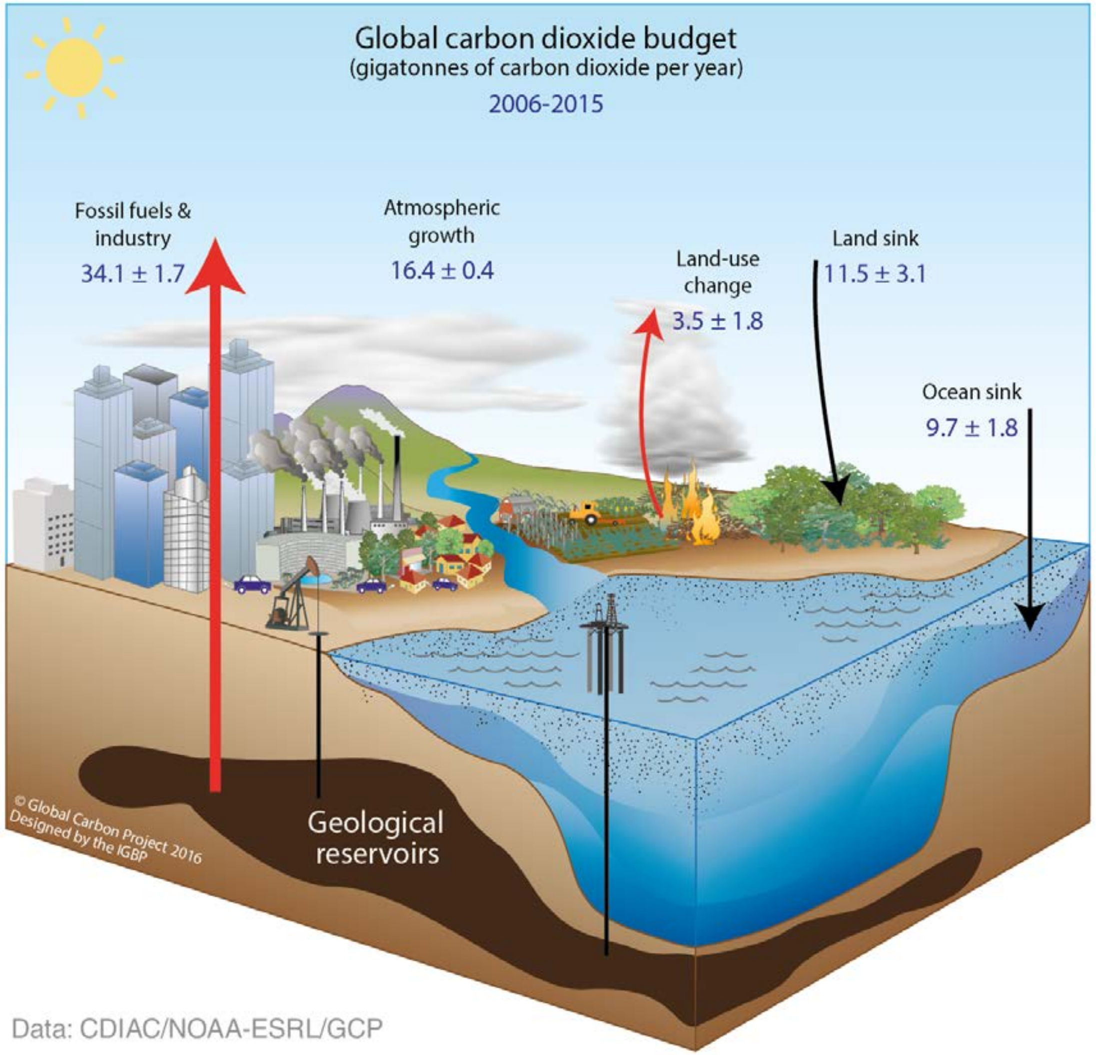
Surface pH, its mechanisms, and future projections in the global ocean

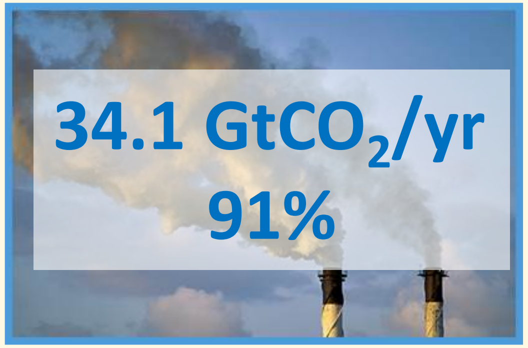
Li-Qing Jiang[1,2], Richard A. Feely[3], and Brendan Carter[3]

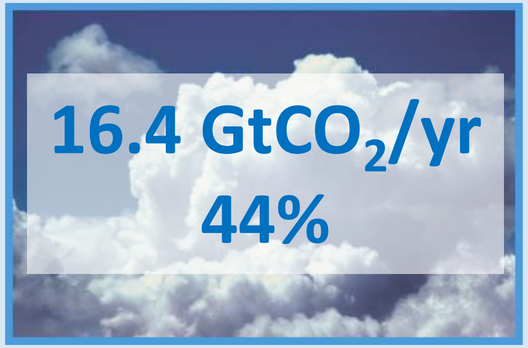
Outline

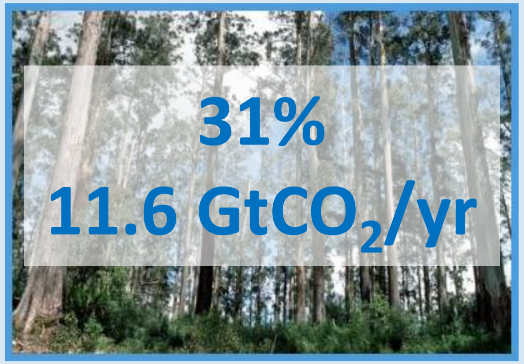
* Background + Method
* pH distribution + mechanism
* Decadal change
* Projected pH in the 21st Century

Global Carbon Budget (2006-2015)



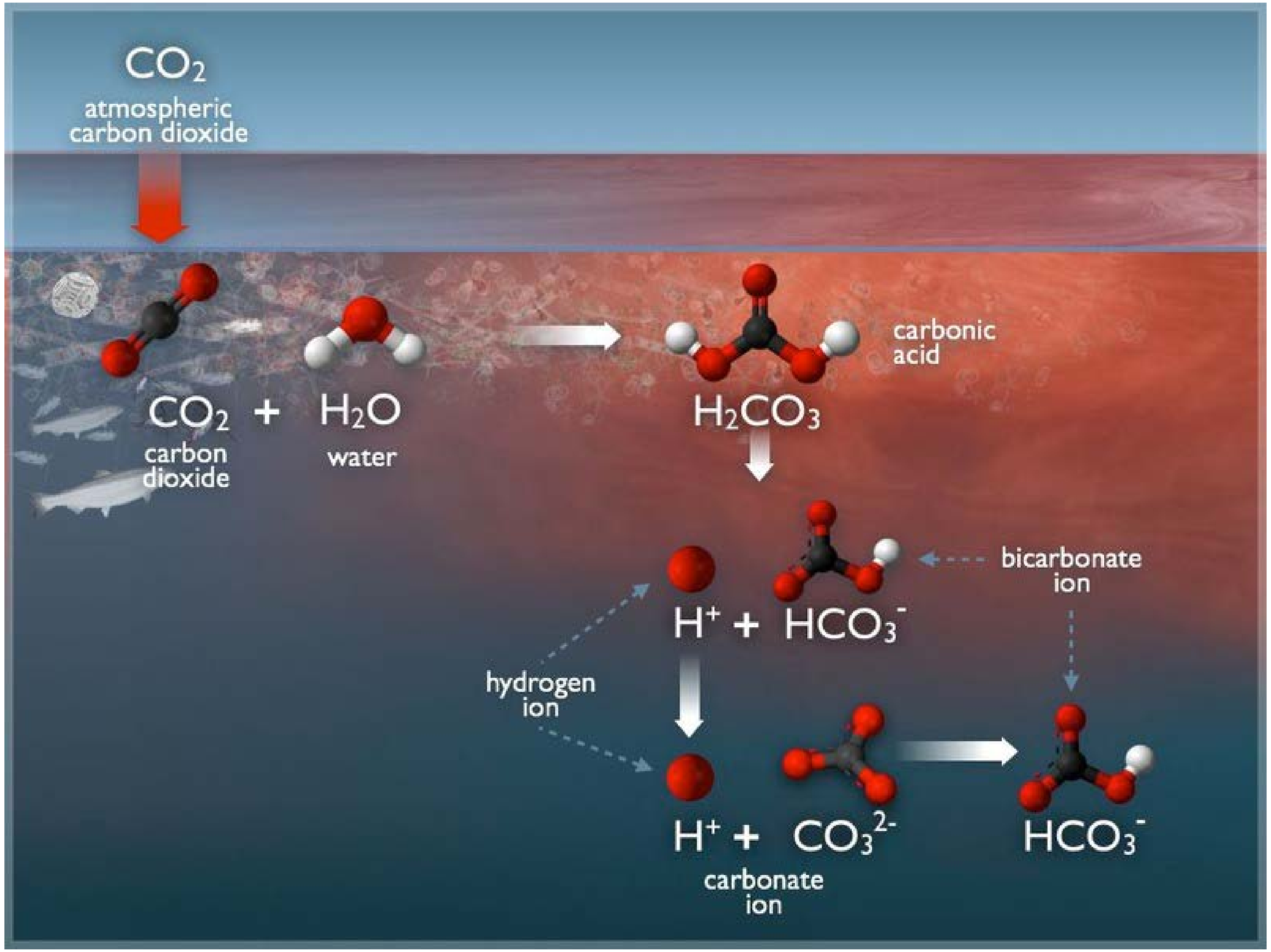




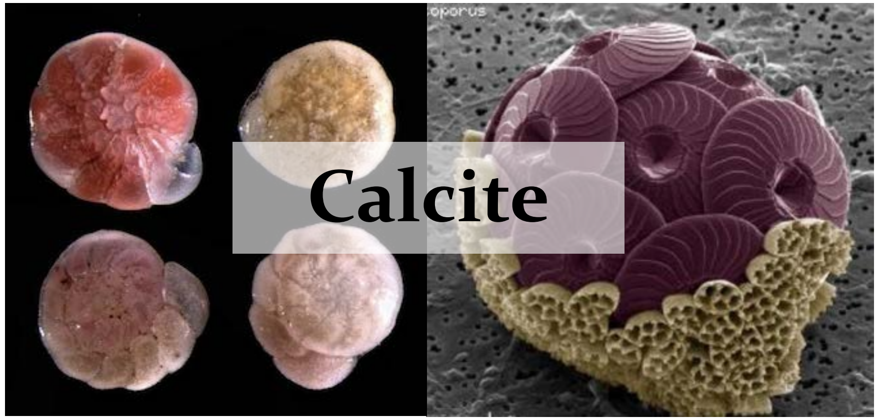


Source: CDIAC; NOAA-ESRL; Le Quéré et al 2016; Global Carbon Budget 2016

Ocean acidification



Such as calcareous algae and coral reef.



Such as Foraminifera and coccolithophorids.

