The Impact of Anthropogenic Forcing on ENSO Amplitude

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What is El Niño/Southern Oscillation (ENSO)?

- Cyclical change in the temperature of the equatorial Pacific Ocean
- Driven by feedback loops involving air circulation, water movement, and heat transfer.
- Significant impact on global climate
- Occurs every 2-7 years
- Intensity can be expressed as the amplitude of its cycle

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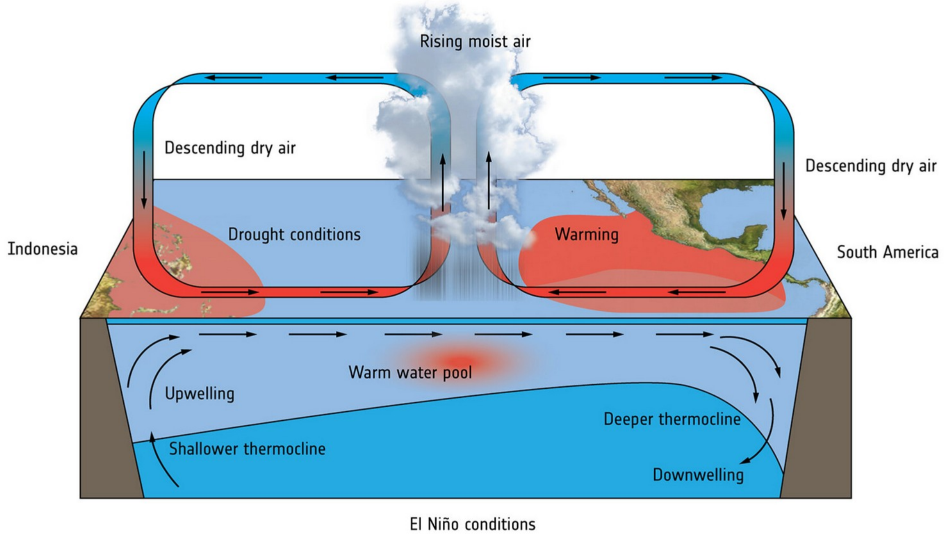
Figure 1: Changes to tropical Pacific climate during El Niño



Internal Variability vs. Climate Change

Internal Variability

- Cyclical/repetitive
- Caused by feedback loops inside the climate system
  - AMOC (Atlantic Meridional Overturning Current)
  - PDO (Pacific Decadal Oscillation)

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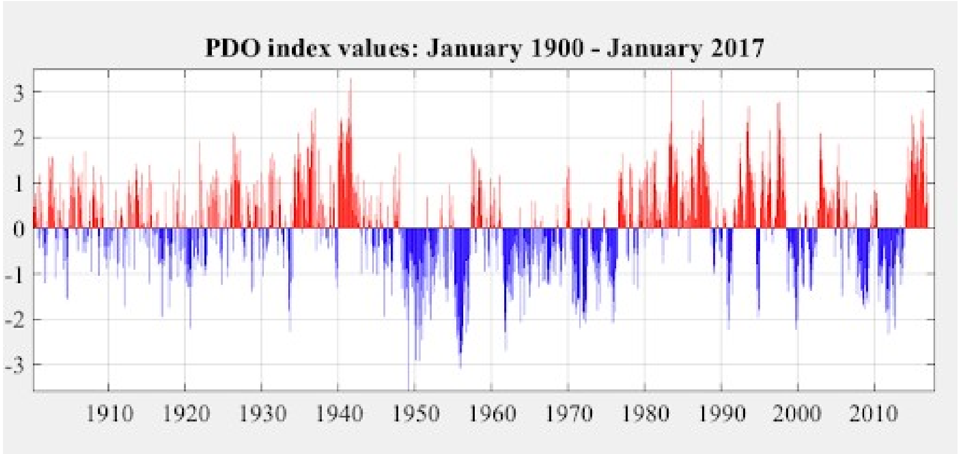

Figure 2: PDO index since 1900

Climate Change

- Long-term trend
- Caused by external forcing, such as:
  - Greenhouse emissions
  - Aerosol emissions
  - Etc.

