Journal Club
30. March 2020

machine learning in climate science

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Motivation

- Gain a better understanding about Ocean gyres
- What drives those gyres?
- How are they changing?
- The impact of ocean gyres on marine life and terrestrial systems

This week's paper

Poleward Shift of the Major Ocean Gyres Detected in a Warming Climate

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Published in Advancing Earth and Space Science in January 2020

Motivation for this study

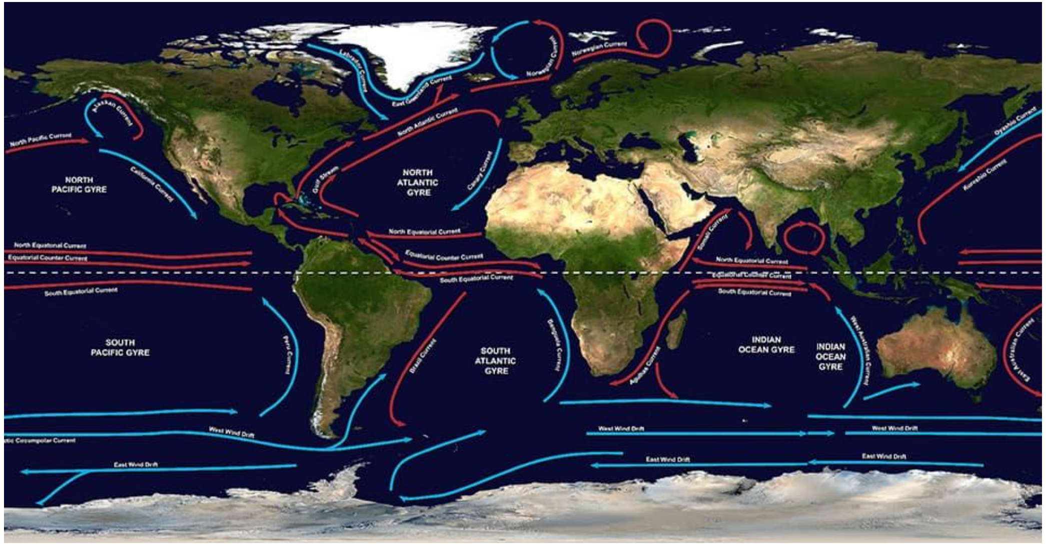
- Multiple indications for a poleward shift of ocean gyres
- Poleward shift of
  - Westerly winds
  - Jet streams
  - Storm tracks
  - Clouds
  - Precipitation
- Southward advance of the Eastern Australian Current, the Brazil Current front and the Antarctic Circumpolar Current front

Limitations of this study

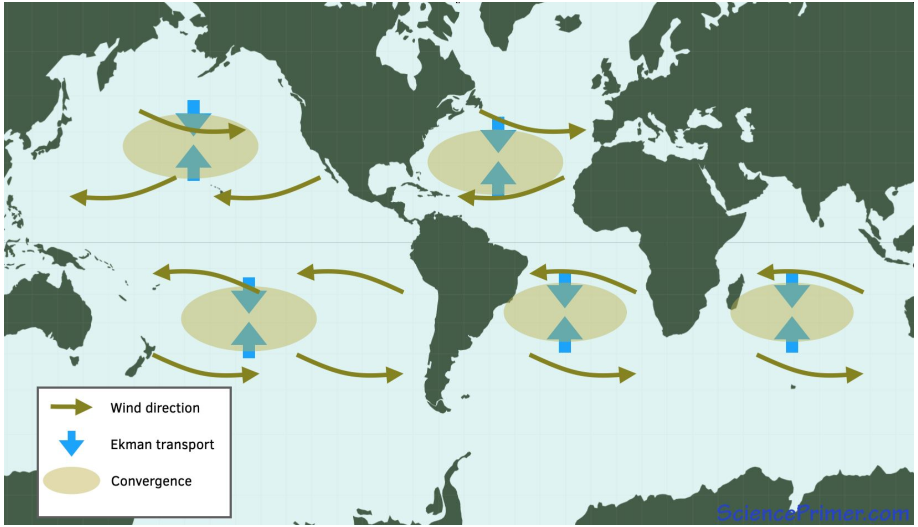
- Short duration and sparse data coverage
    - Direct and continuous observations of ocean currents are rare
- High uncertainty as results due to natural variability
- Only few results pass the student’s t-test
- Continuous observations of ocean currents are rare
    - Indirect approach by defining centers of ocean gyres via SSH and borders via SST