Calcium carbonate saturation state

pH distribution

Global Biogeochemical Cycles

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Research Article

Climatological distribution of aragonite saturation state in the global oceans

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First published: 13 October 2015 Full publication history

DOI: 10.1002/2015GB005198 View/save citation

Earth Syst. Sci. Data, 8, 297-323, 2016
https://doi.org/10.5194/essd-8-297-2016

glodap v2

The Global Ocean Data Analysis Project version 2 (GLODAPv2) – an internally consistent data product for the world ocean

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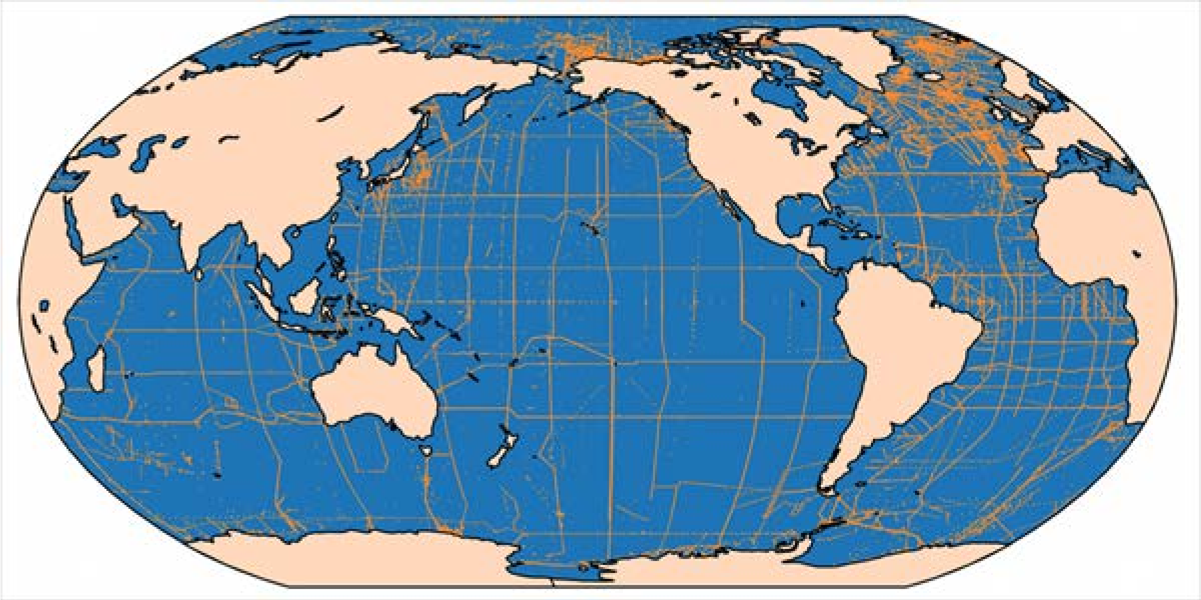
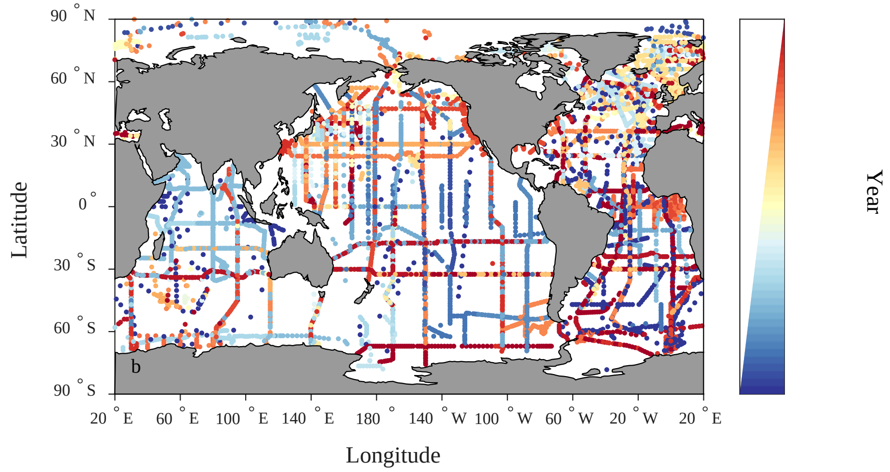


- We extracted data that meet the below criteria from GLODAPv2:
  - Depth <=20 m
  - Contains both DIC and TA
  - Salinity>=30
- Further QC by removing clear outliers (e.g., data with DIC>TA).



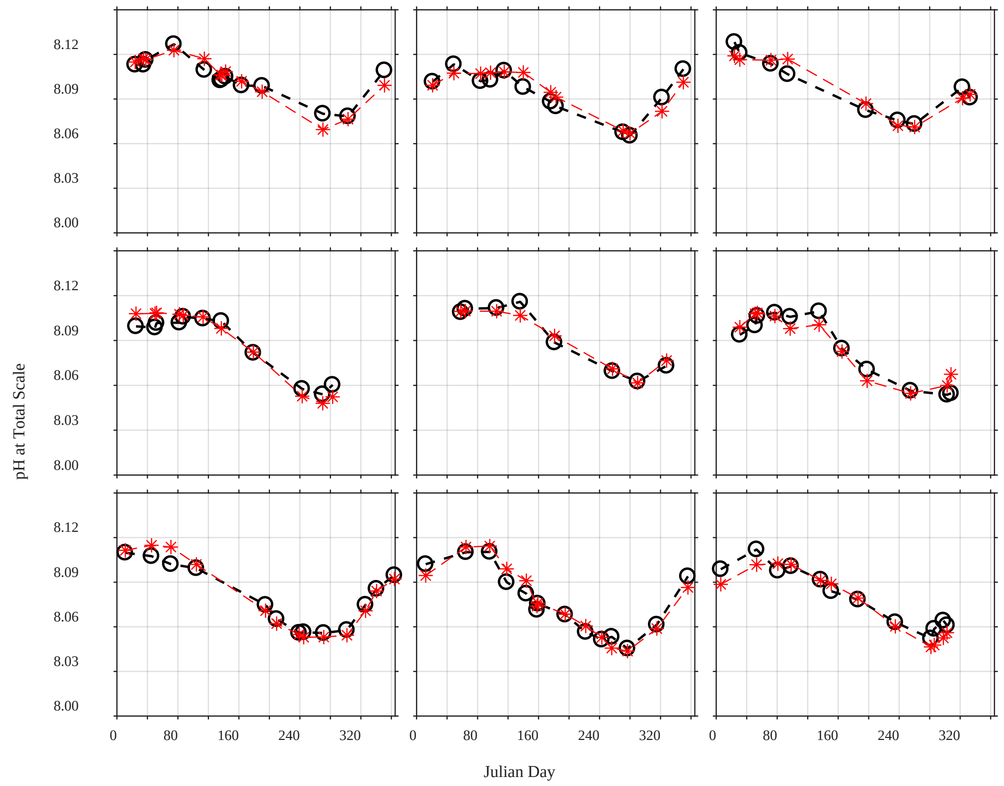
pH calculation

- For stations with missing silicate and phosphate data, they were filled in by extracting from the nearest grid of the GLODAPv2 climatologies (Lauvset et al. 2016)

- pH is then calculated from in-situ temperature, salinity, pressure, DIC, TA, silicate and phosphate using a MATLAB version [van Heuven et al., 2009] of the CO2SYS program [Lewis and Wallace, 1998].
  - the dissociation constants for carbonic acid of Lueker et al. [2000]
  - potassium bisulfate ($KHSO_4^-$) of Dickson [1990a]
  - boric acid of Dickson [1990b]
  - total borate concentration equations of Uppstrom [1974]

Seasonal pH correction

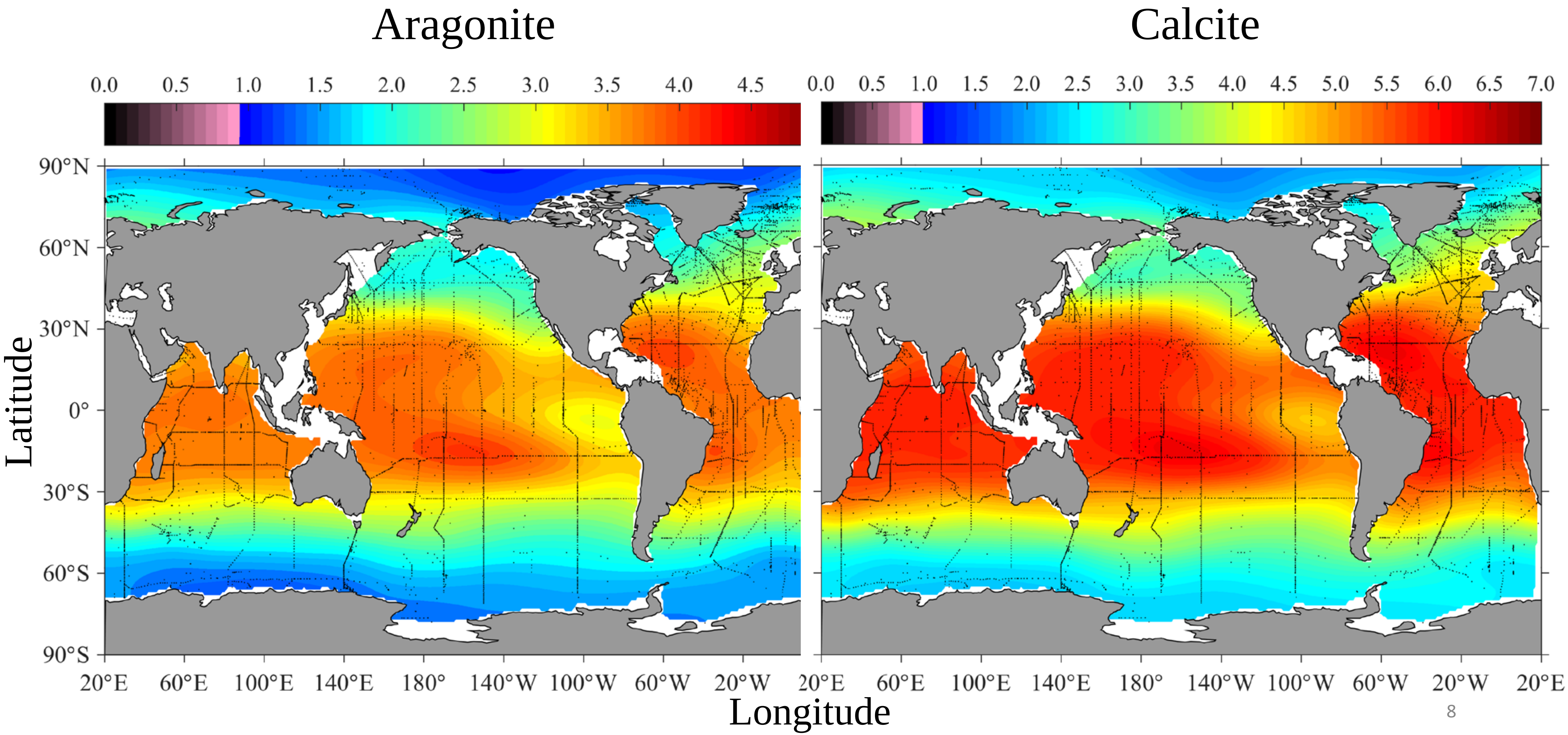
Issue: Data are collected from different time of the year with a bias towards summer.



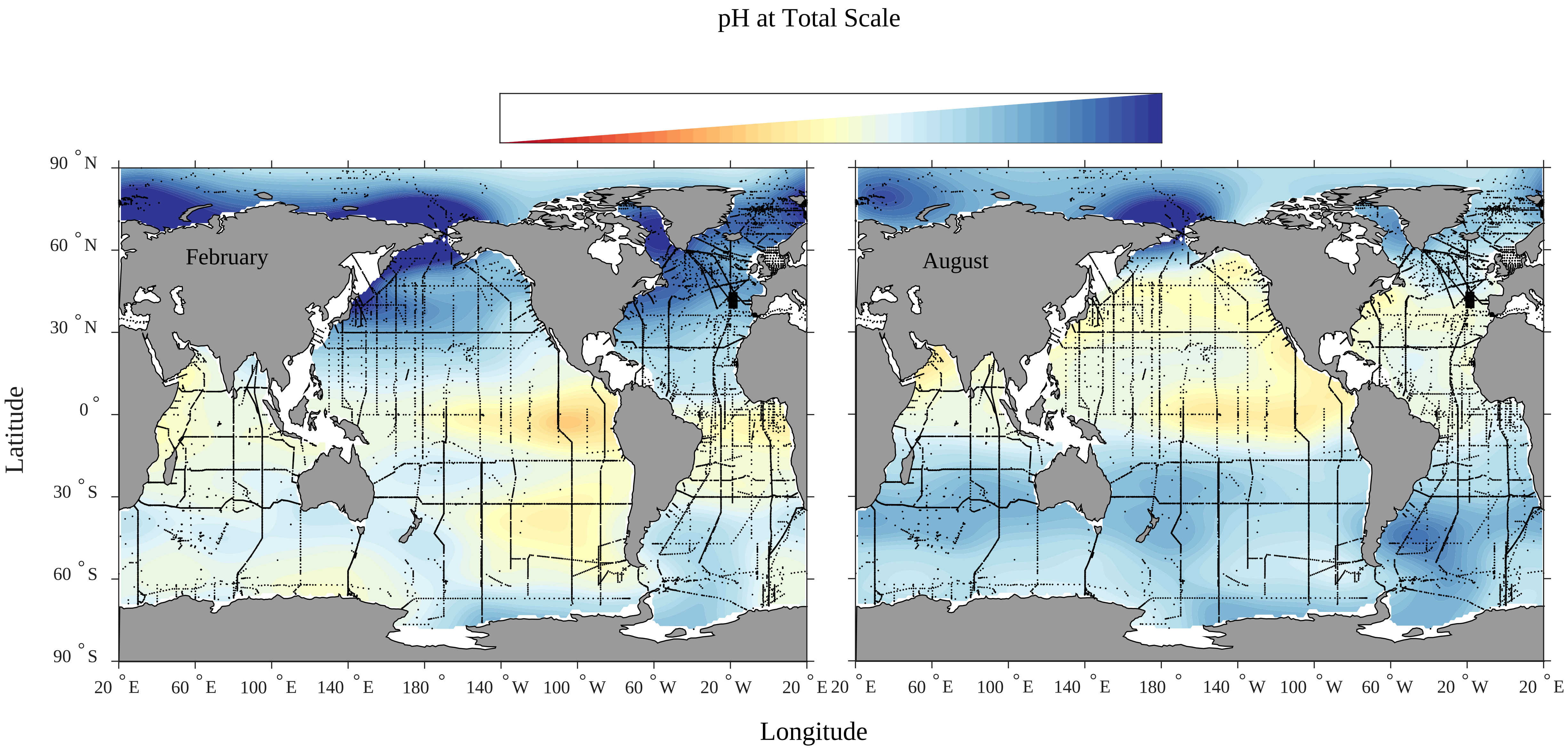
A seasonal pH model was derived based on time-series OA monitoring from European Station for Time series in the ocean (ESTOC).