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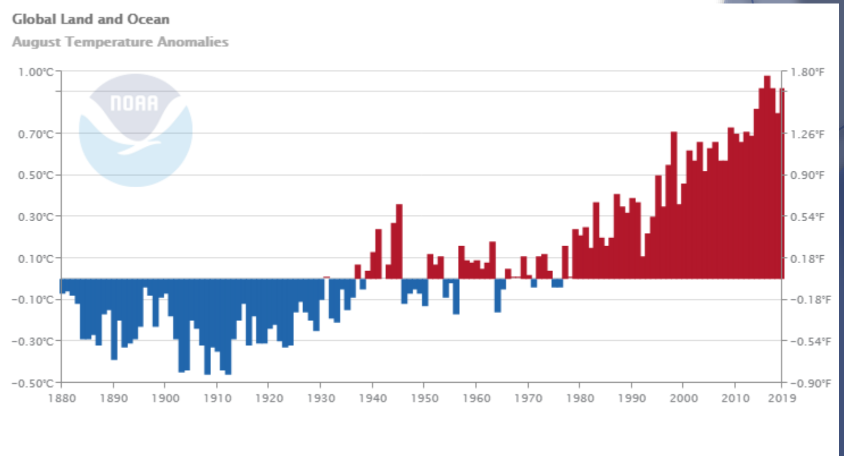


Figure 3: Global average temperature since 1880

Review of Literature

Stevenson et. al. 2012

- Did not detect statistically meaningful difference in ENSO amplitude between the 20th century and projections of the 21st century

Chen et. al. 2017

- Showed that irregularities in the simulation of the air currents above the Pacific may be responsible for disagreements of future change to ENSO intensity

Maher et. al. 2018

- Used an ensemble of climate models with a sample size of 40 and 100, observing increased ENSO amplitude under anthropogenic forcing, with a large amount of internal variability.

Gap

- Little research on the role of individual factors
- Conflicting results on whether ENSO intensity will increase or decrease

Research Goals

Problem:	How large of an effect does climate change have on ENSO intensity? What factors play the largest role?
Estimate future changes	Use a large group of climate models to estimate changes to ENSO amplitude in the future under a variety of forcing conditions.
Single forcing	Compare the roles of greenhouse gasses and aerosol emissions in affecting ENSO using a bootstrap test.
Ocean structure	Analyze possible mechanism through which climate forcing affects ENSO amplitude

Data: The CESM LE

- Community Earth System Model Large Ensemble (CESM LE) is an ensemble of coupled model simulations.
- Coupled model: Simulation of the Earth's climate (land, ocean, atmosphere) that uses mathematical equations to predict future or past climate when input with initial conditions and prescribed forcing.
- Ensemble: a collection of model simulations that have the same physics but slightly different initial conditions.
- Control run with forcing fixed at pre-1850 levels.

Methodology Step 1: Niño 3.4 Variance

- Calculate ENSO amplitude by taking the variance of sea surface temperature in the Niño 3.4 region for each ensemble.
- 20-year sliding windows from 1920-2100
- Sliding window: calculate variance for first 240 years centered around one date, move forward by one month, calculate variance centered around that date, repeat