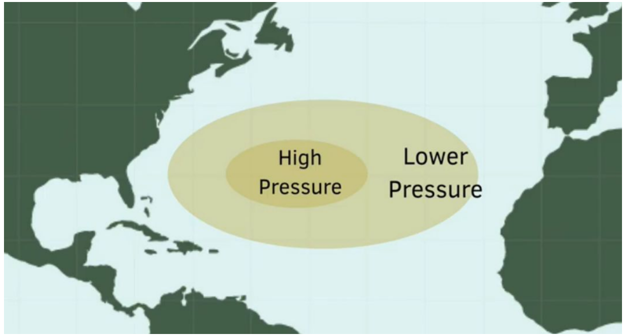
Ocean Gyres

- Large wind driven systems of ocean currents
- 5 main ocean gyres
- Eastern and western boundary currents
- Result of geostrophic flow



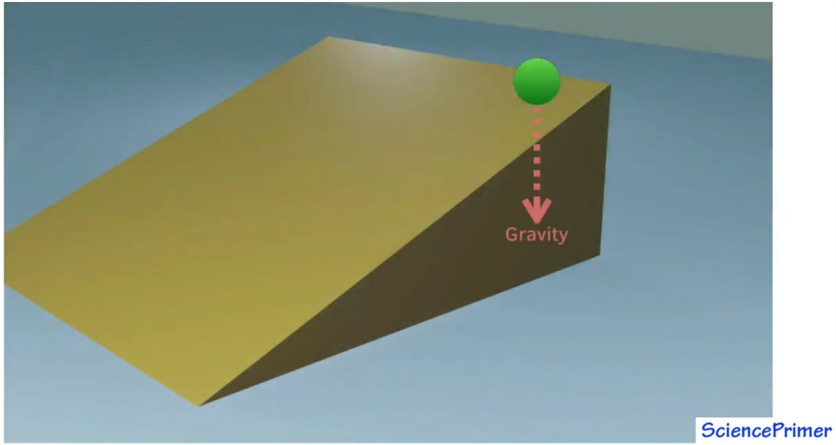
Sea Surface Height

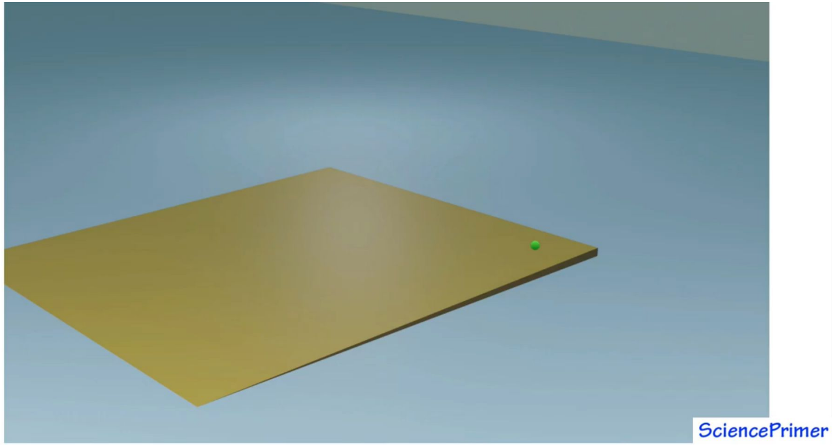




Geostrophic flow

- Small derivative in SHH and therefore small force
- Coriolis deflection is much stronger and therefore more relevant to the system