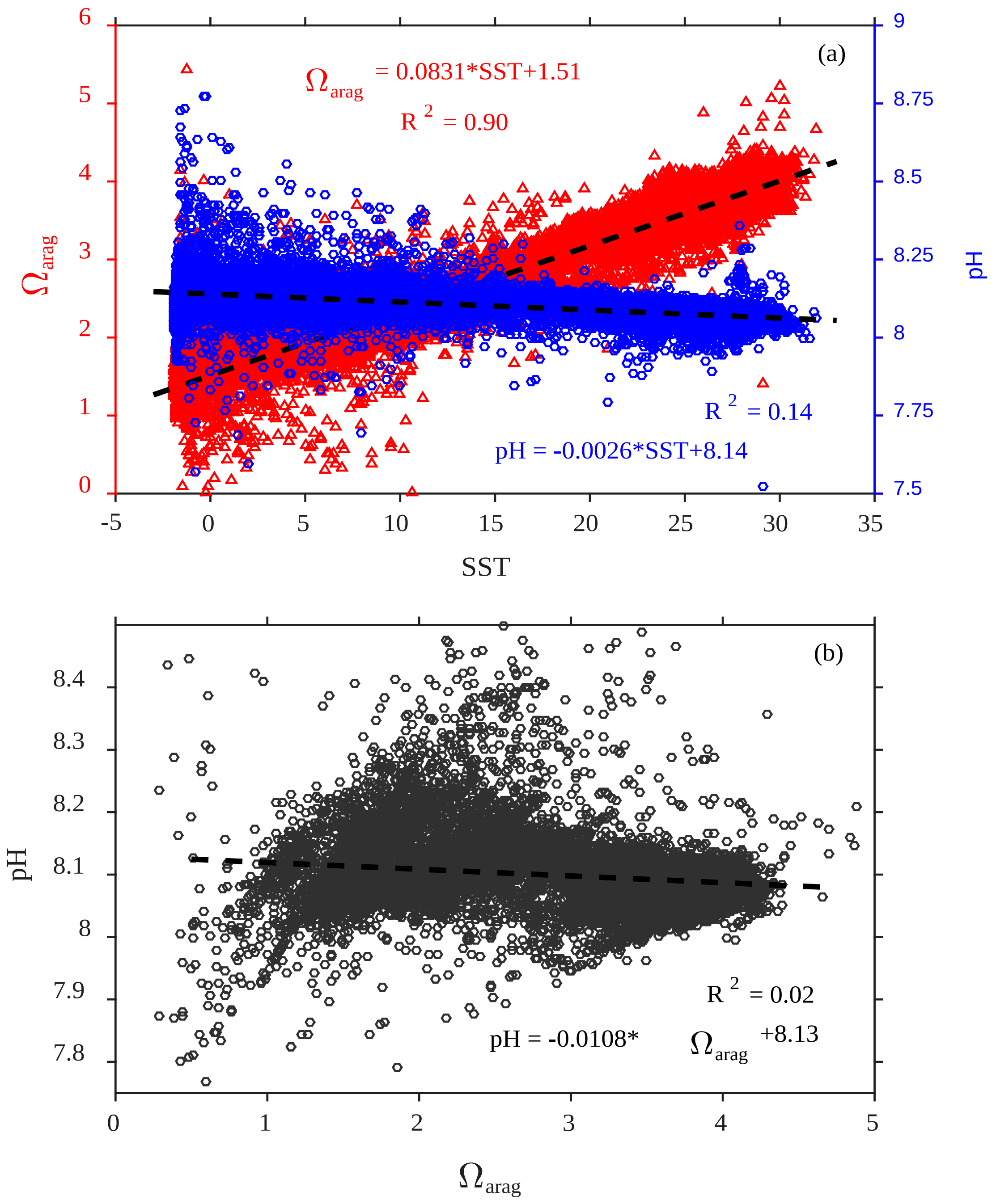
- SST in February and August 2000 are extracted from an SST atlas that is based on data collected from 1995 to 2004 (World Ocean Atlas 2013 version 2, Boyer et al. 2013)
- pH data was first corrected to the year of 2000, assuming constant TA and oceanic CO_2 increases at the same rate as the atmospheric CO_2.
- pH was then corrected to February and August based on this seasonal correction model.

Aragonite and calcite in the surface ocean



pH in the surface ocean





Surface pH vs. SST

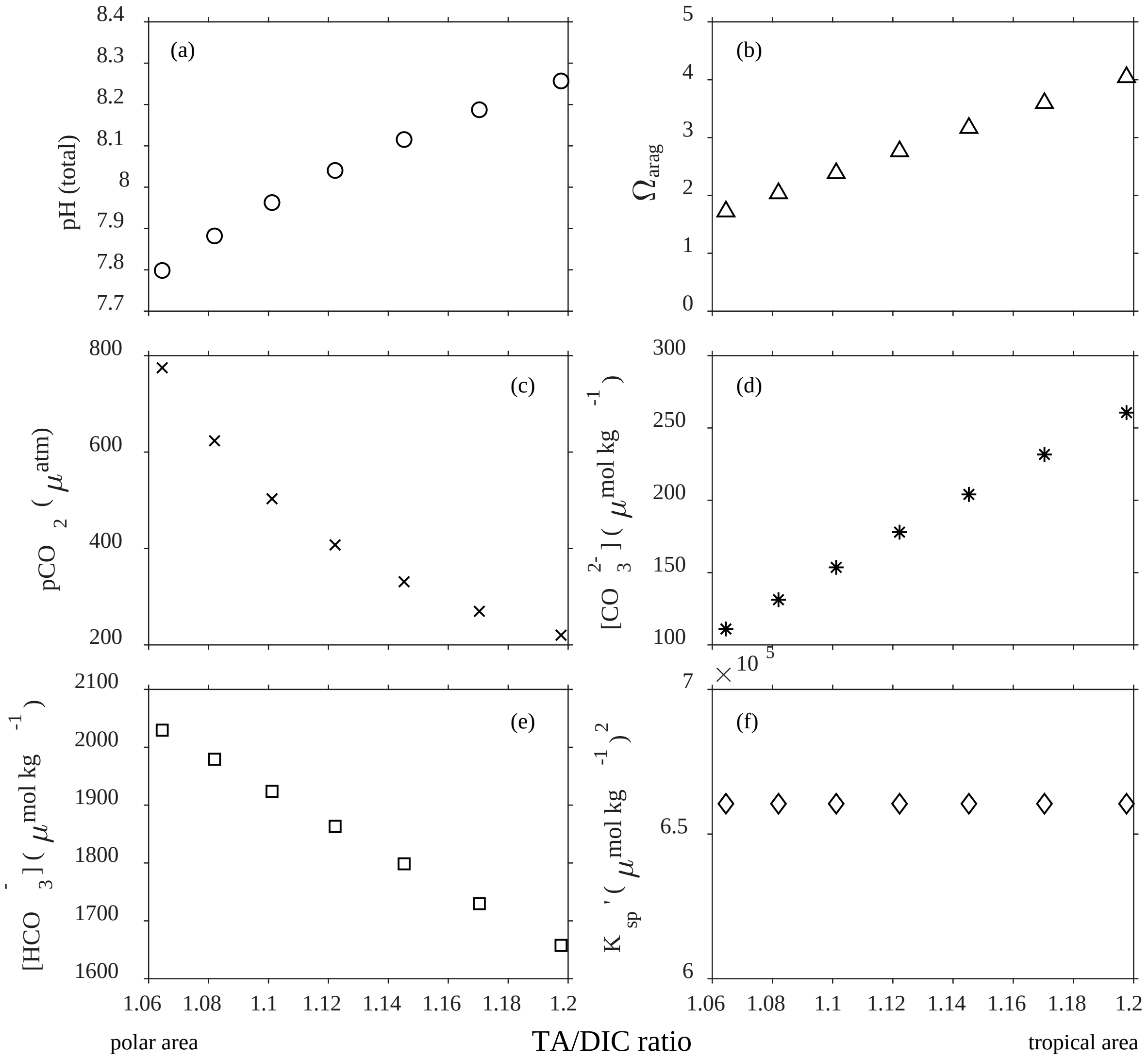
- ❑Surface pH shows a weak negative relationship with SST, while saturation is positively correlated.

- ❑Surface pH does not correlate with aragonite saturation state much.

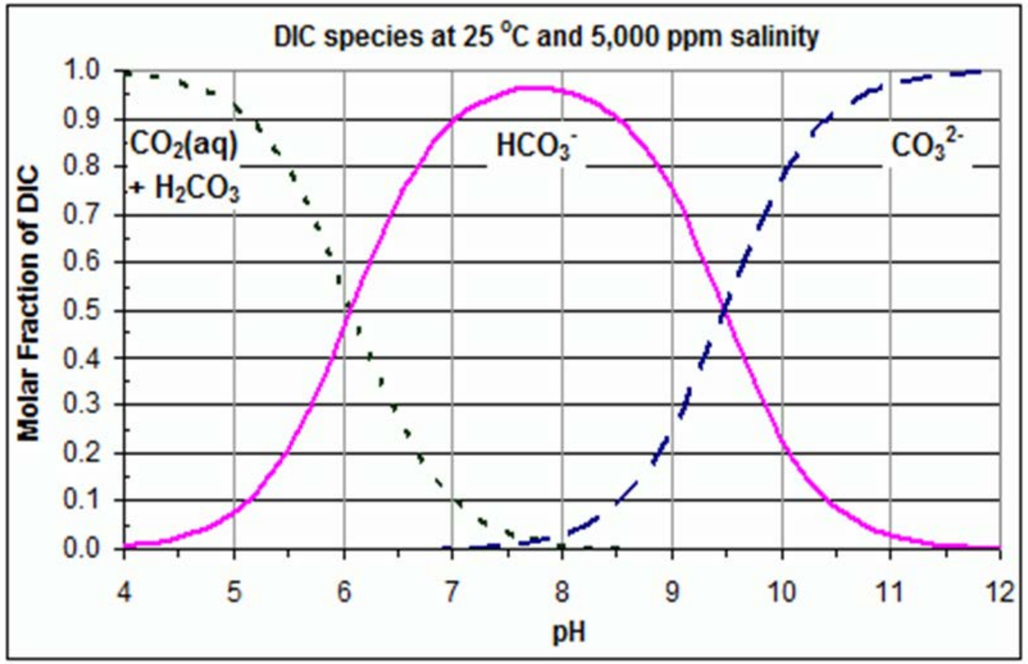
SST effect I: Controls TA/DIC of surface water

