Compressing CESM Data… while Preserving Information

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ICAS 2017
Sept. 12, 2017

Climate models produce lots of data

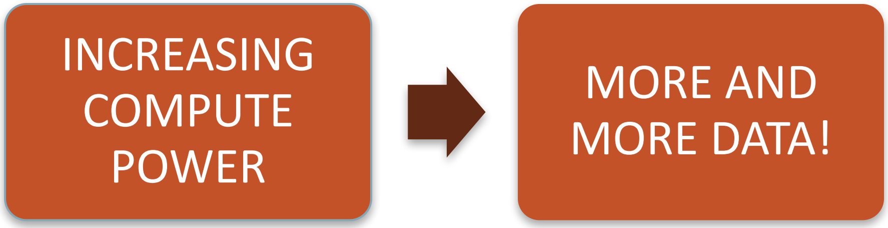
..and it's getting worse!

IPCC Coupled Model Comparison Projects (CMIPs)

- Phase 5 (2013): 2.5 PB of output
- Phase 6 (2018): >20 PB expected (40 PB?)

Storage at NCAR

- More precious than CPU-hours?



INCREASING COMPUTE POWER

MORE AND MORE DATA!

Climate models produce lots of data

..and it's getting worse!

IPCC Coupled Model Comparison Projects (CMIPs)

- Phase 5 (2013): 2.5 PB of output
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Storage at NCAR

- More precious than CPU-hours?

Storage resources are limiting climate science objectives!

Simulation length, output frequency, ensemble size, output variables, …

Data compression

Compression: $X \Longrightarrow C$

Reconstruction: $C \Longrightarrow \tilde{X}$

Lossless: $X = \tilde{X}$

Lossy: $X \sim \tilde{X}$

- *Lossless* compression is (relatively) ineffective on CESM data
- *Lossy* is much better

Data compression

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Reconstruction: $C \Longrightarrow \tilde{X}$

Lossless: $X = \tilde{X}$

$$\boxed{\text{Lossy:} \quad X \sim \tilde{X}}$$

- *Lossless* compression is (relatively) ineffective on CESM data
- *Lossy* is much better … *but it makes scientists nervous!*

How to evaluate the effect of lossy compression on climate simulation data?

Lossy data compression

Issue: Quantify the error between X and $\tilde{X}$

Common “simple” compression metrics:

- average error *(peak signal-to-noise ratio, RMSE, …)*
- pointwise error (*max norm)*
- “eye-ball” norm

Lossy data compression

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Common "simple" compression metrics:

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Not sufficient for evaluating whether compression has (negatively) impacted science results.

What has been done at NCAR so far?

(1) Establish feasibility:

→ evaluate compression in the context of an ensemble.

The compression-introduced differences should not exceed ensemble variability!

- choose appropriate compression with ensemble-based metrics (per-variable)

- impact of compression on solution *is less than* a bit-perturbation to initial conditions

Possible!

What has been done at NCAR so far?

(2) Direct experience:

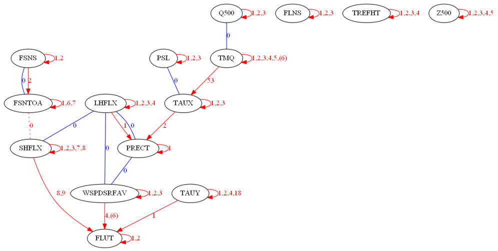
Provide climate scientists with reconstructed data.

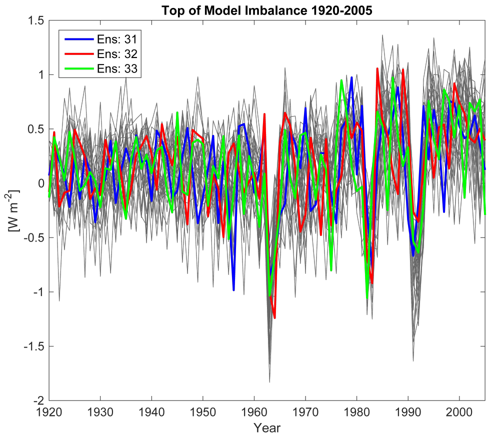
Can climate scientists differentiate between compressed and uncompressed data?