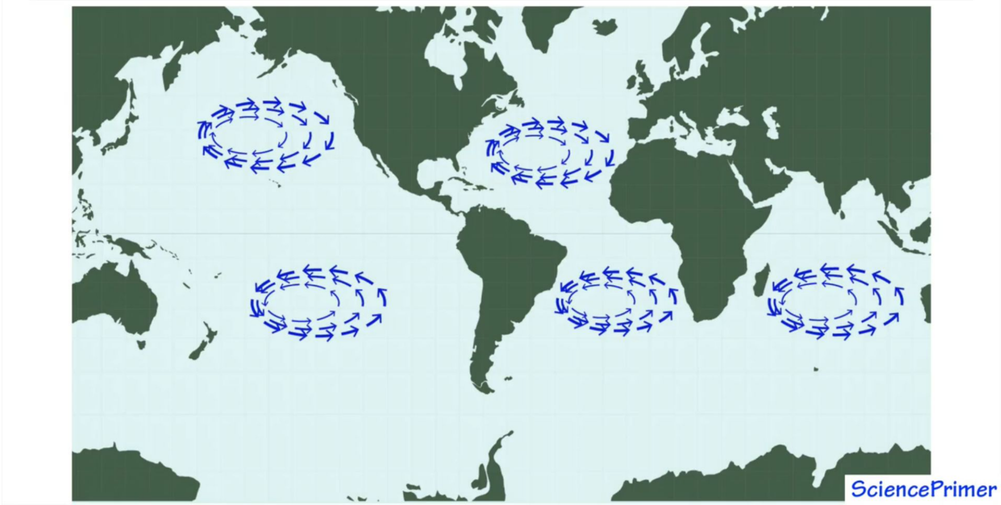


Geostrophic flow

- Small derivative in SHH and therefore small force
- Coriolis deflection is much stronger and therefore more relevant to the system
- Water is not moving along the derivative

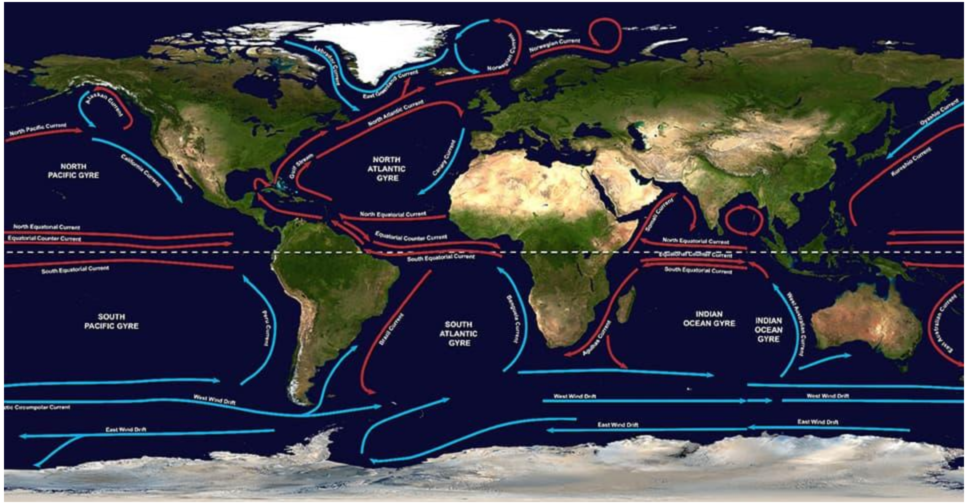
  of SSH but “around” the SSH peak

  -> “center of gravity of gyre”



Western boundary currents

- Warm water from the tropics are moving on the west side of the basins towards the poles
- Due to Coriolis effect narrow stream of warm water along the west side
- Cold, slow and broad currents on the east of the ocean basin



Data and Methodology

- SSH data from 1992–2018 - AVISO (satellite based)
- SST data from 1982–2018 - National Oceanic and Atmospheric Administration Optimum Interpolation Sea Surface Temperature, OISST)
- Near-surface wind and sea level pressure data from the National Center for Atmospheric Prediction/National Center for Atmospheric Research
- ERA-Interim reanalysis data

Data and Methodology

- Analysis based on observations and simulations
- Two series of simulations (pre-industrial control run and a set of doubled CO_2 runs) to validate the observational trend with the Alfred Wegener Institute Climate Model (AWI-CM)
  - Linear increase of CO_2 to a double of the pre-industrial level
  - Doubled CO_2 is run 5 times for reduction of model variability based on different initial conditions obtained from the pre-industrial run

Methodology

- P = meridional location of ocean gyres
- lat= latitudinal coordinate of SSH
- △var = SSH - SSH_{min} for subtropgical gyres
- △var = SSH - SSH_{max} for subpolar gyres
- Gyre center and gyre boundary are physically associated with the patterns of SSH and SST gradient
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$$P = \frac{\int \Delta var \cdot lat}{\int \Delta var}$$