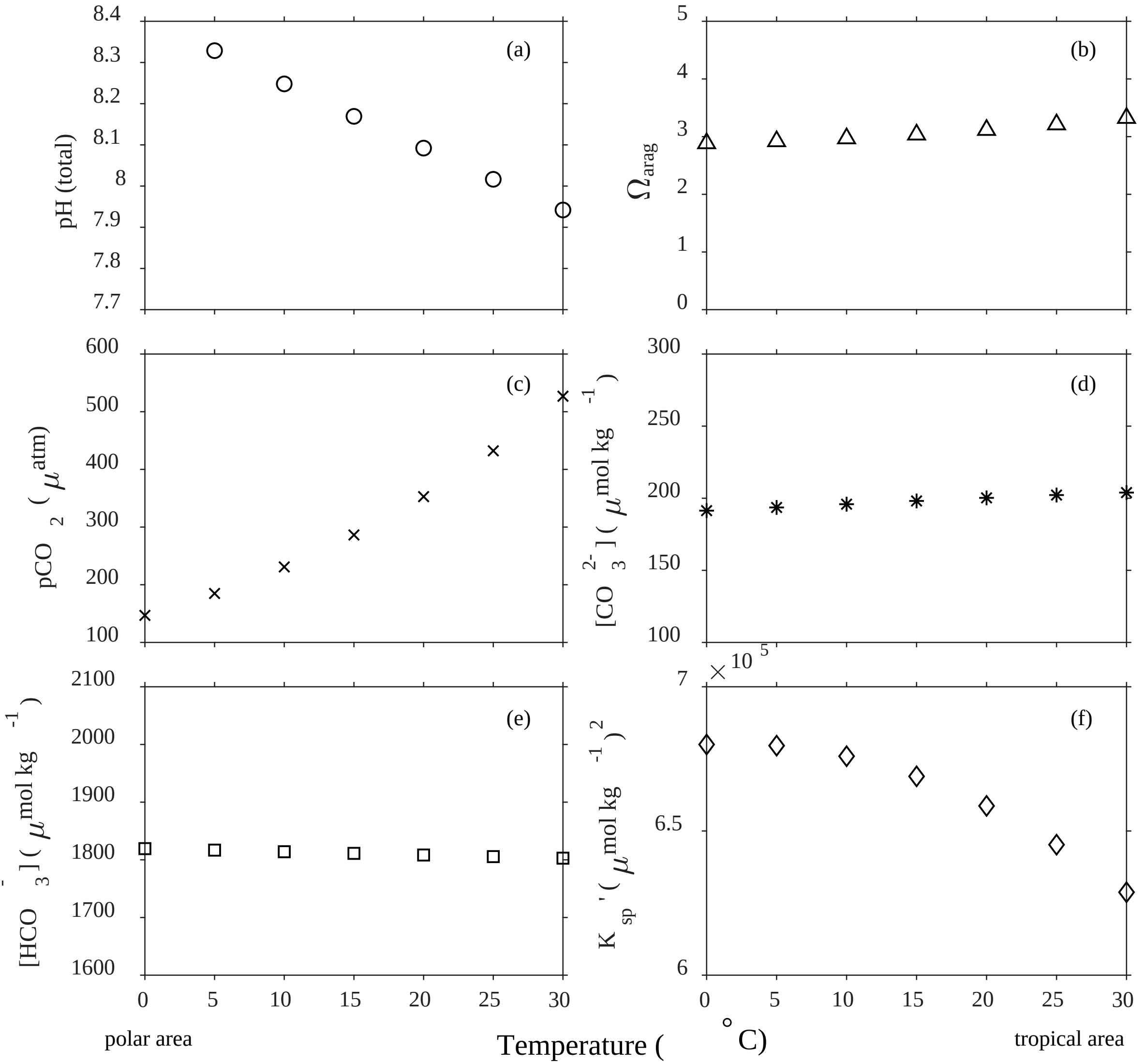
- Temperature can change CO_2 solubility and influence exchange of carbon with the atmosphere or the surrounding water and changes the ratio of TA/DIC.

- For a body of water, colder temperature enables the water to absorb more CO_2, hence higher DIC, in order to maintain the same pCO_2 level.

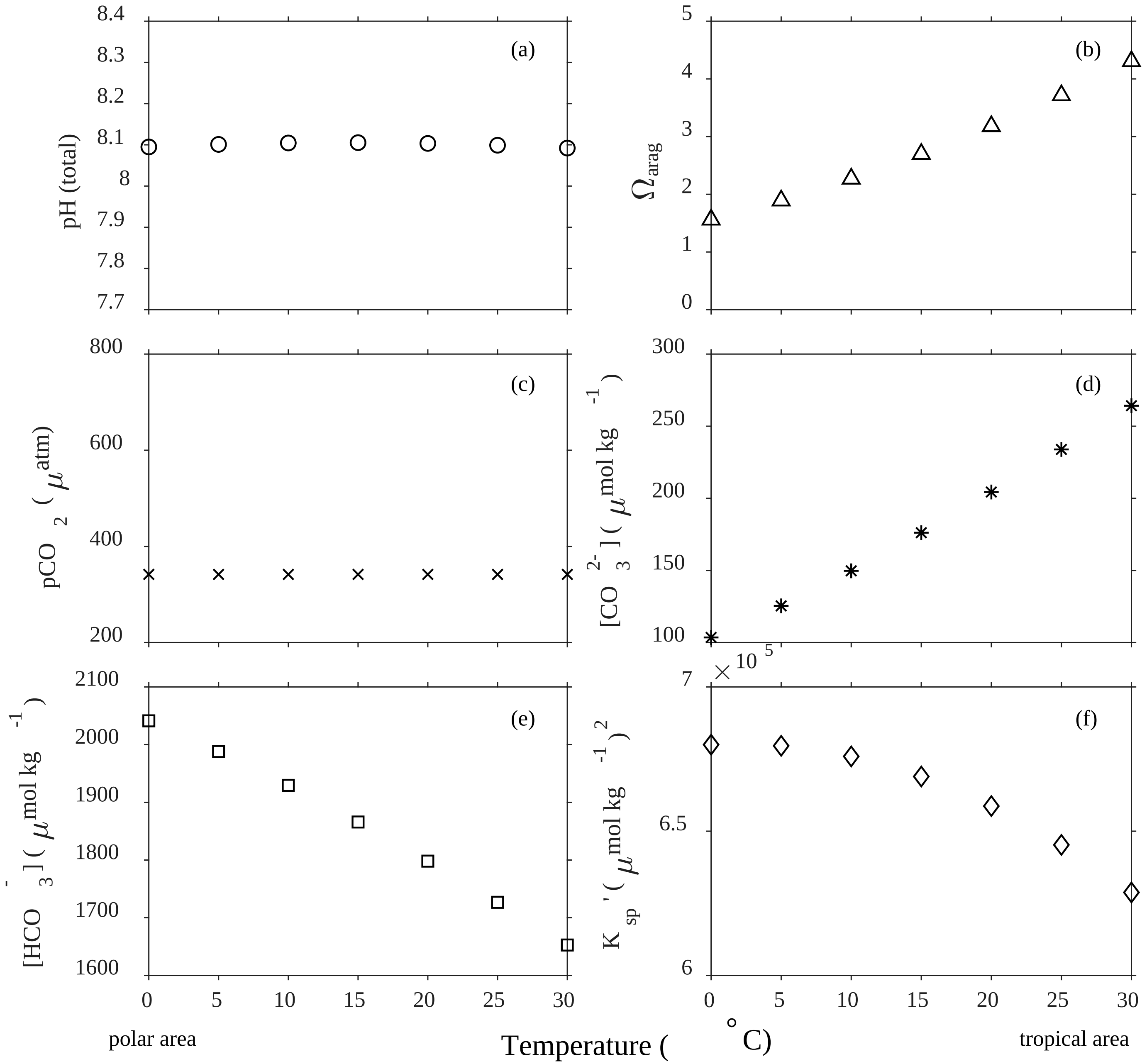


SST effect II: Controls TA/DIC of surface water



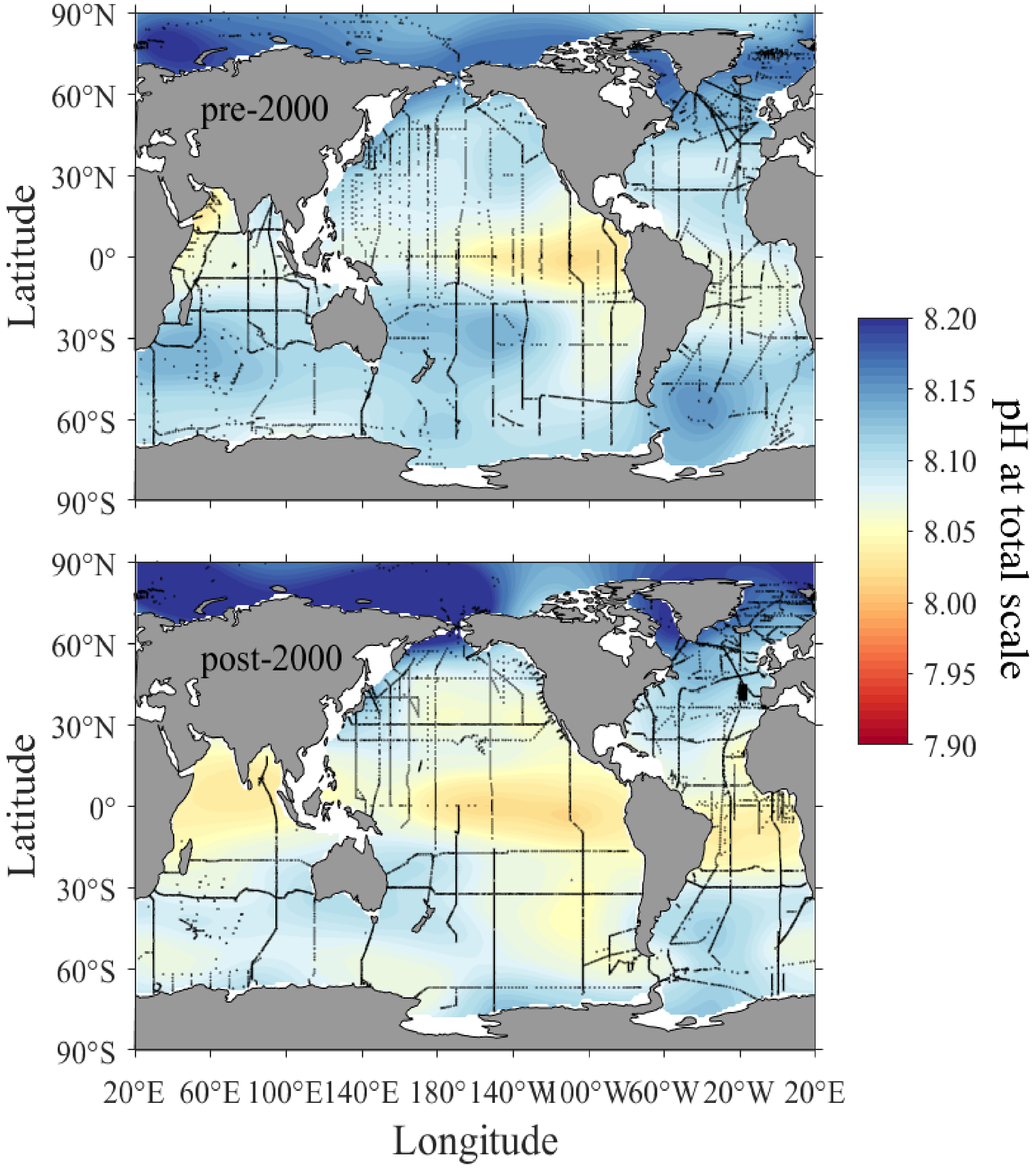


The relative amounts of $CO_{2(g)}$, H_2CO_3, HCO_3^-, CO_3^{2-}, and subsequently the pH in a body of water changes as temperature shifts.



Combined SST effect on surface pH

- ❑pH does not show much latitudinal variations, although saturation state does.
- ❑pH is **NOT** a good indicator for carbonate ion, and saturation state in the surface ocean.



Decadal pH change

- ❑Not enough data to cover the globe in two decades. We plotted all data before 2000 and after 2000

- ❑pH shows clear decrease in the equatorial region, north Pacific, and Southern Ocean.

