

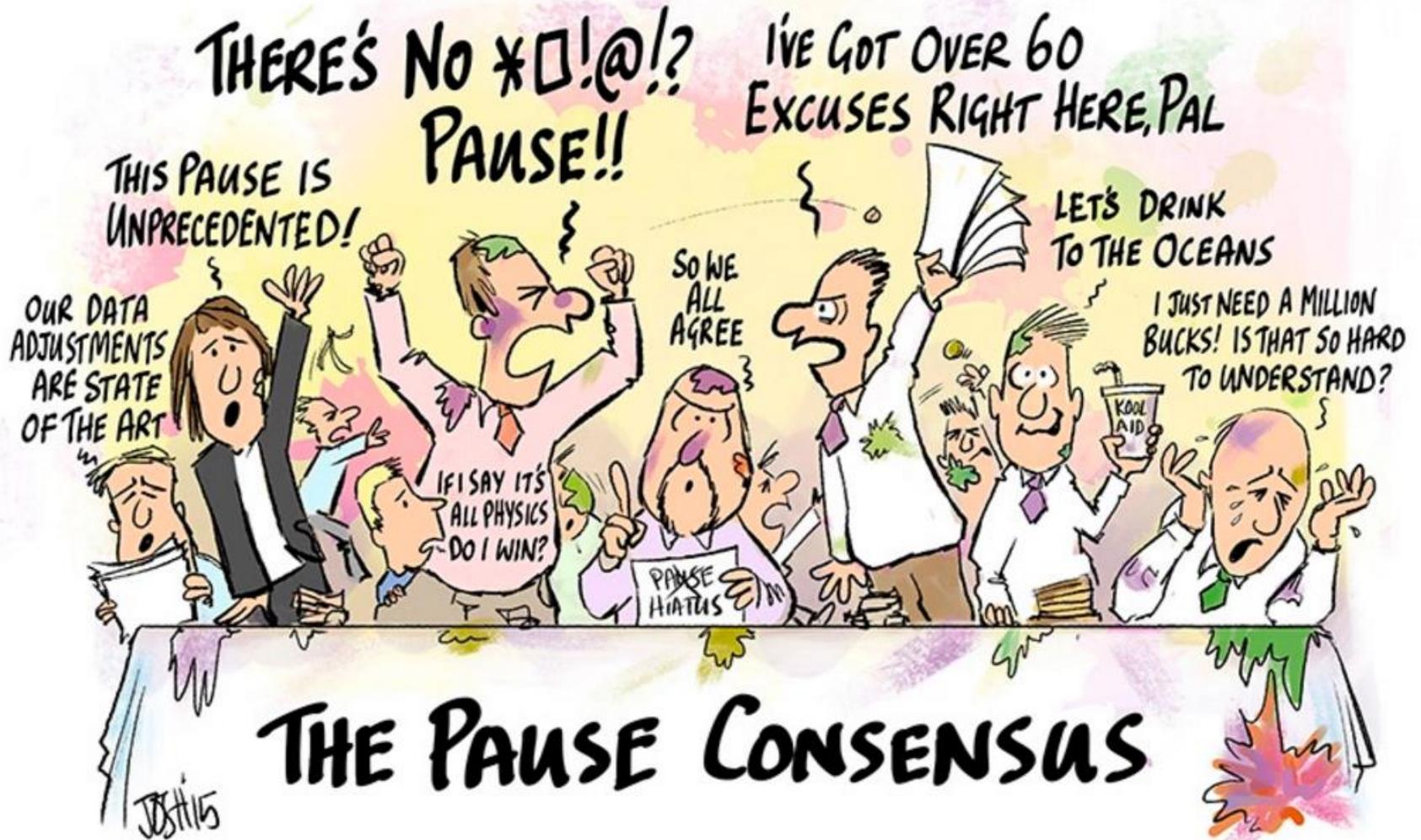
Merging Disparate lines of Evidence Subtle is Probability