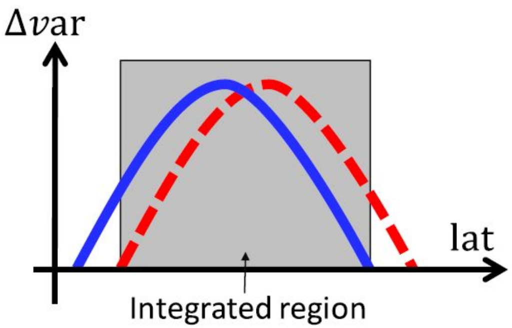


Figure 2. Schematic of the method of tracking the meridional variations of ocean gyres. As gyre-related SSH patterns, subtropical fronts, and barotropic stream function all resemble the shapes of hills. We use the center of mass of these hills to track the position of ocean gyres. The gray shading box illustrates the region (also shown as gray rectangles in Figures 3a and 4a) where the integration is performed. These regions are defined primarily based on the climatology position of each parameter and do not vary over time. Following equation (1), *lat* is the latitudinal coordinate of each parameter. For the SSH parameter, Δvar represents $SSH - SSH_{min}$ for calculating the position of subtropical gyres, and $SSH - SSH_{max}$ for calculating the position of subpolar gyres. SSH_{min} and SSH_{max} are the regional minimum and maximum SSH within the integrated regions. For the SST parameter, Δvar represents horizontal SST gradient. For the stream function parameter, Δvar represents barotropic stream function.

Sea Surface Height and SST Anomalies

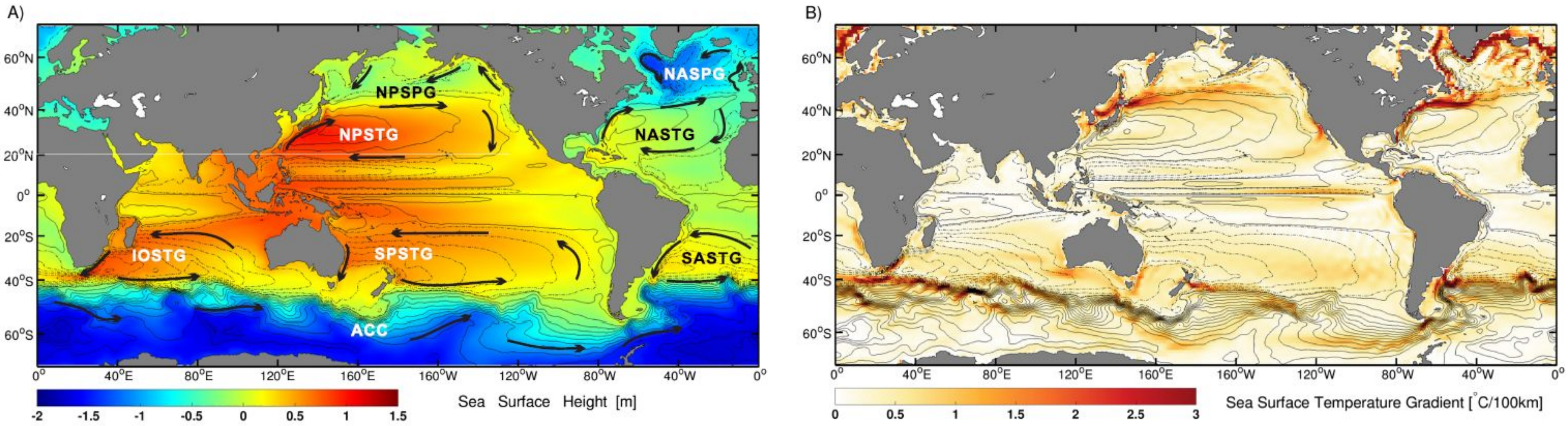
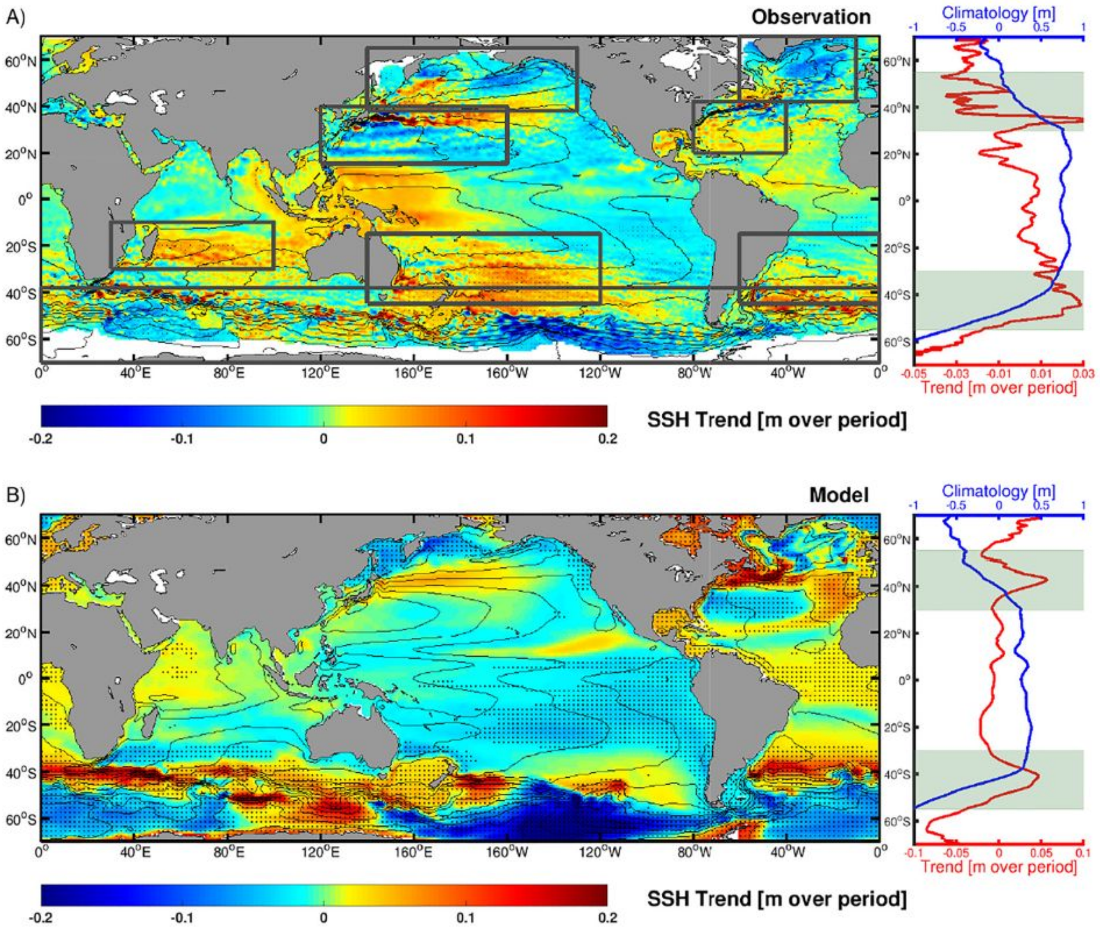