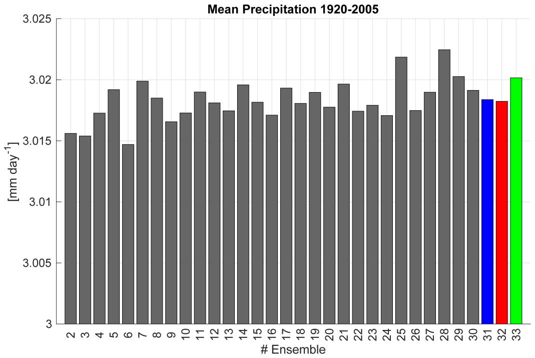
Let your taste decide.
Take the Pepsi Challenge!
Nationwide, more people prefer Pepsi over Coca-Cola!

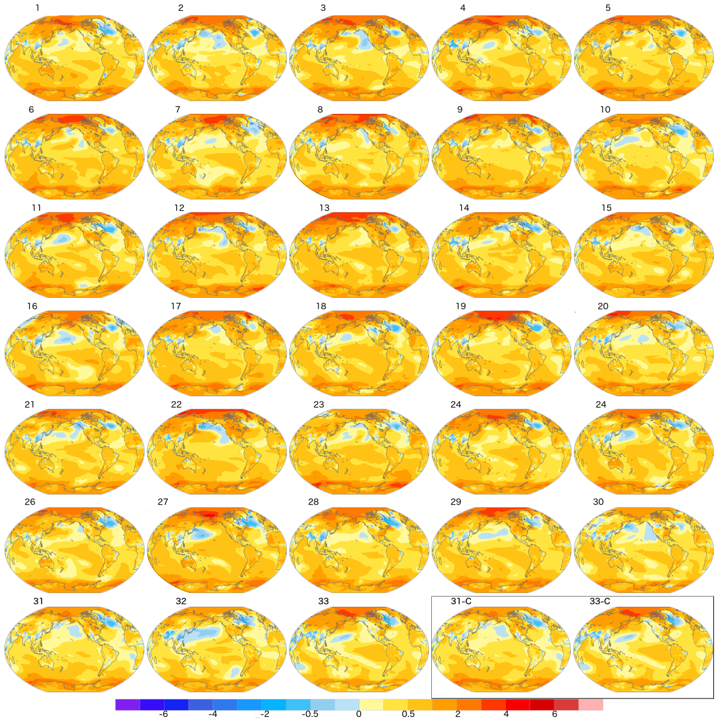
What has been done at NCAR so far?

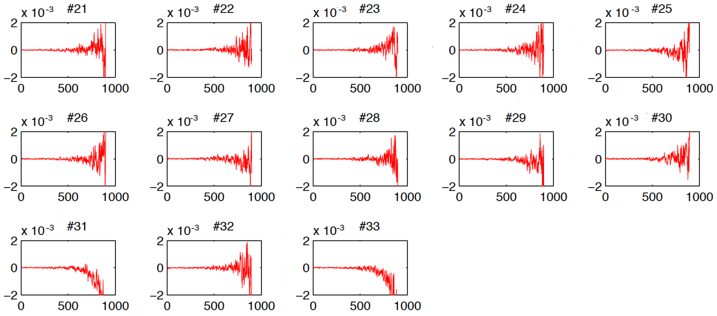
(2) Direct experience …





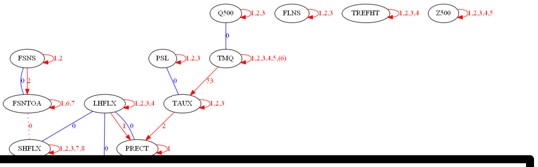


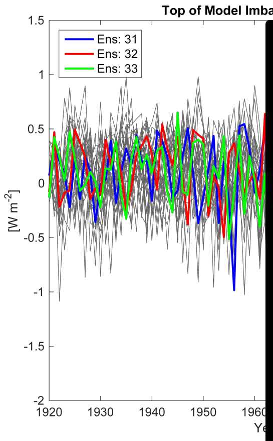




What has been done at NCAR so far?