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Destructive disagreement



Probabilistic thinking is counterintuitive...when our intuitions are wrong

- Illustration: Learning about Equilibrium Climate Sensitivity (ECS): CLARREO

CLARREO Mission Overview

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BAMS

Bulletin of the American Meteorological Society

POLLUTION FROM WILDFIRES

GLOBAL CLOUD DATASETS

WEATHER DATA FROM CARS

A MEASURE FOR MEASURES



In-Orbit Calibration of Climate-Change Monitoring

ACHIEVING CLIMATE CHANGE ABSOLUTE ACCURACY IN ORBIT

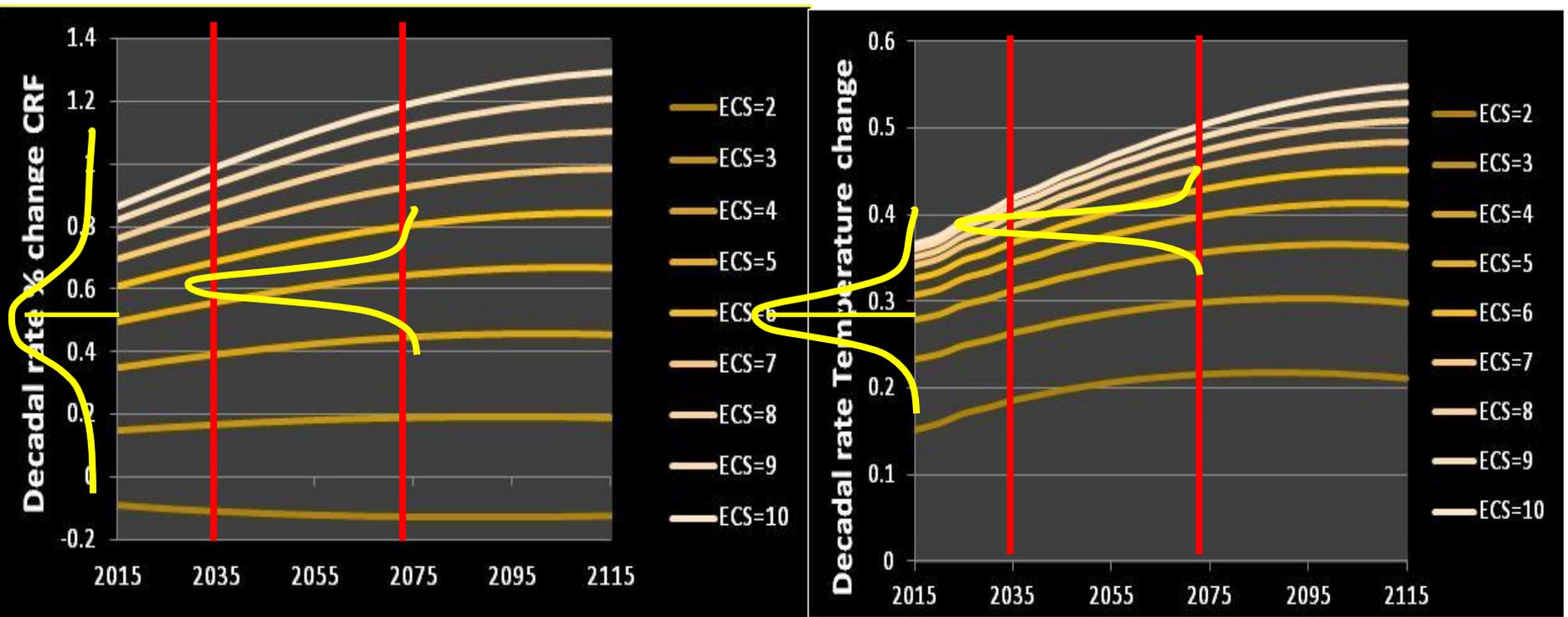
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With its unprecedented accuracy, the Climate Absolute Radiance and Refractivity Observatory substantially shortens the time to detect the magnitude of climate change at the high confidence level that decision makers need.