4: Map with Niño 3.4 box

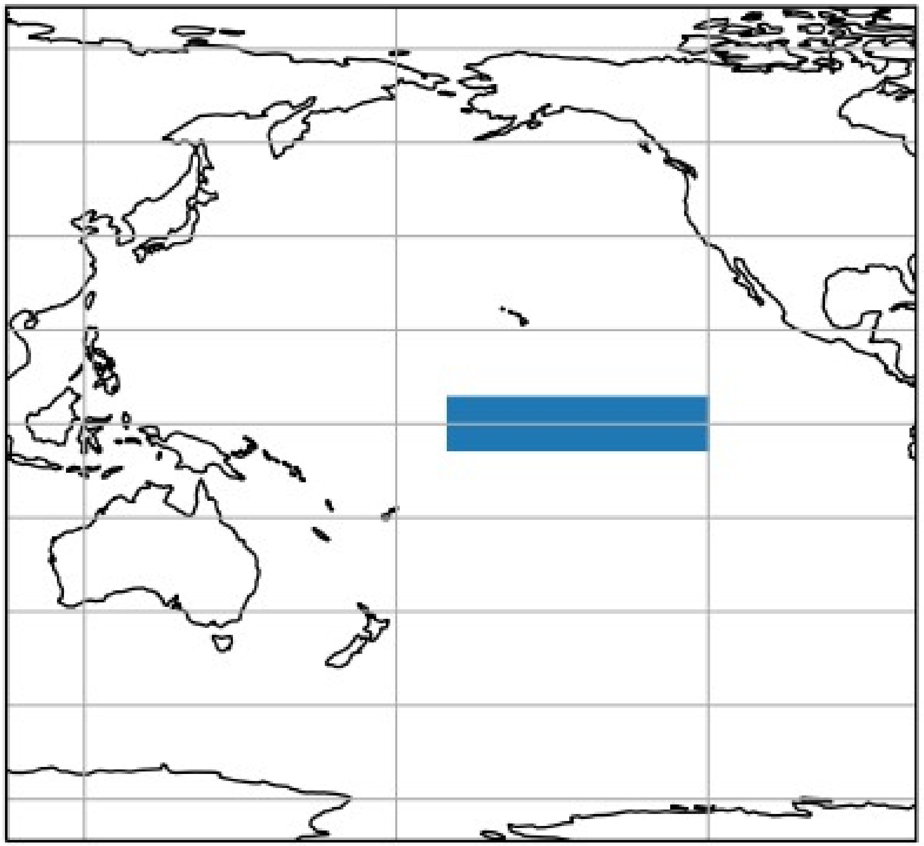
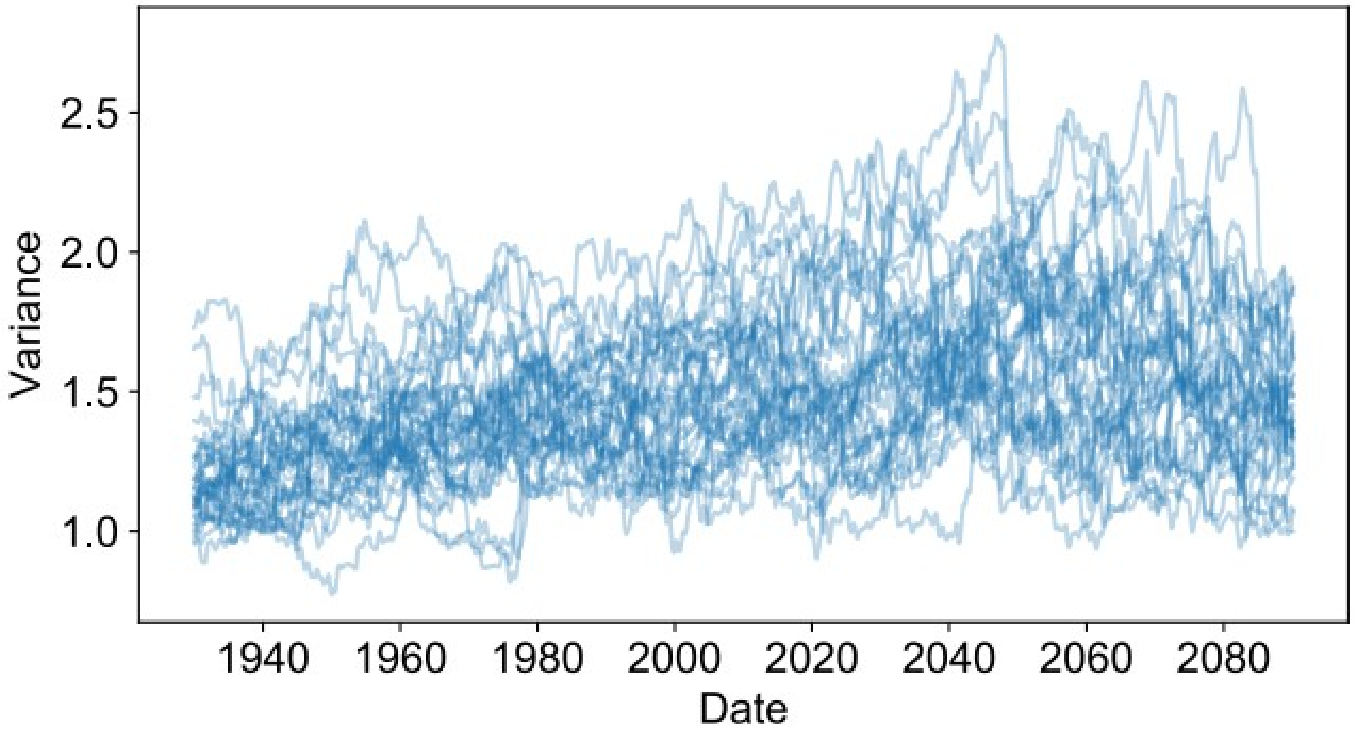


Figure 4: Niño measurement regions, Niño 3.4 is the shaded box.