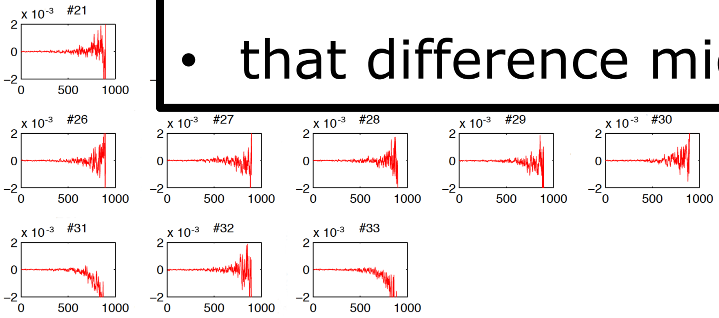
(2) Direct experience …

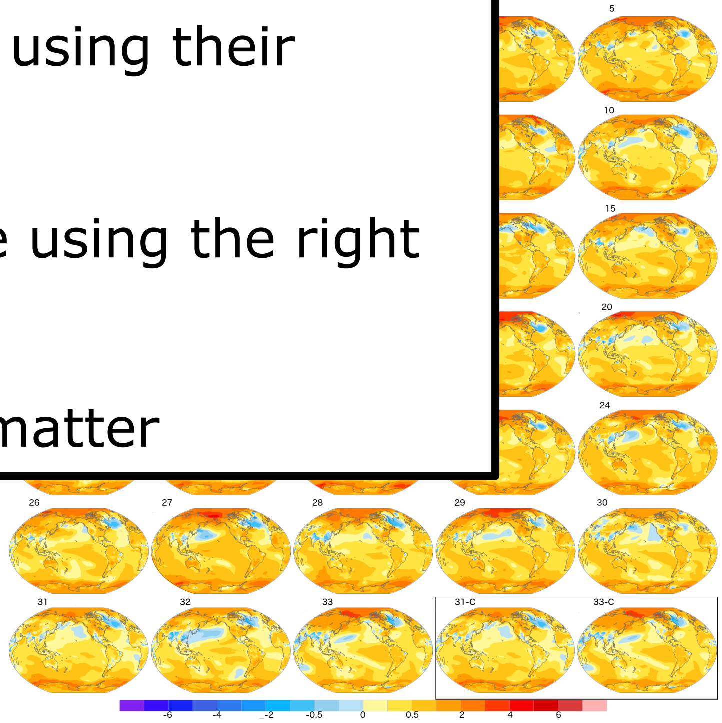




***Main insights*:**

- did not notice a difference using their standard analysis tools
- but can detect a difference using the right (i.e., clever) methods
- that difference might not matter





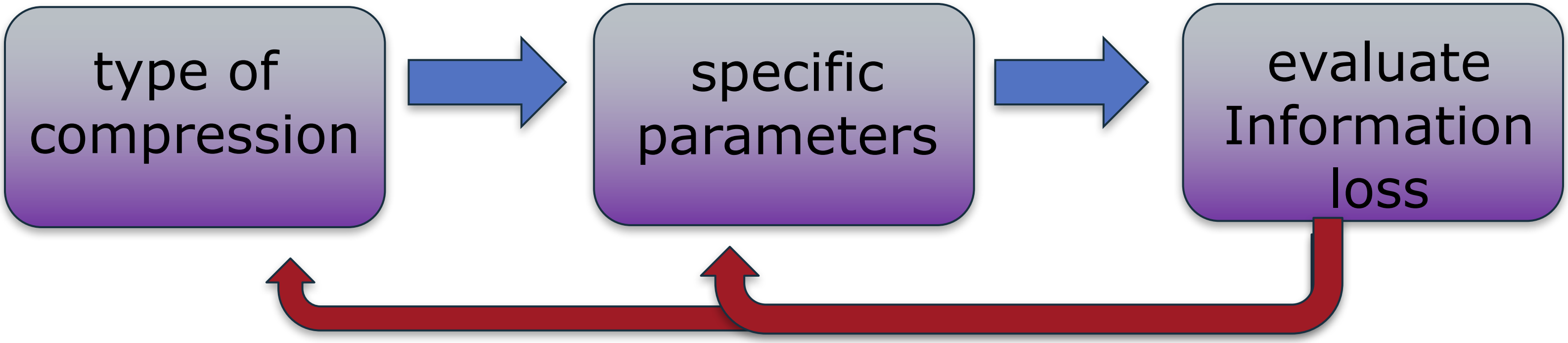
Current: best method for each variable

Determine max compression for each variable that preserves its scientific value

- *Many diverse variables:*
  - constants, abrupt changes, smooth, # of zeros
  - fill values (10^{35}), NANs, missing values