THE CLARREO VISION FROM THE NATIONAL RESEARCH COUNCIL DECADAL SURVEY. A critical issue for climate change observations is that their absolute accuracy is insufficient to confidently observe decadal climate change signals (NRC 2002; Trenberth et al. 2013; Trenberth and Fasullo 2010; Ohring et al. 2005; Ohring 2007). Observing decadal climate change is critical to assessing the accuracy of climate model projections (Solomon et al. 2007; Masson and Knutti 2011; Stott and Kettleborough 2002) as well as to attributing climate change to various sources (Solomon et al. 2007). Sound policymaking requires high confidence in climate predictions verified against decadal change observations with rigorously known accuracy. The need to improve satellite data accuracy has been expressed in

Orbit of CLARREO (red orbit track) obtaining matched data to serve as reference intercalibration for instruments on a polar-orbiting weather satellite (green track). For more information see Fig. 4.

Joint measurement:



Correlations

- If random variables X (signal) and ξ (noise) are independent,
- Observation $Z = X + \xi$
- Correlation of X and Z is $\sigma_x / (\sigma_x^2 + \sigma_\xi^2)^{1/2}$,
 - σ is standard deviation.

- $X = \text{ECS}$ follows truncated Roe Baker distribution (US Social Costs of Carbon).

Launch in 2020, Observation through 2030

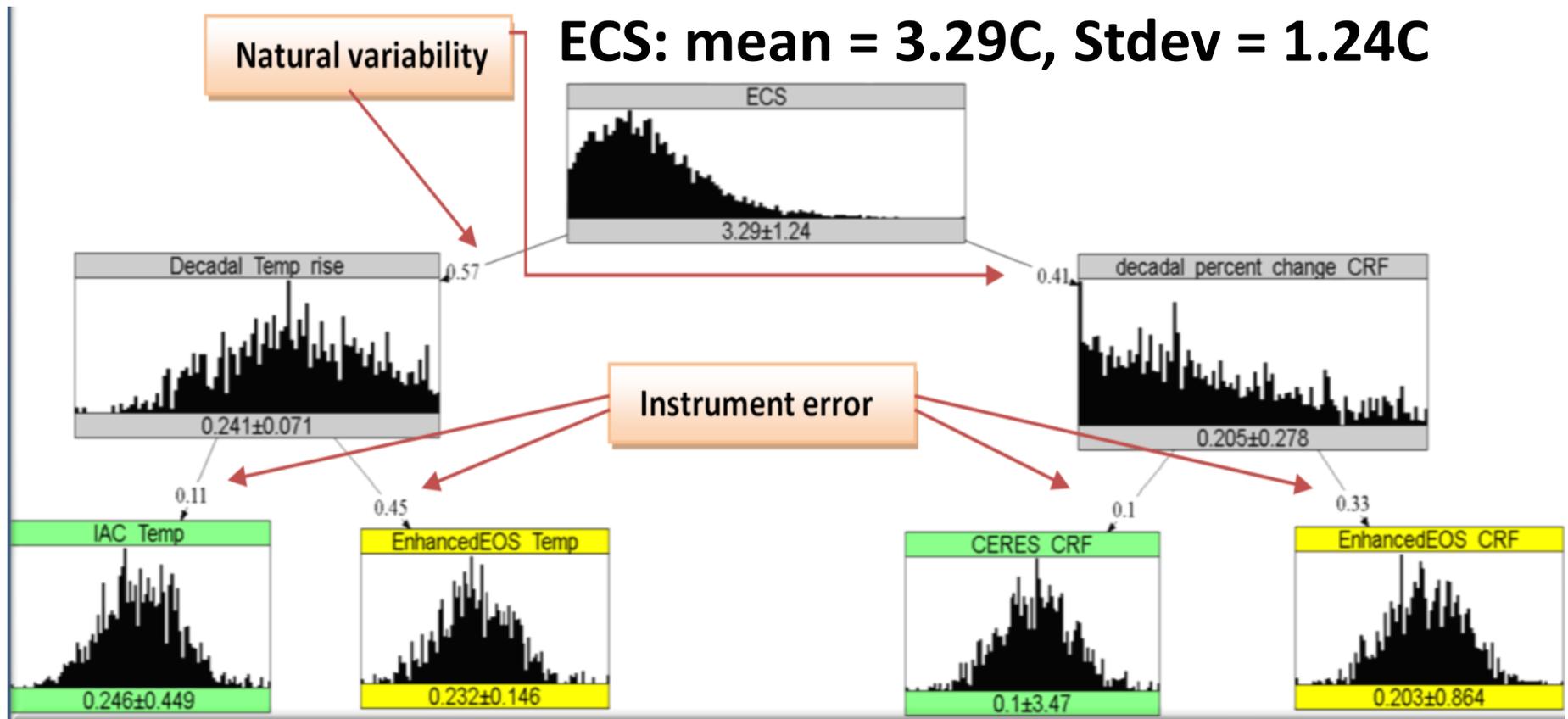


Figure 2: Correlations in 2030 following a launch in 2020. In DICE, Decadal Temperature Rise and Decadal Percentage rise of CRF are deterministic non-linear one-to-one functions of ECS, for a given emissions scenario (which is always Business as Usual). The correlations shown here with ECS are correlations between the theoretical trend values (from which ECS can be uniquely inferred) and the trend values perturbed with natural variability.

ECS: mean = 4.36C, Stdev = 1.57C

Prior: ECS: mean = 3.29C, Stdev = 1.24C

Negative Learning

Observing Through 2030

ECS: mean = 4.36C, Stdev = 1.57C

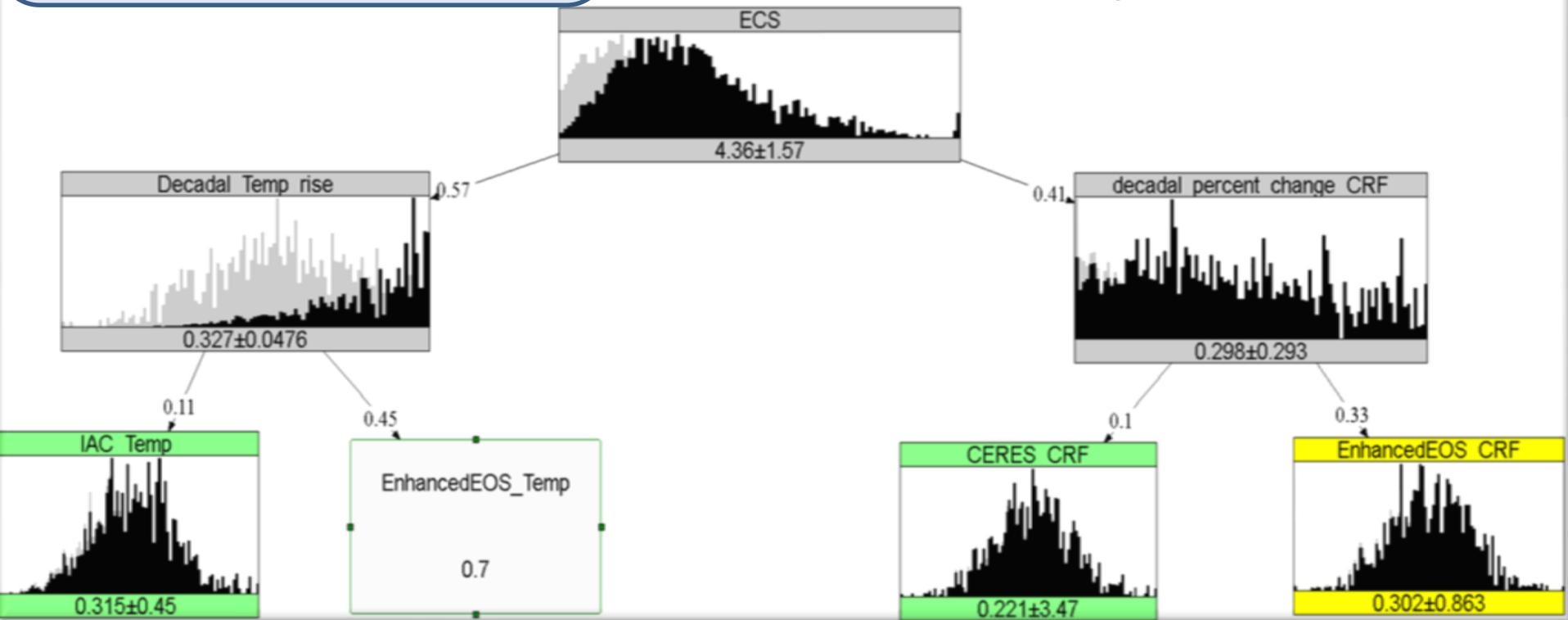


Figure 3: BN in Figure 1 is conditionalized on a high measured value for decadal temperature rise by the Enhanced EOS

Simple intuition violated

Measurements always reduce uncertainty??