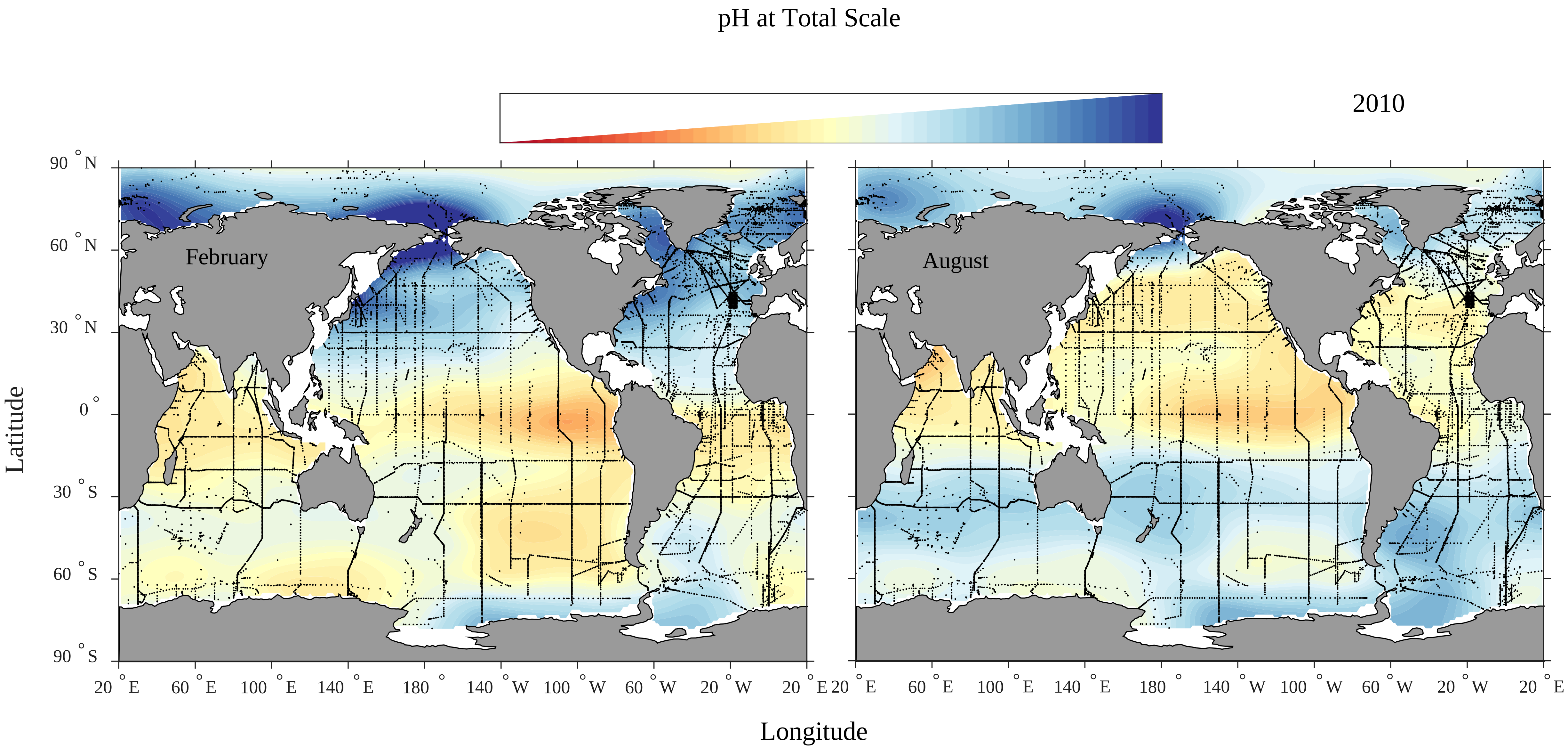
Projection of pH into the future

- **Assumption I**: Total alkalinity remains constant.

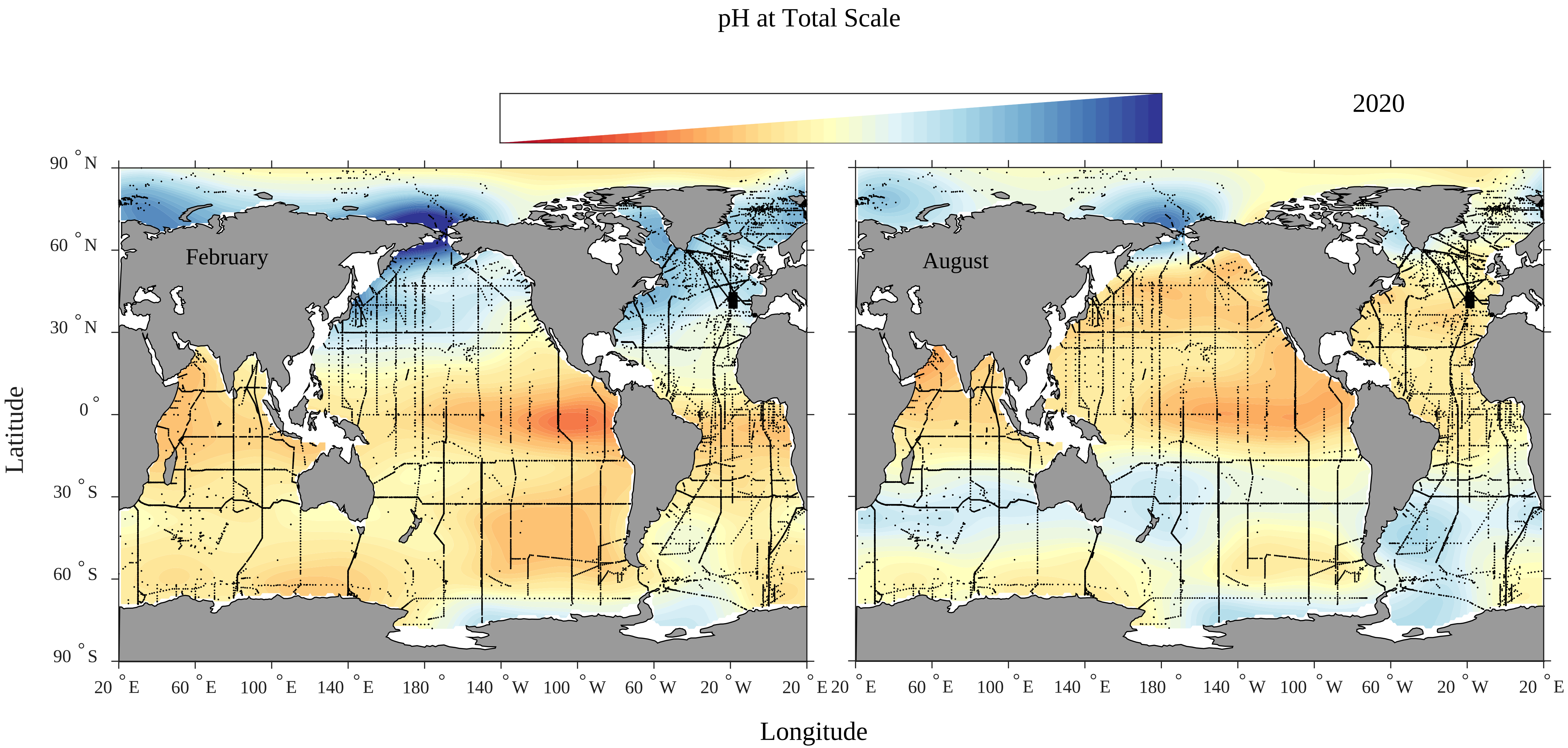
- **Assumption II**: Sea surface pCO_2 increases at the same rate as atmospheric CO_2 under the IPCC business as usual scenario (RCP 8.5).

- **Assumption III**: SST increases at a rate of 0.15 ^{o}C per decade at the beginning of the 21st Century and linearly increased to 0.40 ^{o}C per decade at the end of the Century.

pH in 2010

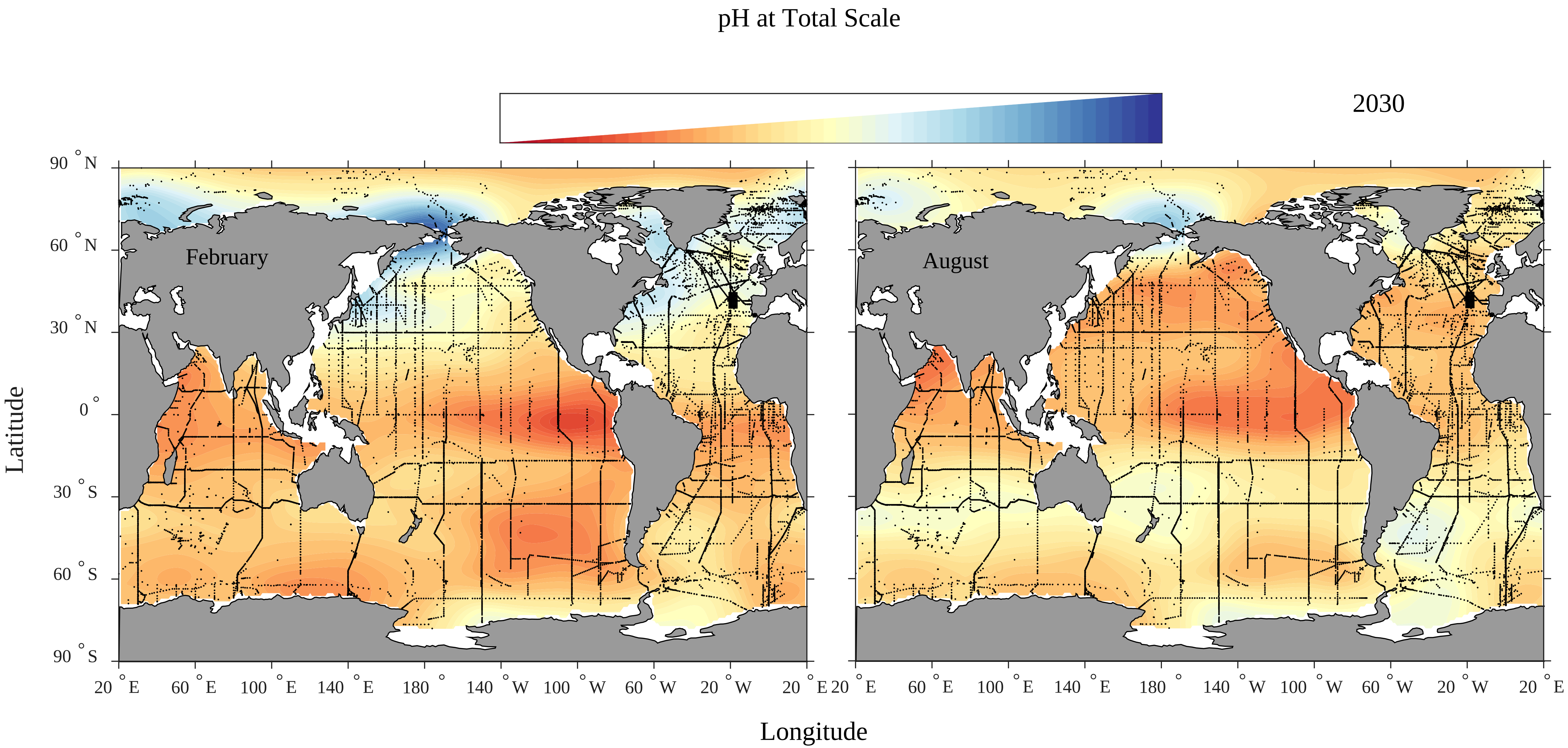

pH at Total Scale
2010
February
August
Latitude
Longitude
90 °N
60 °N
30 °N
0 °
30 °S
60 °S
90 °S
20 °E
60 °E
100 °E
140 °E
180 °
140 °W
100 °W
60 °W
20 °W