Figure 1. The major ocean gyres and associated climatological conditions. Contour lines represent the barotropic stream function. Solid lines indicate clockwise flow, and dashed lines indicate anticlockwise flow. (a) Background shading shows the sea surface height (SSH). Black arrows illustrate the significant features of the currents.
(b) Background shading represents the horizontal sea surface temperature gradient. Results are based on the last 100 years of the AWI-CM pre-industrial control run. The abbreviations in the figure are listed as follows: North Atlantic Subtropical Gyre (NASTG), South Atlantic Subtropical Gyre (SASTG), North Pacific Subtropical Gyre (NPSTG), South Pacific Subtropical Gyre (SPSTG), Indian Ocean Subtropical Gyre (IOSTG), North Pacific Subpolar Gyres (NPSPG), North Atlantic Subpolar Gyres (NASPG), and Antarctic Circumpolar Current (ACC).

The barotropic stream function is defined as the depth-integrated volume transport and illustrates the position of the subpolar and subtropical gyre

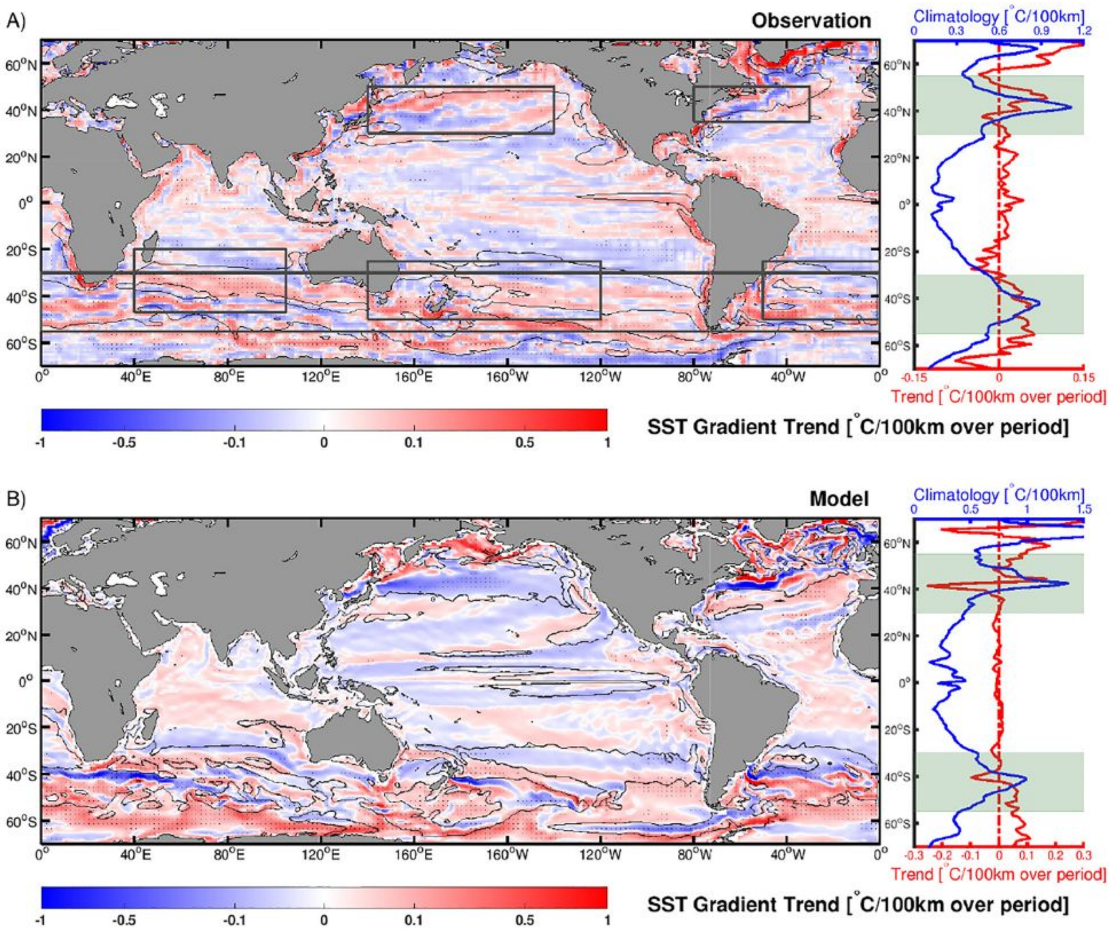
Trends in SSH

- Gray shaded boxes are the regions of integration
- Enhanced regional sea level rise is found over the midlatitude bands in both hemispheres
- Sea level rise over the high latitudes is below the globally averaged trend
- Comparing the trend with its climatology pattern (contours), illustrates a poleward shift of SSH “hills” and “valleys”