- *Many compression algorithms:*
  - *transform, predictive, statistical, …*

Each variable:



type of compression

specific parameters

evaluate Information loss

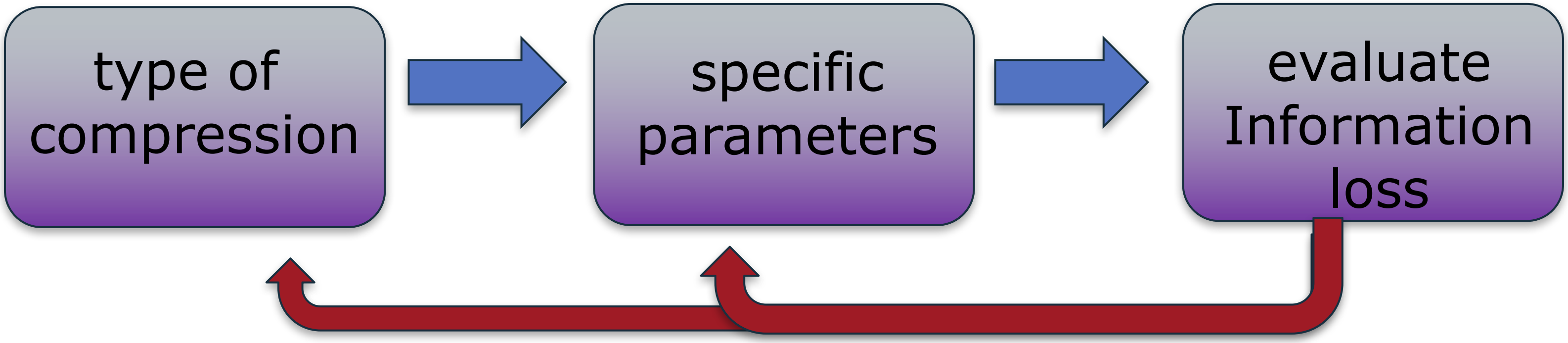
Current: best method for each variable

Determine max compression for each variable that preserves its scientific value

Goal: *automated tool* for CESM workflow

- appropriate metrics
  - reasonable computation cost
- understand compression algorithm properties
- determine important predictive features of data

Each variable:



Metrics: evaluating information loss

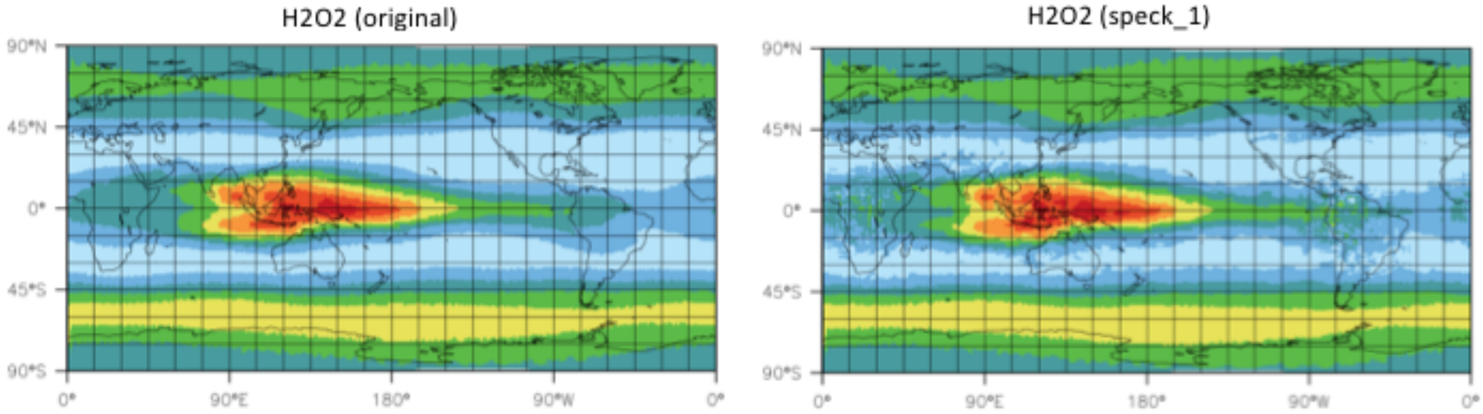
- suite to measure different aspects of data
- not ensemble-based (use only the fields themselves)

(1) Pearson correlation coefficient

(2) Kolmogorov-Smirnov (K-S) test

(3) Spatial relative error

(4) Structural similarity index (SSIM)



Final thoughts

NCAR is suffering from too much data:

- science and $$$
- lossy compression: 4:1 reduction (on average - conservative)

Next:

- determine method-specific parameters (control compression)
  - correlate with features
- further refinement on metrics
  - temporal features (e.g., extremes)
  - derived variables
  - human perception study

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Climate scientists compress their simulation data with confidence!