- Multivariate Normal: conditional variance always \leq unconditional variance. Bivariate normal, ratio of conditional to unconditional variances is $(1 - \rho^2)$, $\rho =$ correlation.
- This is a peculiar feature of the joint normal distribution; error model in elementary statistics.
- Here, and unexpectedly high result moves the prior enough to increase variance

Same measurement results, different conclusions (measurements in 2050)

**Discordant
Agreement**

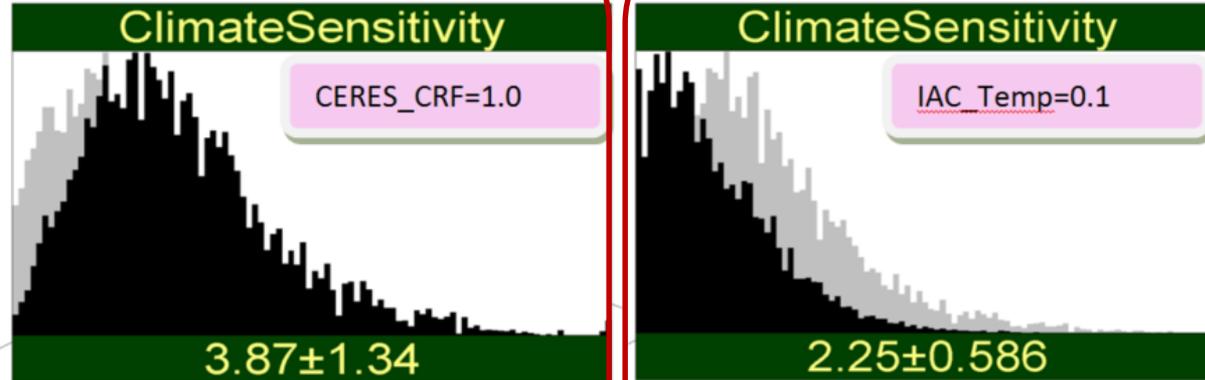


Figure 3: Result of observing a high value (1.0) with only the CERES_CRF system (left) or observing a low value (0.1) with only the IAC system (right). The gray histogram is before measurement, the black histogram is after measurement. The left graphic has higher uncertainty (standard deviation 1.34) than before the measurement (standard deviation 1.24) illustrating negative learning.