pH in 2020



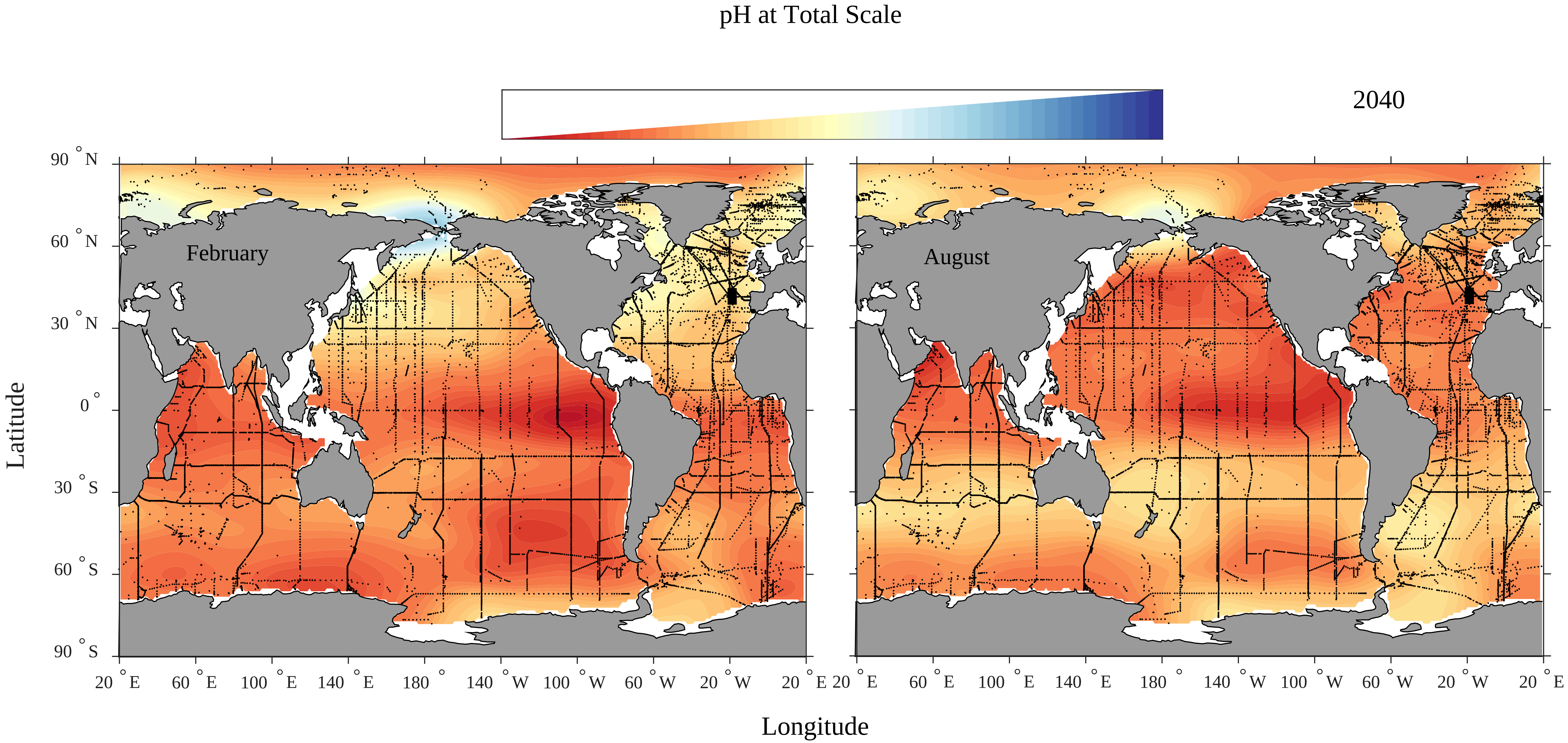
pH at Total Scale
2020
February
August
90 °N
60 °N
30 °N
0 °
30 °S
60 °S
90 °S
Latitude
20 °E
60 °E
100 °E
140 °E
180 °
140 °W
100 °W
60 °W
20 °W
20 °E
Longitude

pH in 2030



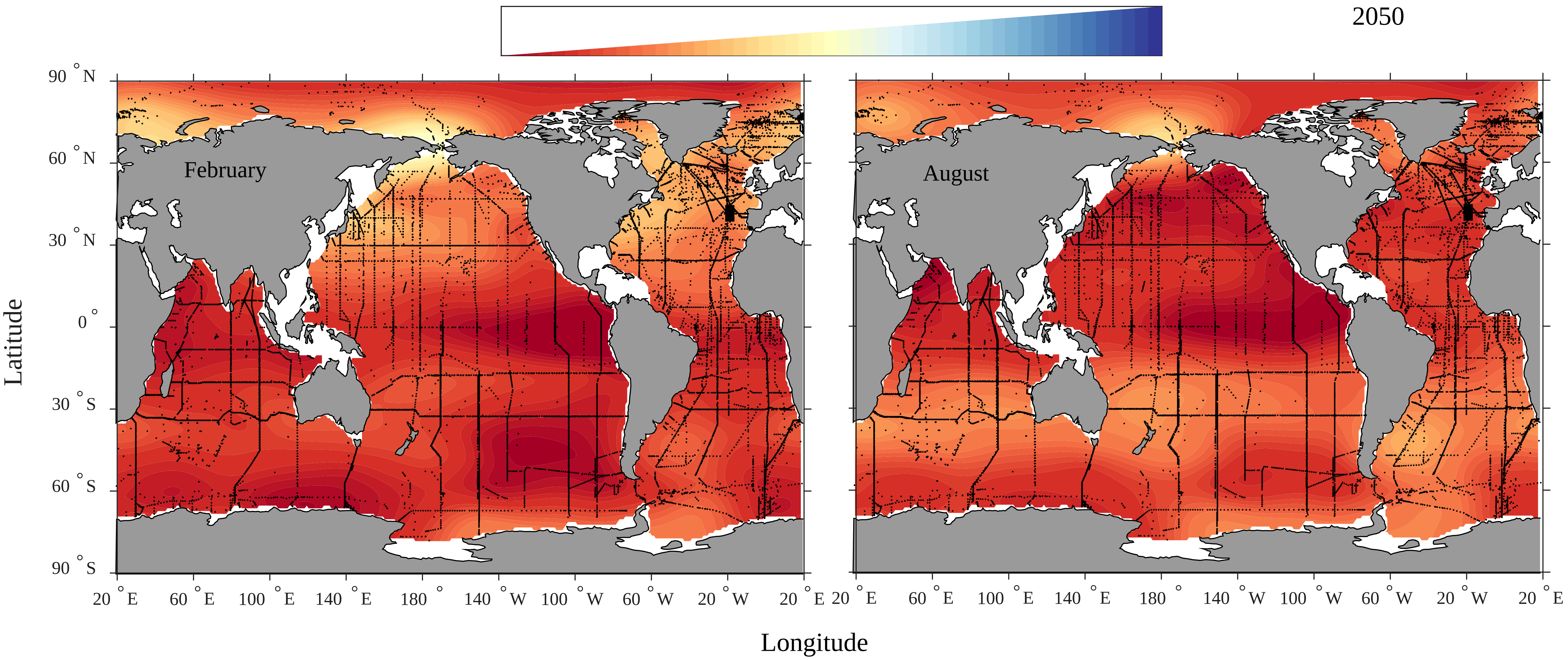
pH at Total Scale
2030
February
August
Latitude
Longitude
90 °N
60 °N
30 °N
0 °
30 °S
60 °S
90 °S
20 °E
60 °E
100 °E
140 °E
180 °
140 °W
100 °W
60 °W
20 °W
20 °E

pH in 2040


pH at Total Scale
2040
February
August
Latitude
Longitude
90 °N
60 °N
30 °N
0 °
30 °S
60 °S
90 °S
20 °E
60 °E
100 °E
140 °E
180 °
140 °W
100 °W
60 °W
20 °W