Need for a Large Ensemble

7: Variance of individual ff ensemble members



- Variability between members of the same ensemble is large
- Difficult to detect statistically significant changes with single members
- Using an ensemble allows researchers to have a larger sample size.

Figure 7: Niño 3.4 20-year variance for individual members in full forcing ensemble

Model Predictions for ENSO Amplitude

- Statistically significant increase in variance for fully-forced ensemble
- Increase in greenhouse gas and aerosol ensembles, may not be significant.
- No significant changes in other ensembles (LULC sample size is small)

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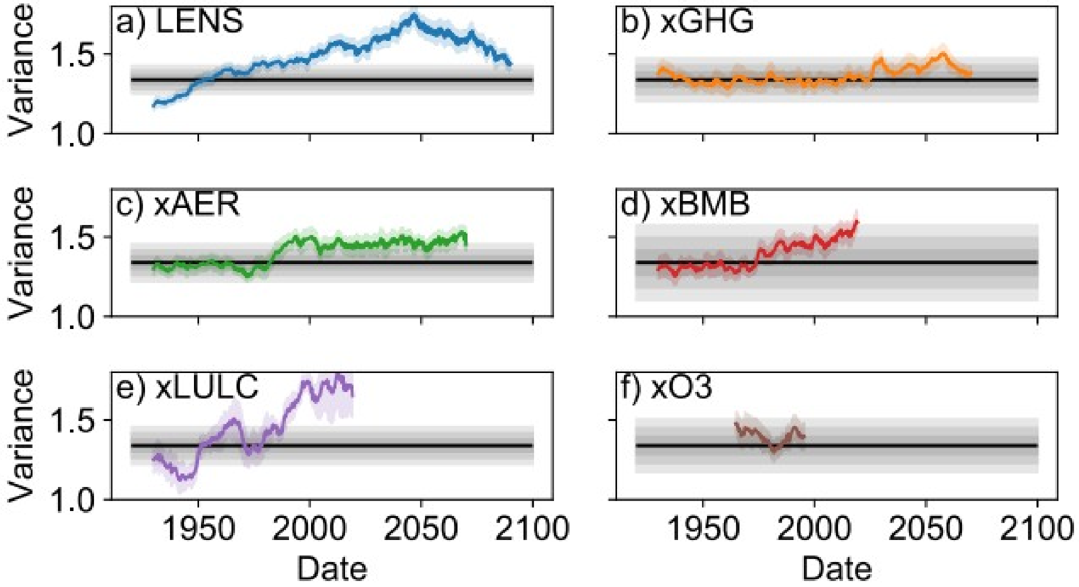


Figure 6: 20-year variance of Niño 3.4 index for each ensemble. Grey bars are control mean and 1, 2, 3x standard error a) fully forced b) greenhouse gasses c) aerosols d) biomass burning e) land use/cover f) ozone

Analysis of Individual Factors

- Single forcing ensembles are forced by all but one factor
- Subtract from fully-forced ensemble to find impact of single factor
- Subtracted randomly selected members in single forcing ensemble from members in fully forced ensemble (Bootstrap test).

