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# Quantifying the Uncertainties in an Ensemble of Decadal Climate Predictions

Ehud Strobach[1,2] and Golan Bel[3,4]

[1]University of Maryland, [2]NASA Goddard Space Flight Center, [3]Ben-Gurion University of the Negev, [4]Los Alamos National Laboratory

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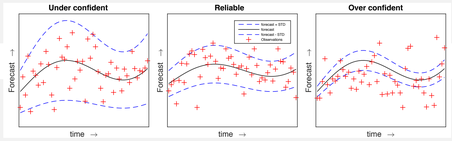
## 1. Introduction

Meaningful climate predictions should be accompanied by the corresponding uncertainty range. Common methods for estimating the uncertainty range are based on the spread of ensemble predictions. However, a simulation ensemble is not necessarily a proper sample of the real distribution of the climate, and therefore, the ensemble spread cannot be interpreted as the actual uncertainty.

**We propose a new method that links between the ensemble spread and the uncertainty without relying on any assumptions regarding the distribution of the ensemble predictions. The method is tested using CMIP5 1981–2010 decadal predictions and is shown to outperform other common methods.**




## 2. Methods

| Institute ID | Model name | Modeling center (or group) | Grid (latitude × longitude) |
|---|---|---|---|
| BCC | BCC-CSM1.1 | Beijing Climate Center, China Meteorological Administration | 64 × 128 |
| CCCma | CanCM4 | Canadian Centre for Climate Modelling and Analysis | 64 × 128 |
| CNRM-CERFACS | CNRM-CM5 | Centre National de Recherches Meteorologiques/Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique | 128 × 256 |
| LASG-IAP | FGOALS-s2 | LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences | 108 × 128 |
| IPSL | IPSL-CM5A-LR | Institute Pierre-Simon Laplace | 96 × 96 |
| MIROC | MIROC5 | Atmosphere and Ocean Research Institute (The University of Tokyo), | 128 × 256 |
| | MIROC4h | National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology | 320 × 640 |
| MRI | MRI-CGCM3 | Meteorological Research Institute | 160 × 320 |

- **Weighted ensemble**

$$P_t \equiv \sum_{E=1}^{N} W_{E,t} \cdot f_{E,t}$$

Models are weighted based on their past performance using the EGA machine learning algorithm (Strobach and Bel, 2015, Strobach and Bel, 2016)

- **Uncertainty range for confidence level c**

$$\Pr\{(\mathrm{p_t} - \gamma_d \cdot \delta_G \cdot \sigma_t) \le y_t \le (\mathrm{p_t} + \gamma_u \cdot \delta_G \cdot \sigma_t)\} = c$$

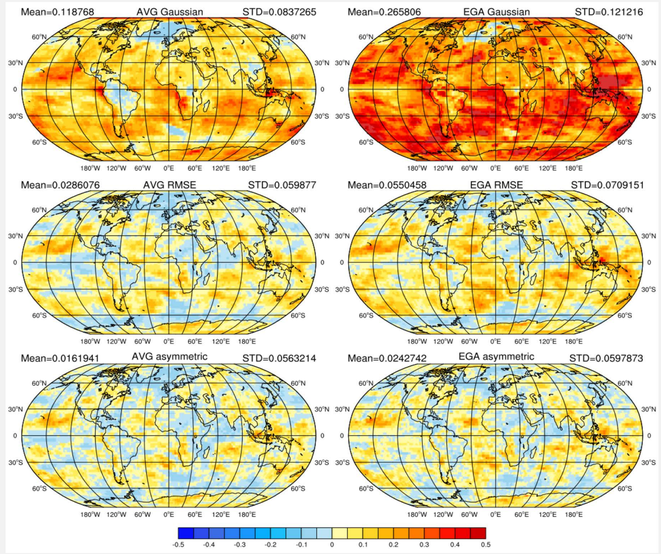
1. Normal distribution (no correction): $\gamma_u = \gamma_d = 1$
2. RMSE-corrected method: $\gamma_u = \gamma_d = \sqrt{\frac{\sum_{t=1}^{n}(p_t - y_t)^2}{\sum_{t=1}^{n}\sigma_t^2}}$
3. Asymmetric range method:

$$\gamma_u = \inf\left\{\gamma_u \in \Re : \frac{1}{n}\sum_{t=1}^{n}\Theta\big((p_t + \gamma_u \cdot \sigma_t) - y_t\big) \ge \frac{1+c}{2}\right\}$$

$$\gamma_d = \inf\left\{\gamma_d \in \Re : \frac{1}{n}\sum_{t=1}^{n}\Theta\big(y_t - (p_t - \gamma_d \cdot \sigma_t)\big) \ge \frac{1+c}{2}\right\}$$

