient (N) is the primary source for high predictability**

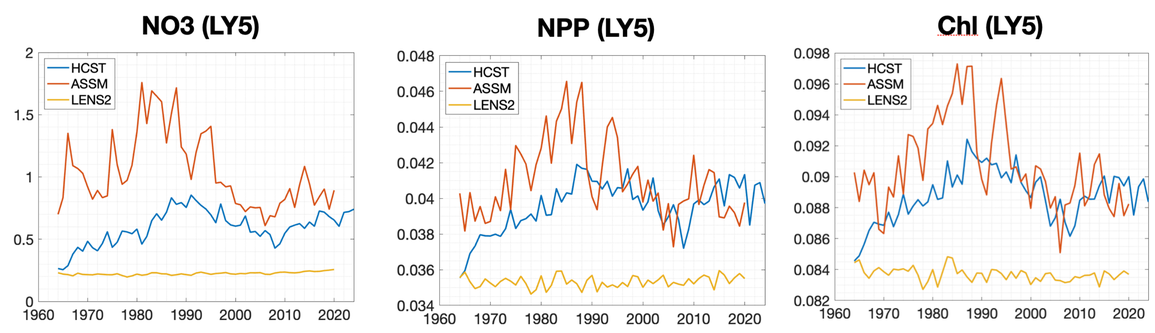


Figure 6. Timeseries of the example of multi-year predictable variables integrated from surface to 100m (Nitrate, NPP and Chlorophyll) at 180°E, 20°N of HCST for lead year 5, ASSM and LENS2. Despite of the lost of initialized information, internal variability of NO3 lasts until 5th simulation year, and this NO3 variability can constrain the variability of NPP and Chlorophyll cause predictable signal.

- **Key regions have prominent interdecadal variability which can be predictable for multi-year to decadal time scale**

## Summary

- **Newly developed multi-year prediction system using CESM2**
- Implementation of the **anomaly assimilation** to minimize model drift
- Chaotic **atmosphere** variables have **low predictability** in climate time scale
- **High predictability of marine NPP** in subtropics associated with the bottom-up **source (nutrients)** with decadal variation