Role of Greenhouse and Aerosol Emissions

8: Full forcing minus single forcing

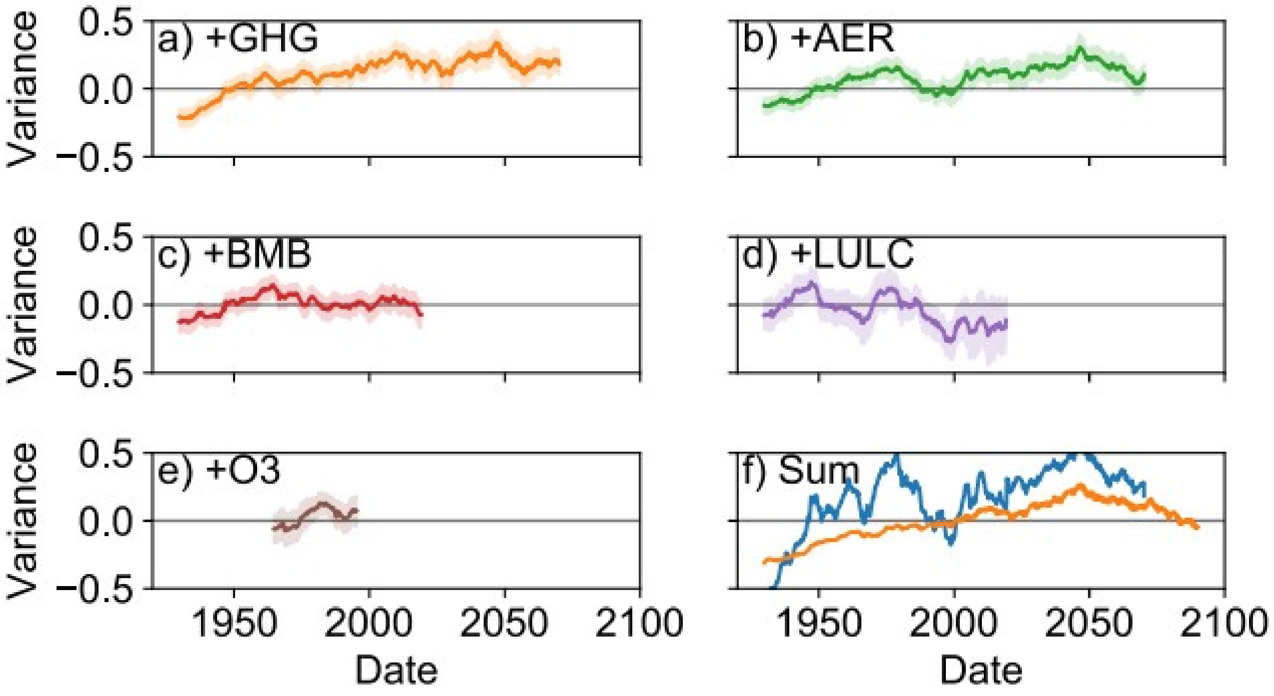


Figure 8: Difference between single-forcing and full-forcing data for each ensemble, and total compared with fully-forced data

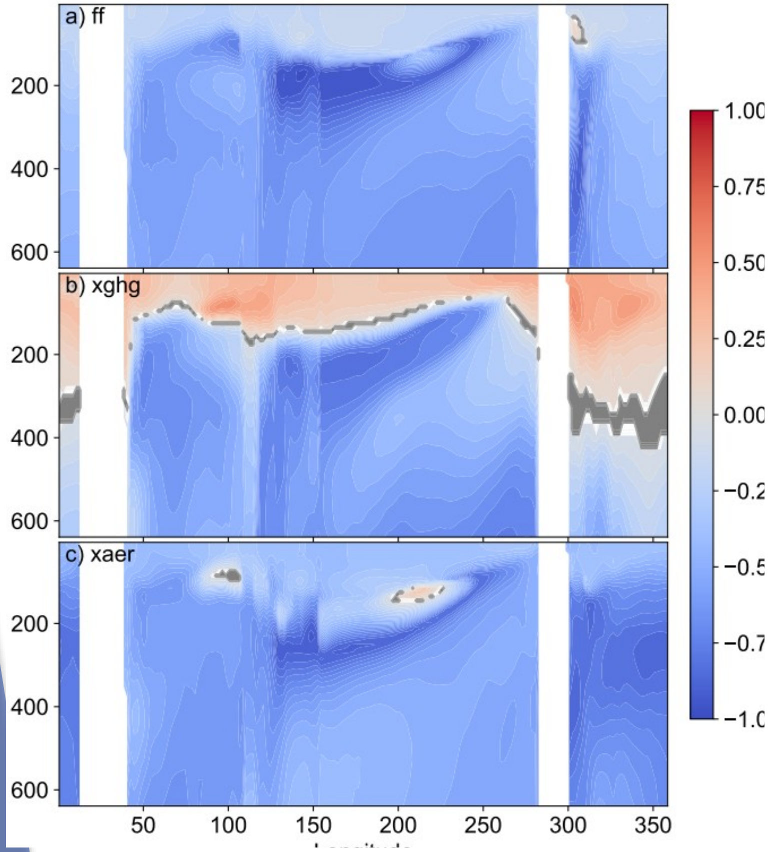
- Greenhouse gasses and aerosols have notable increase in variance.
- Unexplained low variance in mid-20th century
- Sum of individual factors is different from full forcing scenario