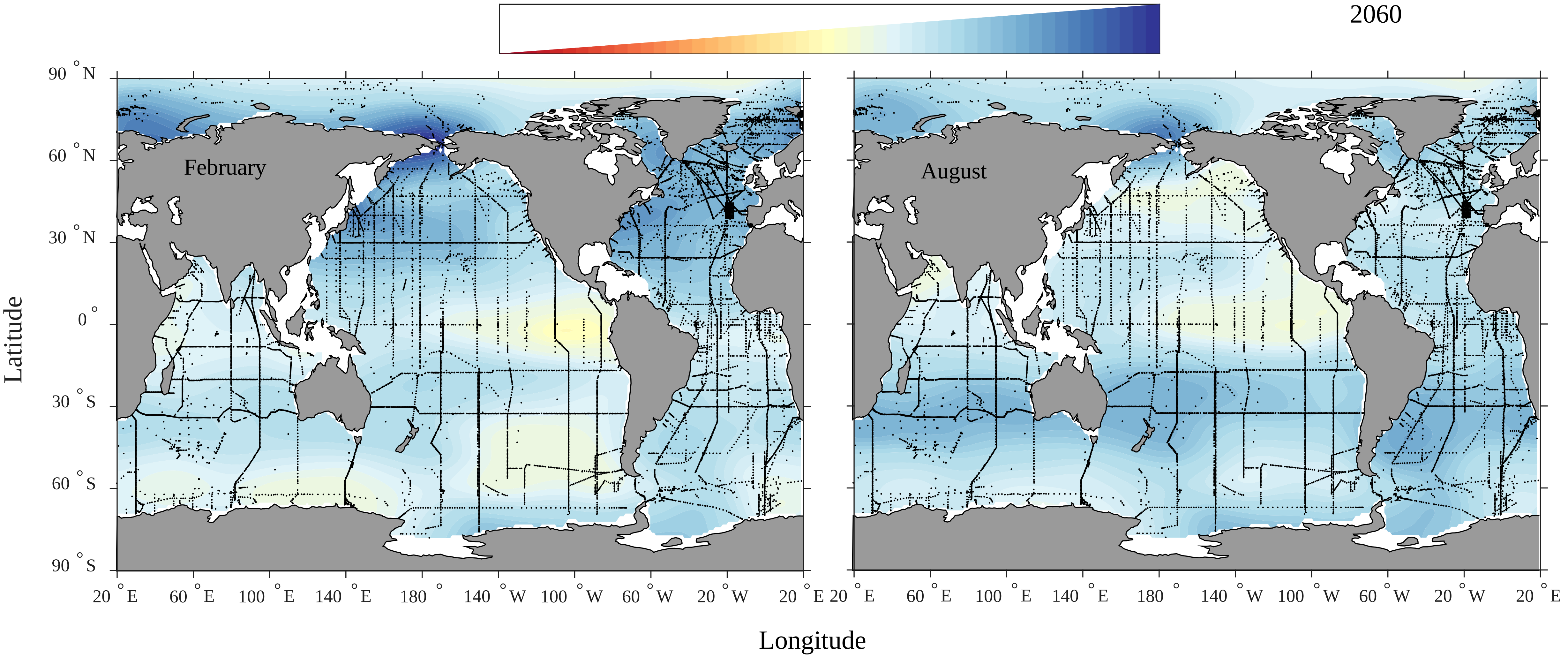
pH in 2050

pH at Total Scale

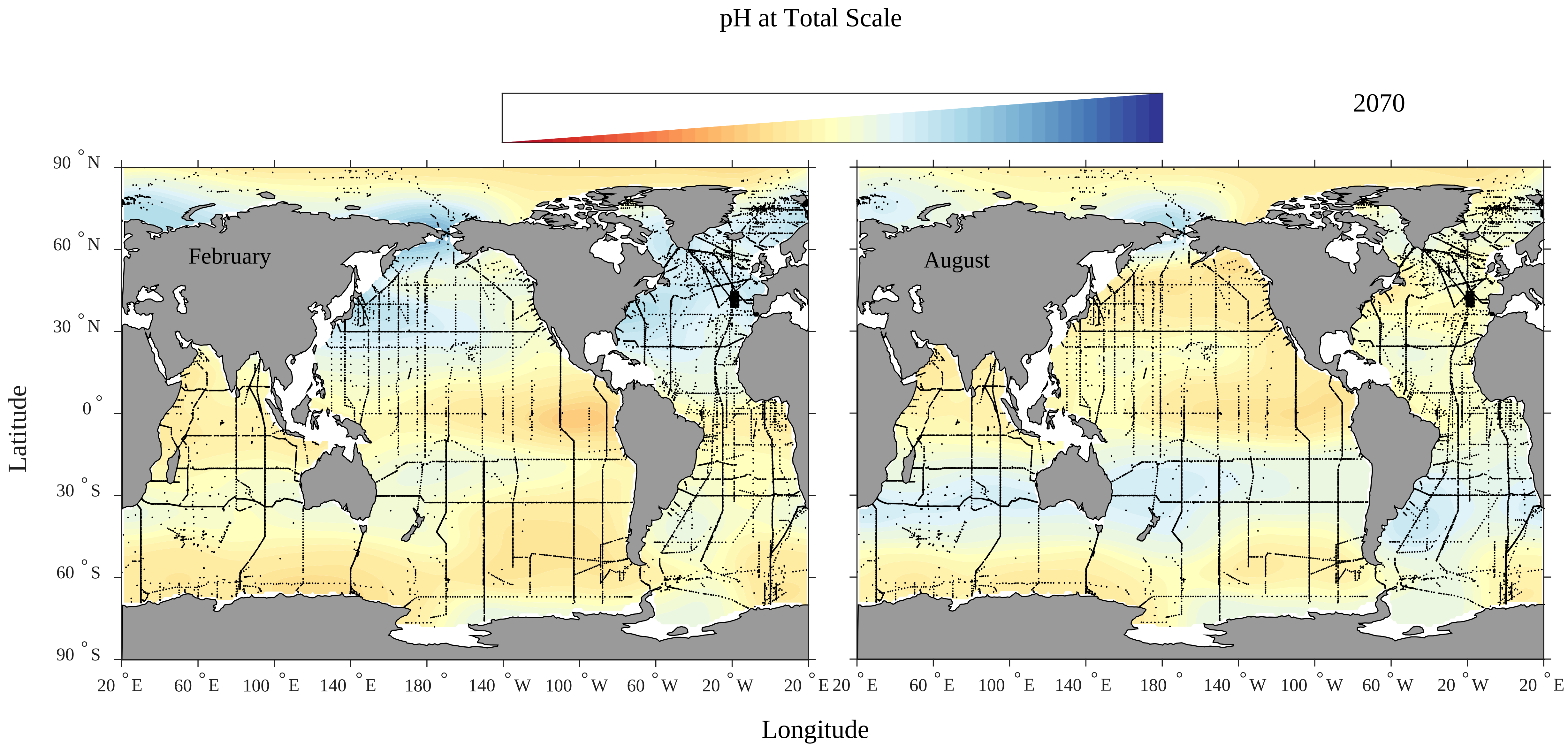


pH in 2060

pH at Total Scale

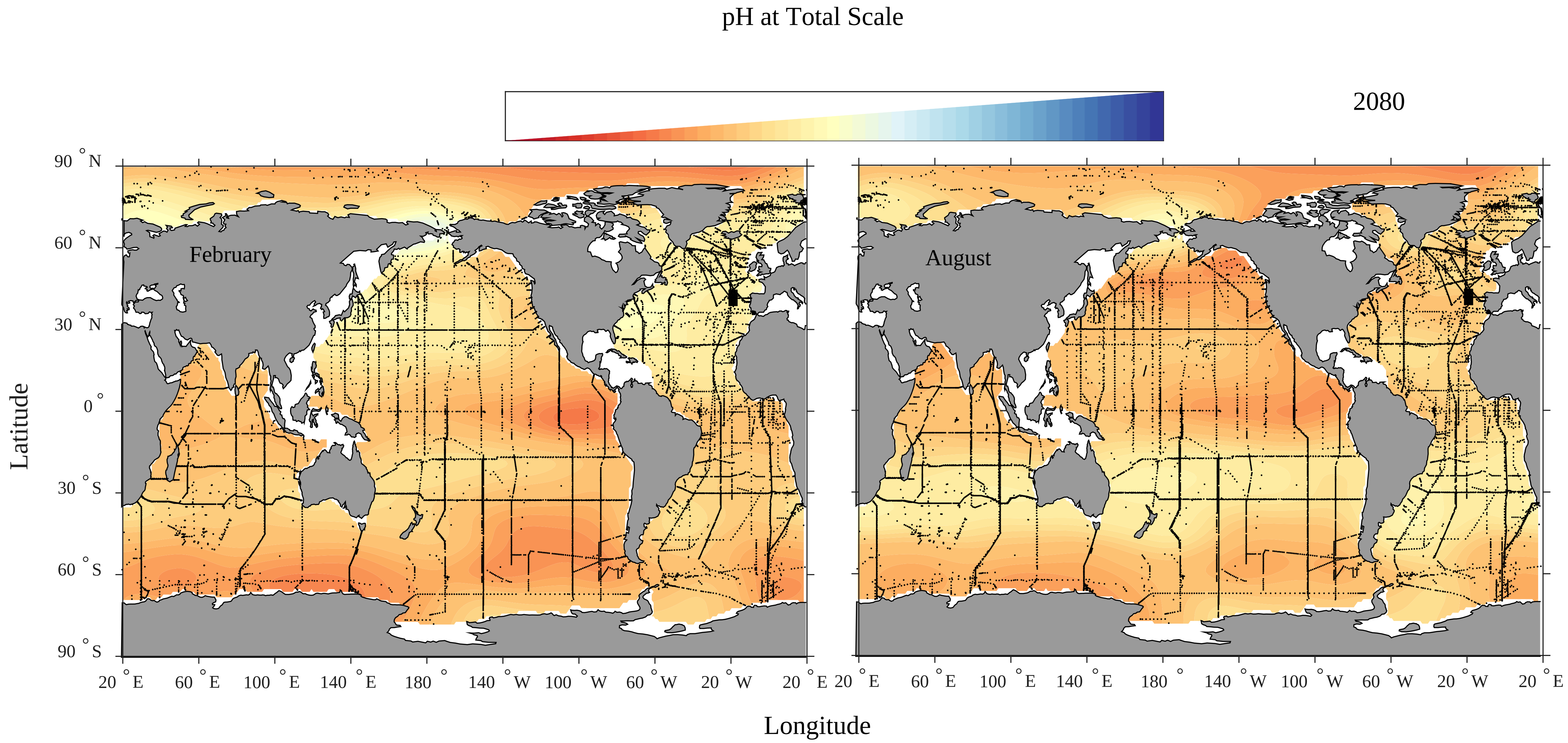


pH in 2070

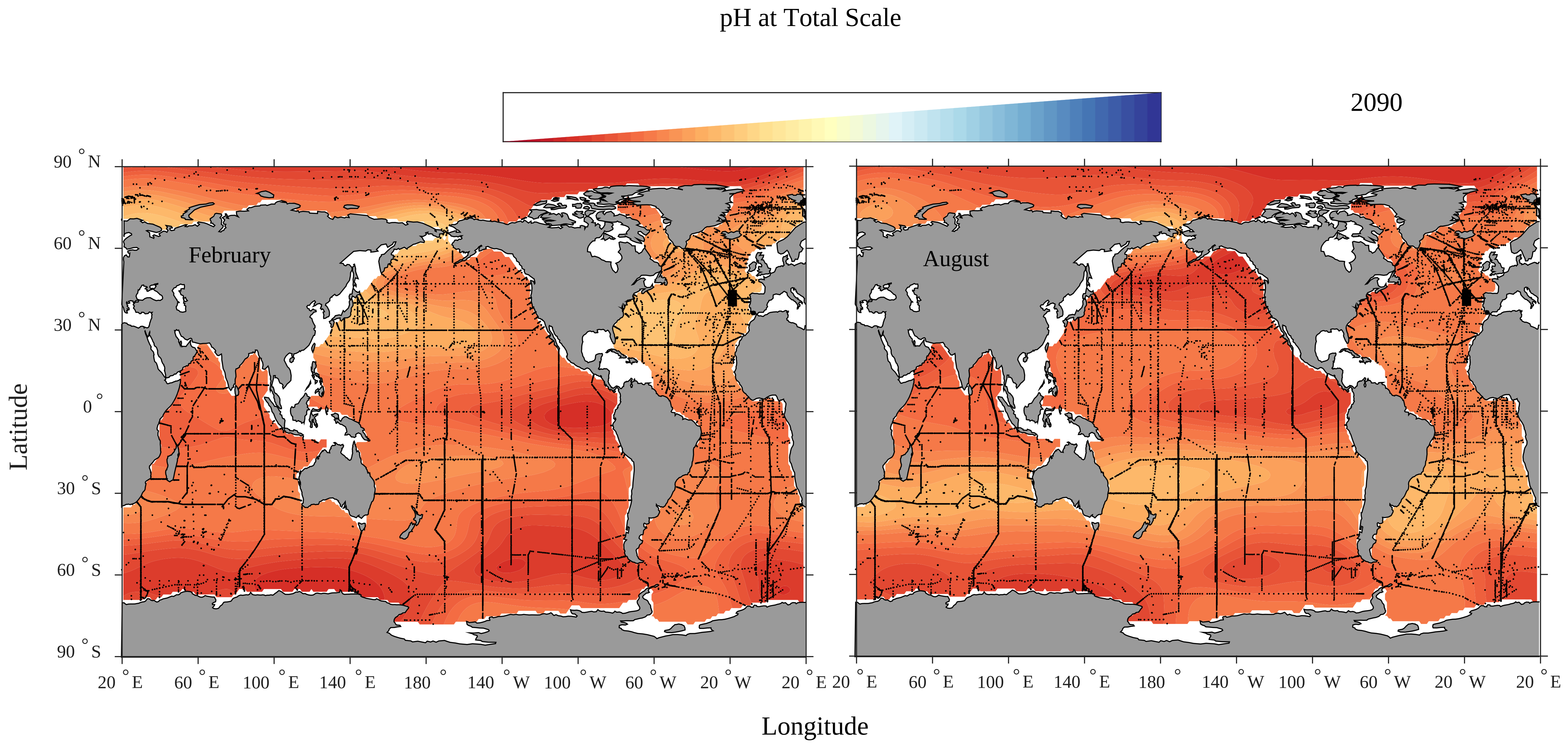


pH at Total Scale
2070
February
August
Latitude
Longitude
90 °N
60 °N
30 °N
0 °
30 °S
60 °S
90 °S
20 °E
60 °E
100 °E
140 °E
180 °
140 °W
100 °W
60 °W
20 °W
20 °E

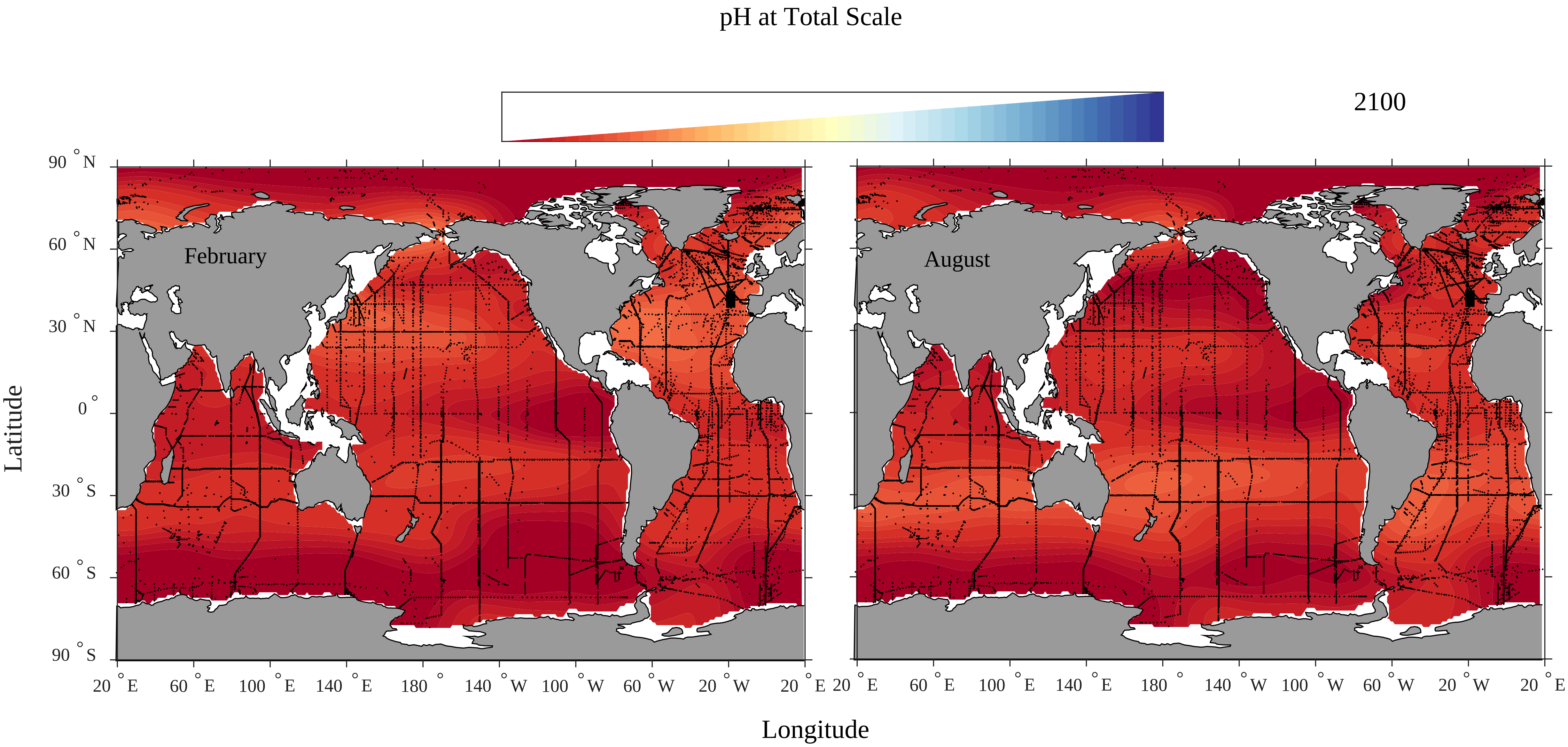
pH in 2080


pH at Total Scale
2080
February
August
Latitude
Longitude
90 °N
60 °N
30 °N
0 °
30 °S
60 °S
90 °S
20 °E
60 °E
100 °E
140 °E
180 °
140 °W
100 °W
60 °W
20 °W