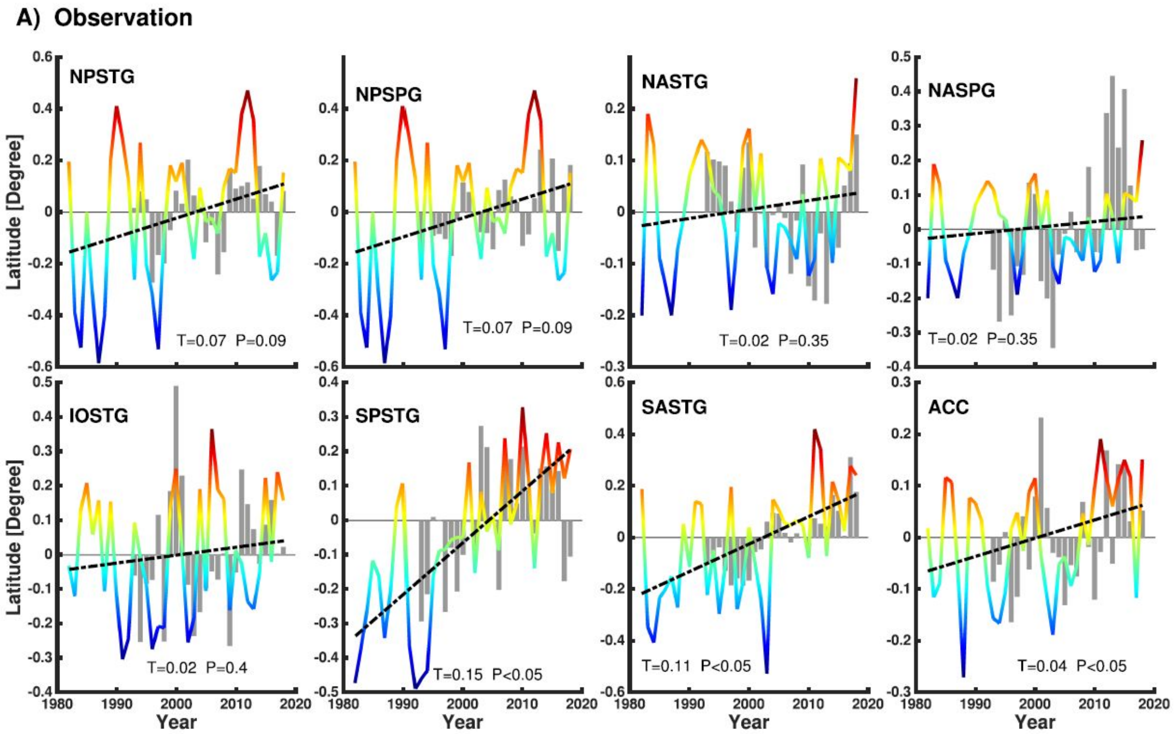
Trends in SST

- Increasing trends of SST gradients are found over polar flanks of the subtropical fronts
- Decreasing trends of STT gradient over equator flanks of the subtropical fronts
- This implies a signal of poleward displacement for subtropical fronts
- Signal of poleward displacement.



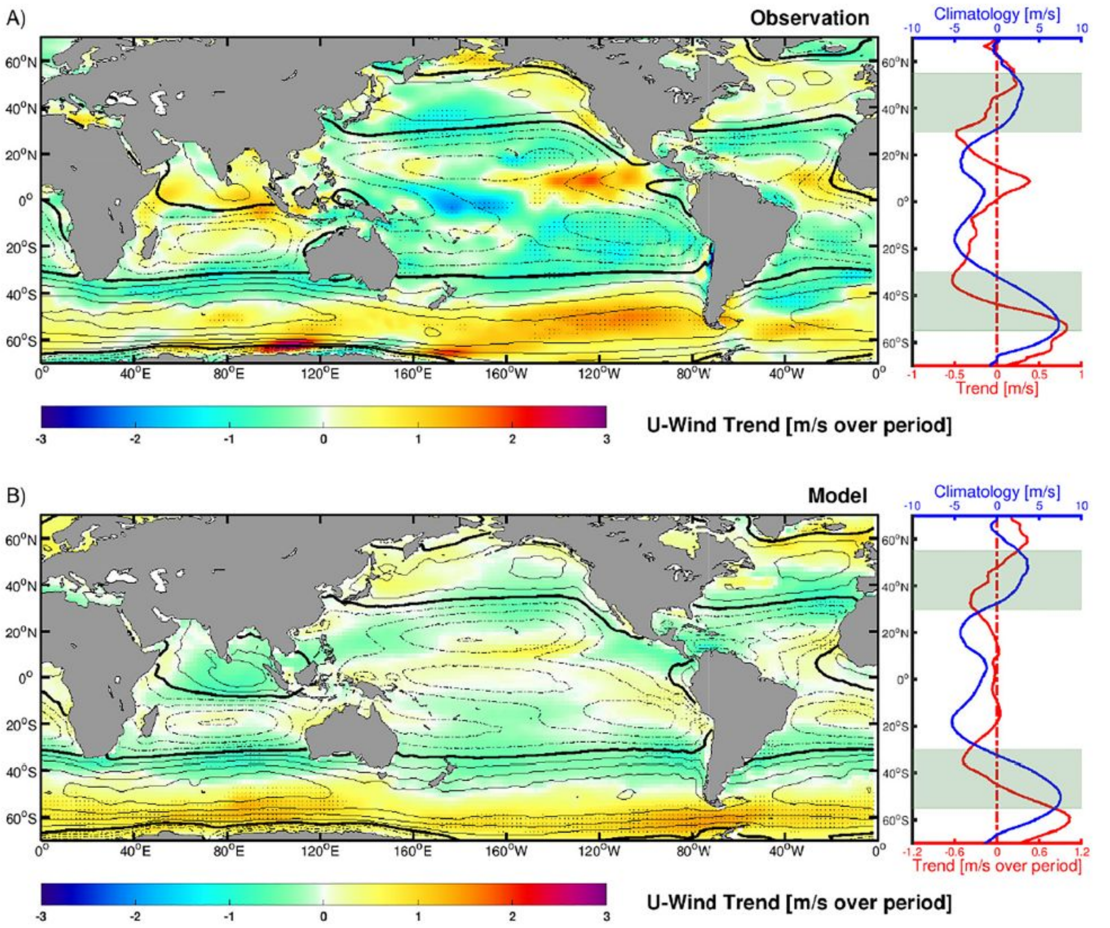
Time series of latitudinal variations

- interannual variations of the location of the major ocean gyres based on SSH and SST gradients
- The average magnitude of the shift is on the order of 0.07° per decade
- Unclear whether the poleward movements are due to natural climate variability or long-term anthropogenic climate change