Thanks!

Questions, comments, suggestions:

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Thanks!

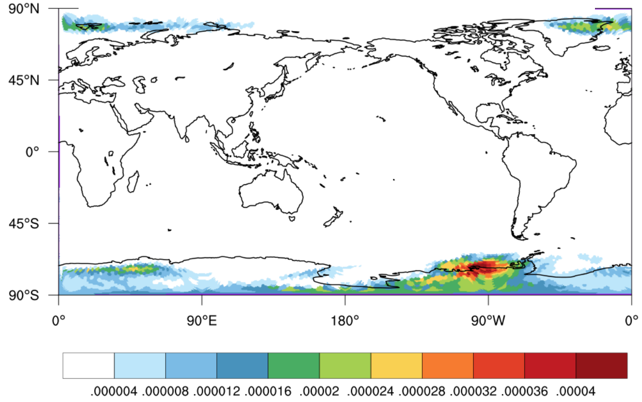
A.H. Baker, D.M. Hammerling, S.A. Mickelson, H. Xu, M.B. Stolpe, P. Naveau, B. Sanderson, i. Ebert-Uphoff, S. Samarasinghe, F. De Simone, F. Carbone, C.N. Gencarelli, J.M. Dennis, J.E. Kay, and P. Lindstrom, "Evaluating Lossy Data Compression on Climate Simulation Data within a Large Ensemble." *Geoscientific Model Development,* 9, 4381-4403, 2016.

A. H. Baker, H. Xu, D. M. Hammerling, S. Li, and J. Clyne, "Toward a Multi-method Approach: Lossy Data Compression for Climate Simulation Data", *International Workshop on Data Reduction for Big Scientific Data (*DRBSD-*1), ISC'17*, 2017.

A.H. Baker, H. Xu, J.M. Dennis, M.N. Levy, D. Nychka, S.A. Mickelson, J. Edwards, M. Vertenstein, A. Wegener, "A Methodology for Evaluating the Impact of Data Compression on Climate Simulation Data." *Proc. of the 23rd International ACM Symposium on High Performance Parallel and Distributed Computing* (HPDC14), pp. 203-214, 2014.