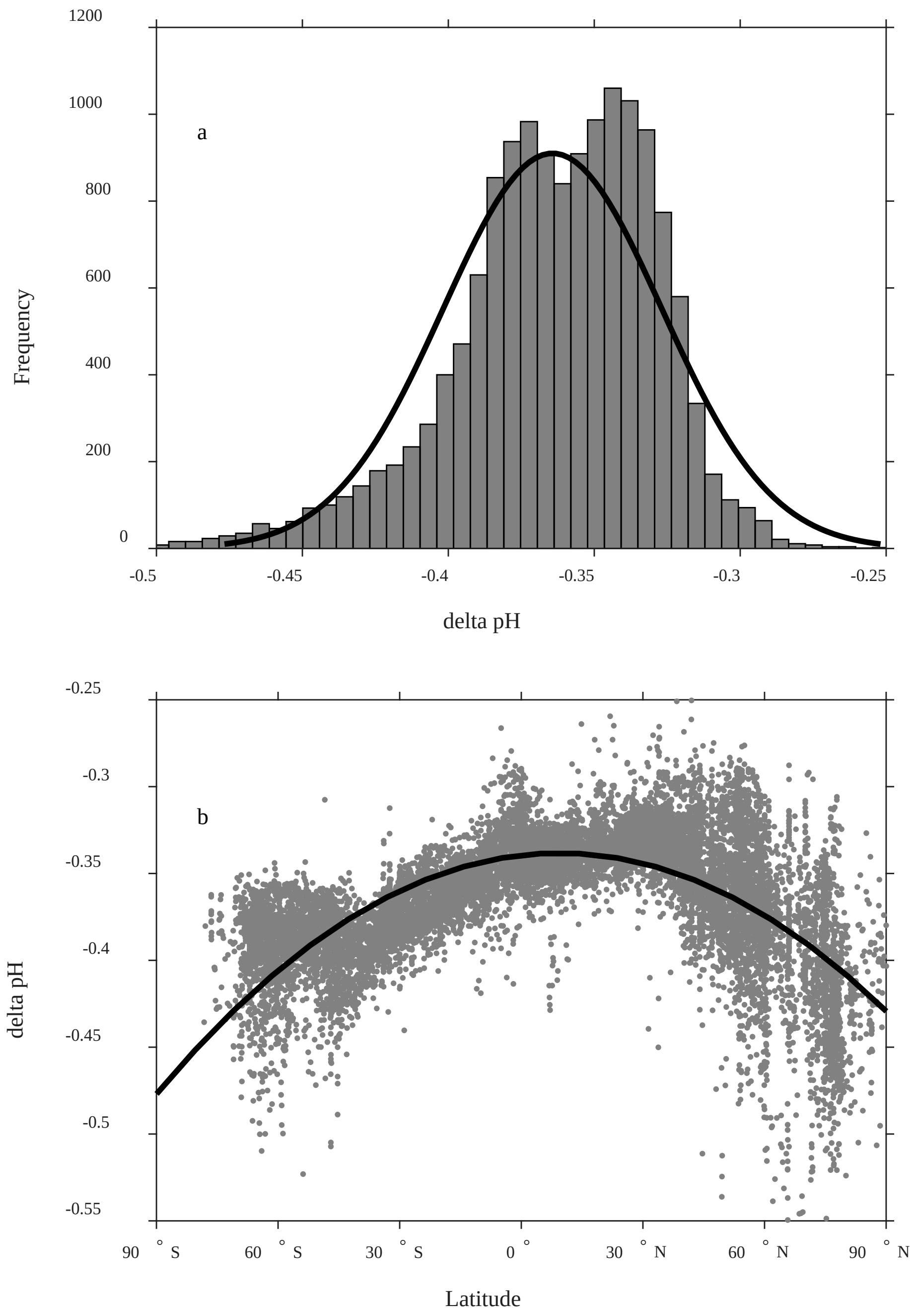
pH in 2090


pH at Total Scale
2090
February
August
Latitude
Longitude
90 °N
60 °N
30 °N
0 °
30 °S
60 °S
90 °S
20 °E
60 °E
100 °E
140 °E
180 °
140 °W
100 °W
60 °W
20 °W

pH in 2100



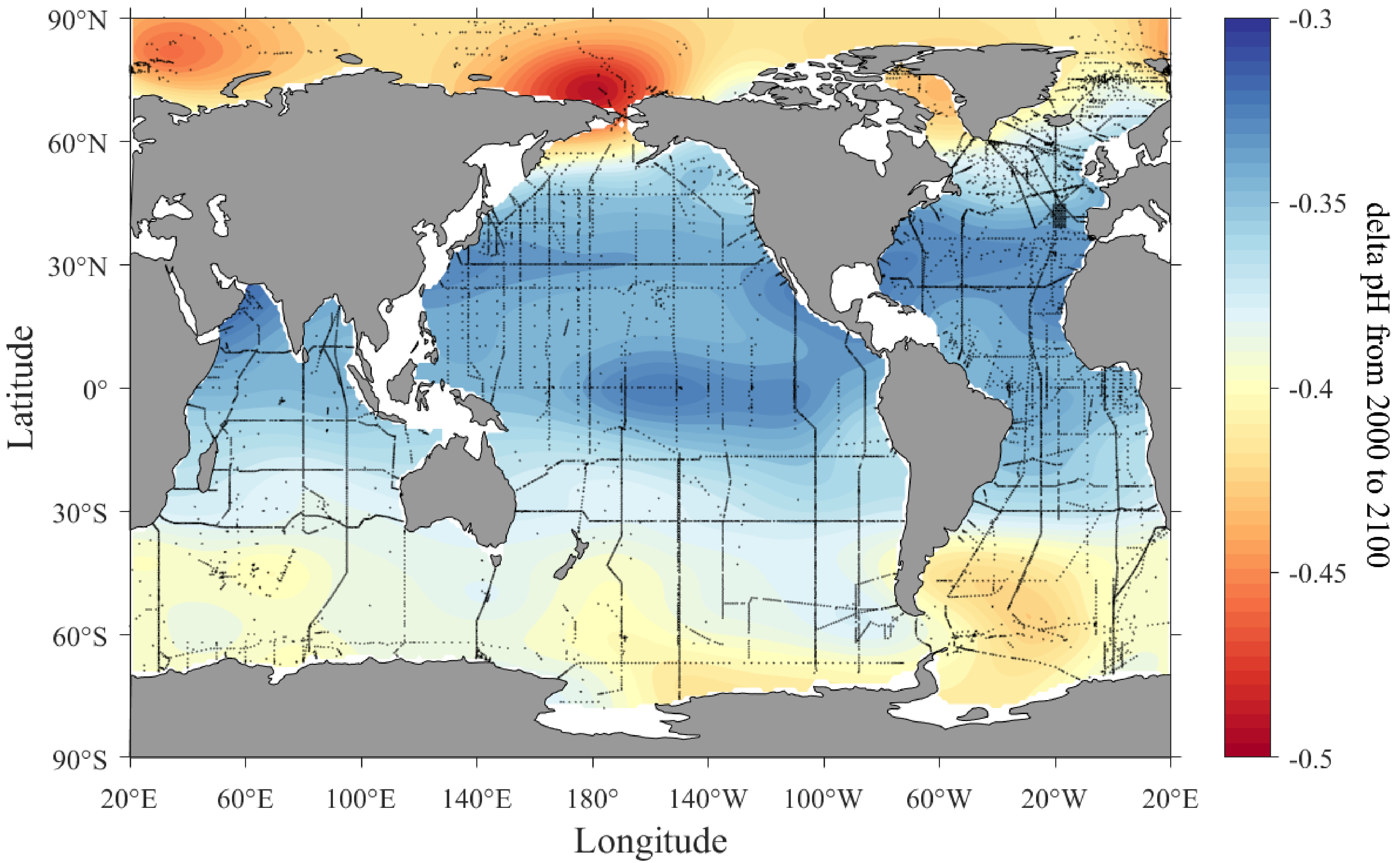
pH at Total Scale
2100
February
August
Latitude
Longitude
90 °N
60 °N
30 °N
0 °
30 °S
60 °S
90 °S
20 °E
60 °E
100 °E
140 °E
180 °
140 °W
100 °W
60 °W
20 °W
20 °E

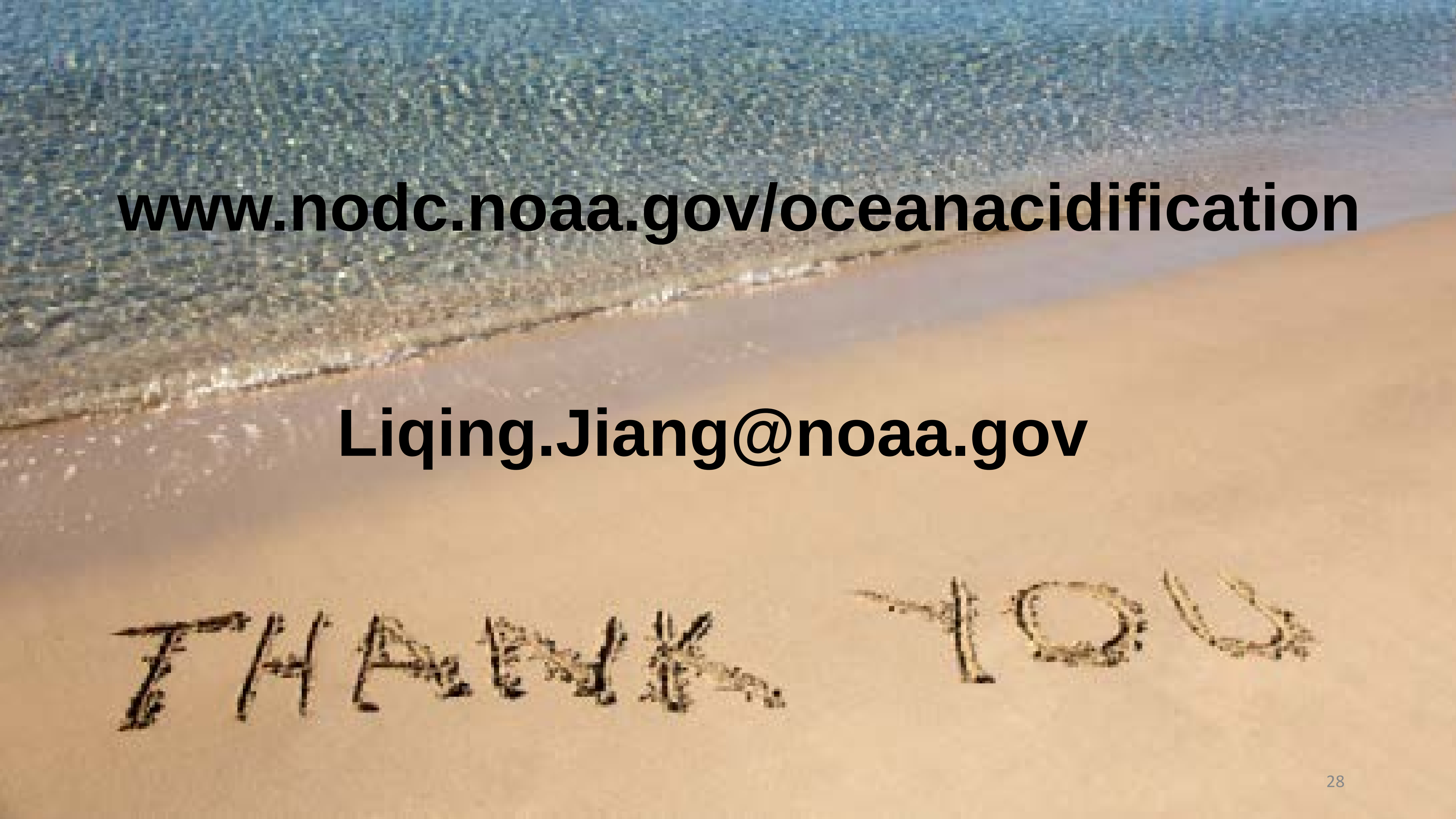


pH change from 2000 to 2100

- On a percentage basis, hydrogen ion increases ~**8.5% per decade**, pH drops about ~**0.45% per decade**.
- pH change from 2000 to 2100 falls between -0.45 and -0.3.
- A mean pH drop of -0.36 (median:-0.36), which translates to an **hydrogen ion increase of 130%**.
- pH drop is smallest in the equatorial region and greatest towards the poles.

Spatial distribution of pH change from 2000 to 2100





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