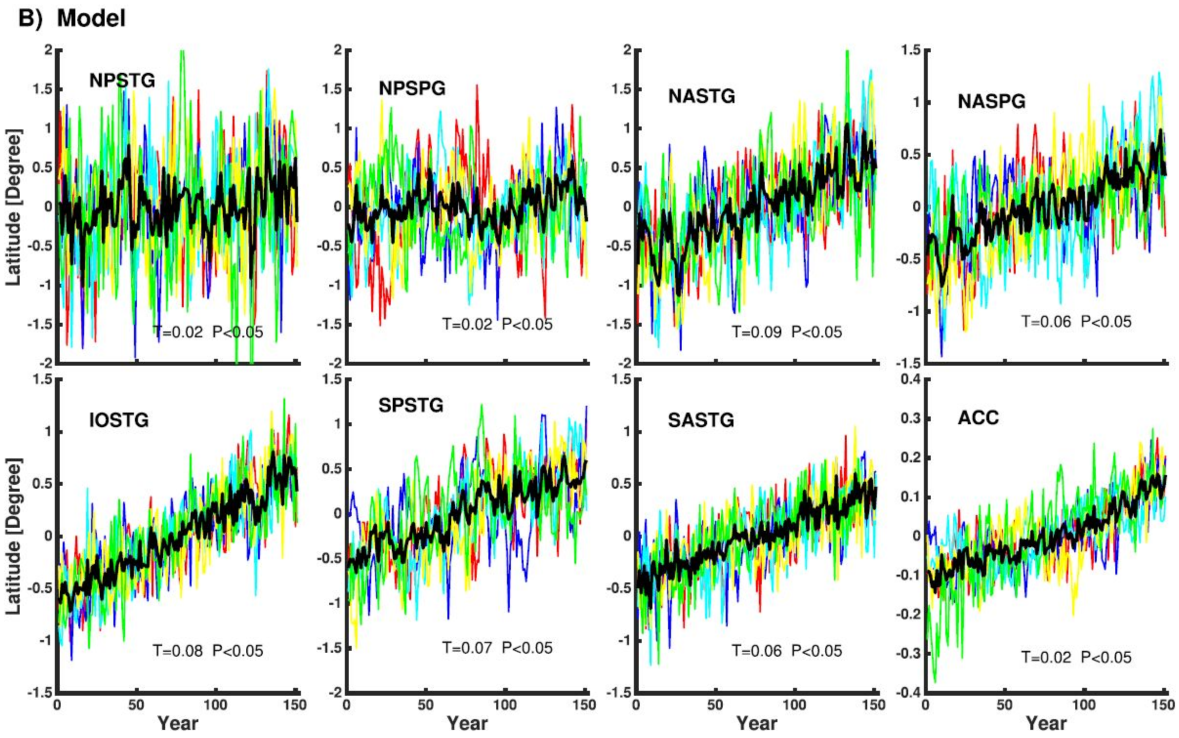


Trends of near ocean surface winds

- Change of velocity of the easterly winds over the 20° - 40° latitude bands
- Change of velocity of the westerly winds over the 40–60° latitude bands
- "Extratropical atmospheric circulation undergoes a systematic poleward shift under greenhouse gases forcing"
- Displacement of the atmospheric circulation can drive the shift in ocean gyres.
- Shifting ocean gyres contribute to moving the subtropical front, which may also alter the atmospheric circulation



Time series of latitudinal variations



Conclusion

- Identified a consistent poleward shift of the ocean gyres
- Observed shifts are not statistically significant, especially over the Northern Hemisphere
- High natural climate variability
- Rate of the shift for subtropical and subpolar gyres in the order of 0.1/0.04. per decade
- Rate for tropical expansion is on the order of 0.2–3.0. per decade during the past four decades.
- The margins of the gyres experience the most significant changes.
- Impacts on fisheries du to warming of the at the margin of the Gyres
    - Uruguay, Paraguay, Gulf of Maine

Possible consequences of the poleward shift

- Decrease of ocean productivity due to growth of the ocean dessert.
- Fish abundance
- Sea level rise
- Potential to reshape ocean circulation over the tropics