Comparing two types of compression

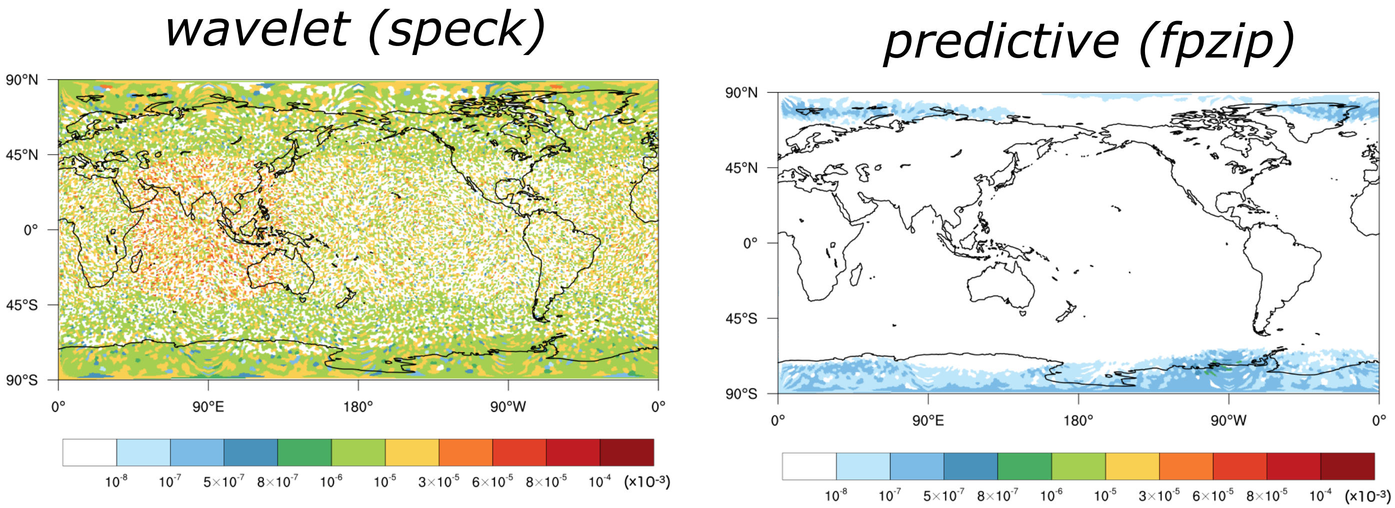
CLOUD



CLOUD

- large range (8 orders magnitude)
- 22% zeros
- small numbers

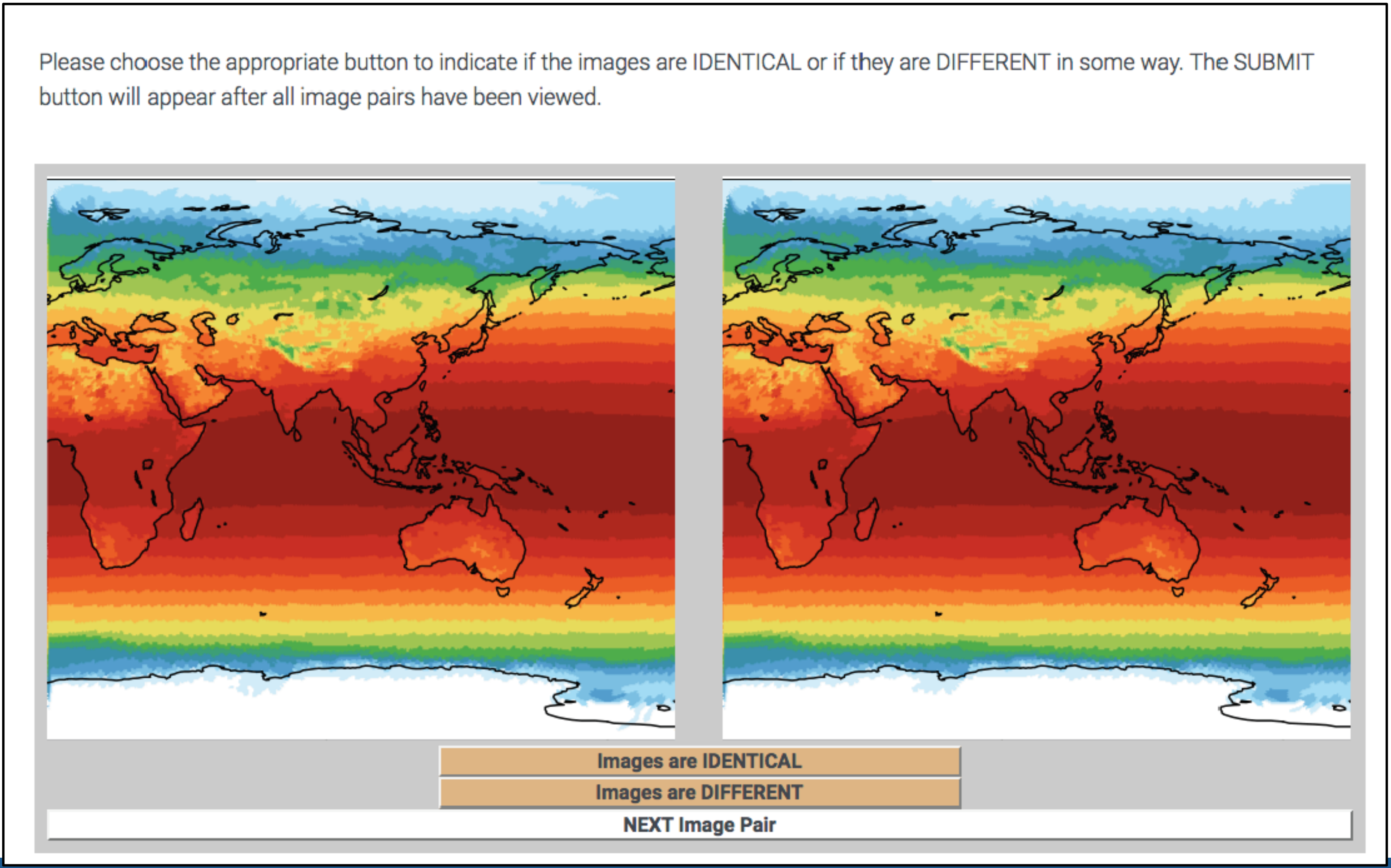
Absolute Error


wavelet (speck)

predictive (fpzip)

SSIM: human perception pilot study

-Visualization is essential!



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