Improving climate projections using “intelligent” ensembles

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CMIP5: group of ~45 models

Models are averaged together to make climate predictions

Predicted temperature changes

IPCC AR5 Ch.12
But models can have a large spread in predictions, and individual models can perform very differently from observations.

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1.5°C above pre-industrial
The traditional Multi-Model Ensemble Approach uses the model mean to provide an improved “best estimate” forecast.
The multi-model ensemble generally performs better than individual models

Example: $I^2$ performance index (Reichler and Kim 2008)

Calculates aggregated model errors relative to NCEP/NCAR reanalyses for multiple climate variables
The multi-model ensemble generally performs better than individual models

Example: $l^2$ performance index (Reichler and Kim 2008)

Calculates aggregated model errors relative to NCEP/NCAR reanalyses for multiple climate variables

"Observations" (reanalysis)

Better performance: Less error
Some models perform better than others:

Can we use knowledge of model performance for a better way to combine model output?

Better performance:
Less error
The “intelligent ensemble” approach for creating multi-model ensemble projections

Conventional method

- Climate model ensemble
- Equal-weighted average
- Climate projections

Proposed “intelligent” method

- Climate model ensemble
- Performance evaluation
- NASA satellite observations
- Unequal-weighted average
- “Intelligent” climate projections
Project goal:
determine future climate state using observed current climate and an ensemble of models

\[ f(x_{obs}) = \Delta x \]

- Observed climate
- Future climate state
Previous work has explored model performance and some unequal-weighting metrics

Several examples:

• Use only subsets of models (USGCRP 2009)
• Create mean-state metrics using model skill (Giorgi and Mearns 2002, 2003; Reichler and Kim 2008)
• Constrain model projections using mean-state CERES data (Tett et al. 2013)
• Weight using regression between observed and future trends (Boe et al 2009)
• Apply bias correction for present-day to future trends (Baker and Huang 2012)

“The community would benefit from a larger set of proposed methods and metrics” (Knutti 2010)
This project tests new climate model performance metrics

Radiation budget quantities:

- Top-of-atmosphere (TOA) longwave (LW) and shortwave (SW) radiation fluxes
- Surface LW and SW radiation fluxes
- Surface temperature

New process-oriented metrics:

\[ \frac{\Delta \text{TOA Radiation flux}}{\Delta \text{Surface temperature}} \]

Statistical tests:

- F-test for equal variances
- Kolmogorov-Smirnov test for distribution similarity
- Earth Mover’s Distance (EMD): test for area of distribution overlap
- Local Variance: test variance of first difference time series (Baker and Taylor 2015)
Model data:

35 CMIP5 models
http://pcmdi9.llnl.gov/

• ‘Pre-Industrial Control’ simulations (monthly mean, 100 years) to create metric weights

• ‘RCP 8.5’ future simulations (monthly mean, 2081-2100 minus 2011-2030 to produce 21st-century trends)

Observational datasets:

NASA CERES EBAF-TOA and surface monthly global-mean
http://ceres.larc.nasa.gov/

NASA GISS Surface Temperature Analysis (GISTEMP)
http://data.giss.nasa.gov/gistemp/
Step 1: Test model quality with selected metrics
Step 2: Using skill-subset of models, apply “perfect model” approach (Räisänen and Palmer 2001)

Create set of potential “Earths” each with a continuous time series of observations

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Model mean $I^2$ performance index
Metric performance and consistency is correlated:

Metrics which best reduce error in future projections behave similarly across model ensemble.
Step 3: Using best-performing metrics, create new “intelligent ensemble” projections

Use metric values as model weights to create unequal-weighted mean projections
Results: new 21st-century projections (surface temperature)

"Intelligent" ensemble mean temperature trend (°C)

Difference between "Intelligent" and Equal-weight ensemble means (°C)
Results: new 21\textsuperscript{st}-century projections (precipitation)
Results: new 21\textsuperscript{st}-century projections (surface downward SW radiation)

"Intelligent" ensemble mean surface shortwave radiation trend (W/m\textsuperscript{2})

Difference between "Intelligent" and Equal-weight ensemble means (W/m\textsuperscript{2})
Results: new 21st-century projections (TOA LW radiation)

"Intelligent" ensemble mean outgoing longwave radiation trend (W/m²)

Difference between "Intelligent" and Equal-weight ensemble means (W/m²)
Results: new 21st-century projections (TOA SW radiation)

"Intelligent" ensemble mean reflected shortwave radiation trend (W/m²)

Difference between "Intelligent" and Equal-weight ensemble means (W/m²)
Results: new 21st-century projections (regional-mean weights)

"Intelligent" ensemble mean temperature trend (°C)

Difference between "Intelligent" and Equal-weight ensemble means (°C)
Results: new 21\textsuperscript{st}-century projections (regional-mean weights)

"Intelligent" ensemble mean precipitation trend (cm/year)

Difference between "Intelligent" and Equal-weight ensemble means (cm/year)
Results: new 21st-century projections (regional-mean weights)
USDA Farm Resource Regions (1° resolution)

- Basin and Range
- Fruitful Rim
- Prairie Gateway
- Northern Great Plains
- Heartland
- Northern Crescent
- Eastern Uplands
- Southern Seaboard
- Mississippi Portal
Results: new 21\textsuperscript{st}-century projections

"Intelligent" ensemble mean temperature trend (°C)

US mean temperature increase: 3.9 °C

- Basin and Range: 3.9 °C
- Fruitful Rim: 3.4 °C
- Prairie Gateway: 3.8 °C
- Northern Great Plains: 4.1 °C
- Heartland: 4.1 °C
- Northern Crescent: 4.3 °C
- Eastern Uplands: 3.8 °C
- Southern Seaboard: 3.5 °C
- Mississippi Portal: 3.6 °C
Results: new 21st-century projections

"Intelligent" ensemble mean precipitation trend (cm/year)

US mean precipitation increase: 3.4 cm/year

Basin and Range: 0.6 cm/year
Fruitful Rim: 0.8 cm/year
Prairie Gateway: -1.8 cm/year
Northern Great Plains: 2.7 cm/year
Heartland: 7.2 cm/year
Northern Crescent: 9.1 cm/year
Eastern Uplands: 6.8 cm/year
Southern Seaboard: 6.8 cm/year
Mississippi Portal: 5.4 cm/year
Results: new 21st-century projections

"Intelligent" ensemble mean surface shortwave radiation trend (W/m²)

US mean decrease in surface solar radiation: -.33 Watts/m²

- Basin and Range: -2.4 Watts/m²
- Fruitful Rim: -0.5 Watts/m²
- Prairie Gateway: 0.7 Watts/m²
- Northern Great Plains: -1.9 Watts/m²
- Heartland: 0.7 Watts/m²
- Northern Crescent: -0.1 Watts/m²
- Eastern Uplands: 2.7 Watts/m²
- Southern Seaboard: 2.5 Watts/m²
- Mississippi Portal: 2.6 Watts/m²