Methodology Step 3: Correlation With Changes in Ocean Temperature

- Find ocean temperature for each ensemble
- Calculate correlation coefficient between ENSO variance and ocean temperature at a range of depths and longitudes for each ensemble.

Results From Step 3

9: Correlation with equatorial slice



10:Correlation with central Pacific slice

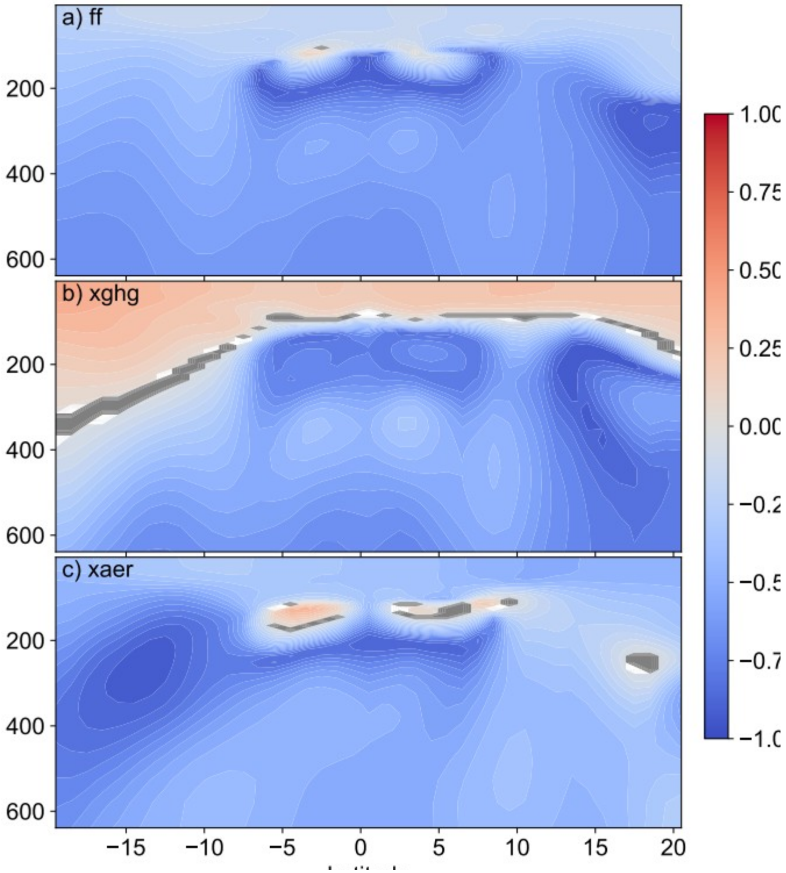


Figure 9: correlation between detrended & smoothed Niño 3.4 20-year variance and equatorial ocean temperature in a) fully forced b) xghg and c) xaer ensembles
Figure 10: Same as 3 but correlation with central pacific temperature.

Conclusions

Estimate future changes	• There is likely to be an increase in ENSO strength over the next 100 years.
Analyze role of single factors	• Increase is likely caused by the combined influence of greenhouse gasses and aerosols.
Physical Mechanism	• Future ocean warming increases ENSO intensity by warming the upper layers of the Pacific faster than the central layers.

Application and Next Steps

- Application: to help humans prepare for future changes to the earth's climate
- Next steps:
  - Continue analysis of association with internal variability to explain low variance from 1920-1960.
  - Compare results to analysis of CMIP6 and CESM2 ensembles.
  - Measure correlation with ocean salinity and potential density to further analyze changes to ocean structure
  - Advanced statistical analysis

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Figure 13: NCAR laboratory in Boulder, CO

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