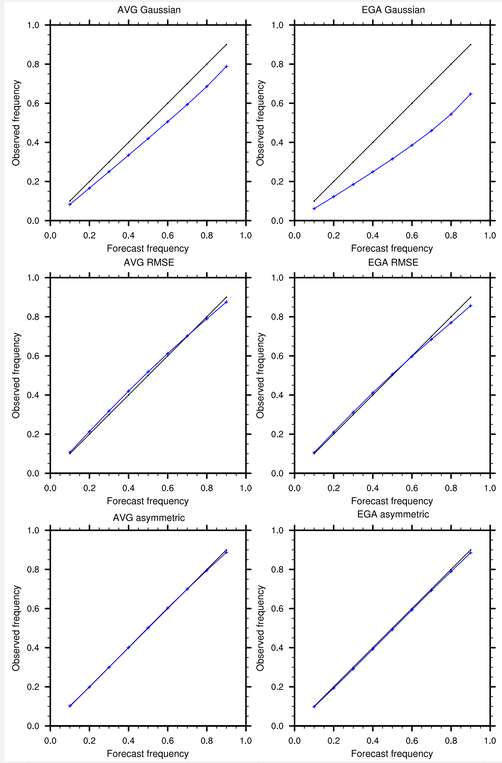
## 3. Results: monthly surface temperature (1991-2010)

### a. Predicted minus observed confidence level



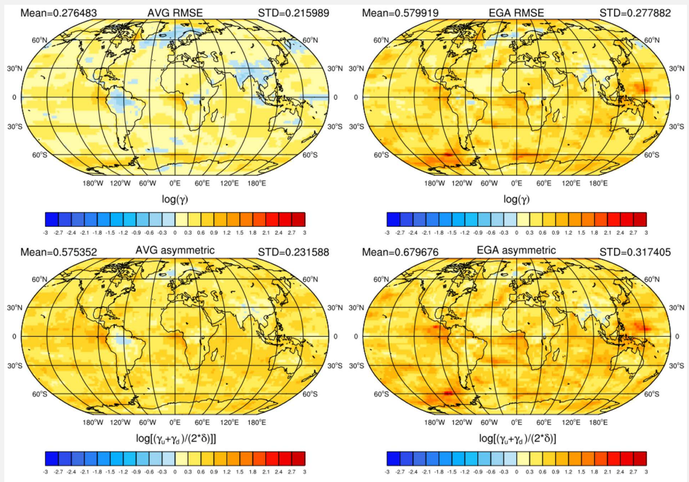

The spatial distribution of the difference between the fraction of observations that were outside the predicted range of the c=0.9 confidence level and the predicted 0.1 fraction, for the surface temperature.

### b. Observed vs. estimated frequency




Reliability diagrams for the different estimation methods of the surface temperature uncertainty range. The observed frequency represents the spatial average over all the grid cells.

### c. Ratio between the uncertainty ranges estimated using different methods




The log of the ratio between the uncertainty ranges of the monthly surface temperature with a confidence level of 0.9 as estimated by the RMSE-corrected and asymmetric methods and those estimated by the Gaussian method. The two left panels show the ratio for the predictions of an equally weighted ensemble, and the two right panels show it for a weighted ensemble (EGA forecaster).

## 4. Conclusions

- **Without correction, the CMIP5 ensemble is over-confident (the variance is smaller than the mean squared error).**
- **The asymmetric method improves the ensemble forecast reliability without relying on any assumption regarding the distribution of the predictions.**

$$^{*}\delta_G = \sqrt{2}\,\mathrm{erf}^{-1}(\mathbf{c}),\ \mathrm{erf}(s) \equiv \frac{1}{\sqrt{\pi}}\int_{-s}^{s} e^{-x^2}\,dx$$

*E-mail:* ehud.strobach@nasa.gov | *Web:* gmao.gsfc.nasa.gov

EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER ESSIC UNIVERSITY OF MARYLAND

UNIVERSITY OF MARYLAND 1856

National Aeronautics and Space Administration