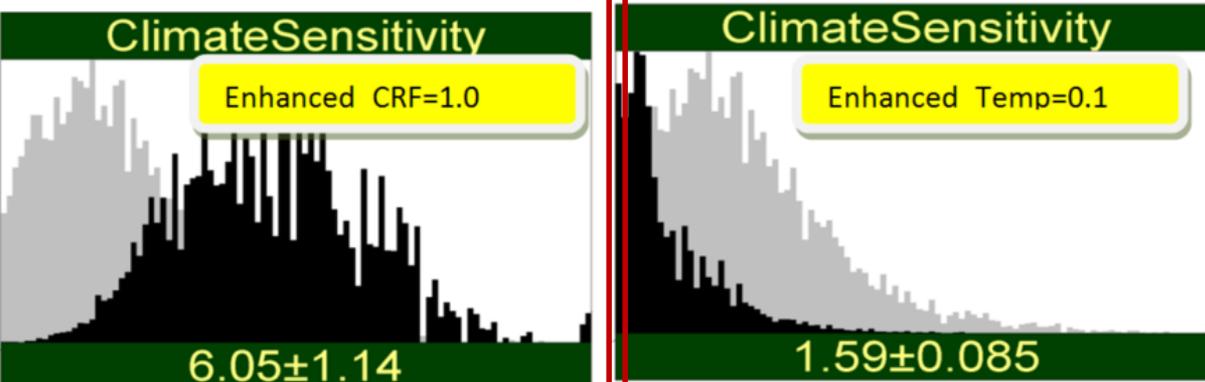


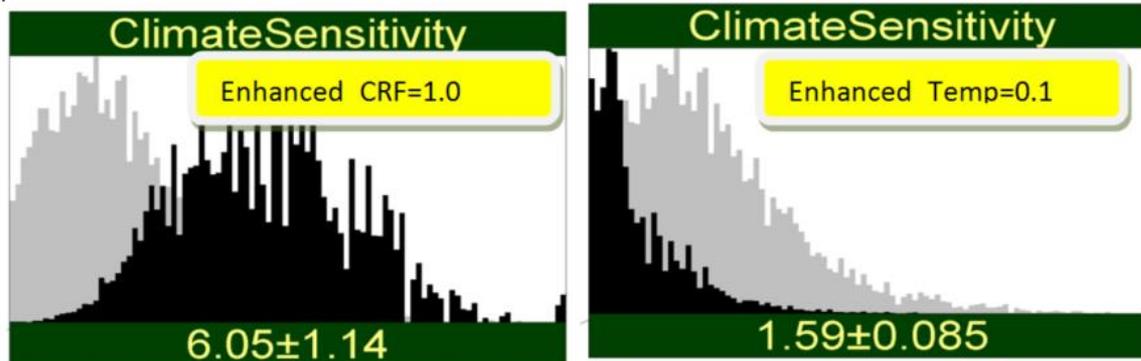
Figure 4: Result of observing a high value (1.0) with only the Enhanced CRF system (left) and observing a low value (0.1) with only the Enhanced Temp system (right). There is no negative learning in this case, because of the lower uncertainty in the enhanced system.

Simple Intuitions Violated:

Different measurements of same system, returning same values, should yield same conclusions??

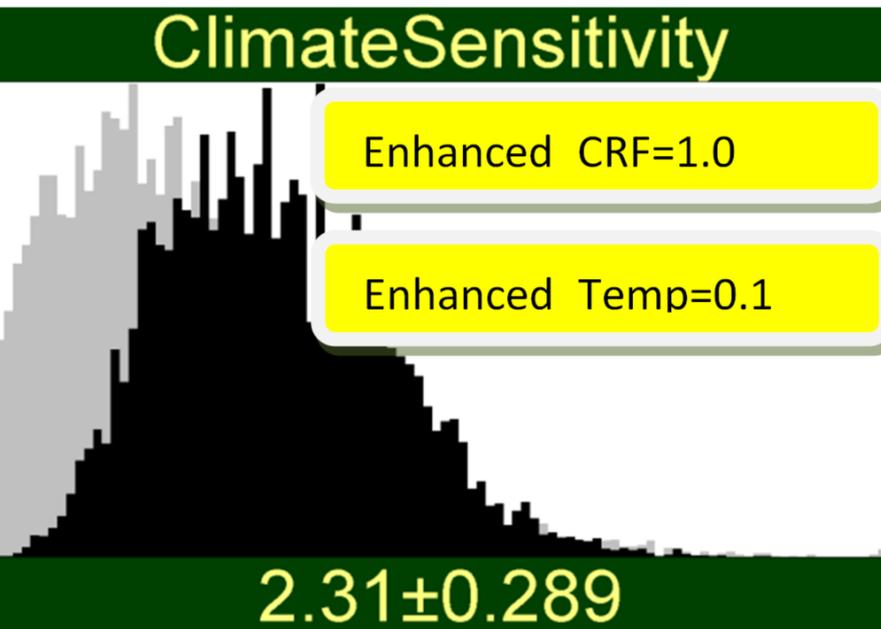
- The variance can affect the mean, causing difference between more and less accurate measurements, even when they return the same value.
- In simple error model, mean and variance are independent.

E Pluribus, Unum (from many, one)



Information in Disagreement

Figure 4: Result of observing a high value (1.0) with only the Enhanced CRF system (left) and observing a low value (0.1) with only the Enhanced Temp system (right). There is no negative learning in this case, because of the lower uncertainty in the enhanced system.



PRIOR: ECS: mean = 3.29C, Stdev = 1.24C
POSTERIOR: mean = 2.31, Stdev = 0.289C

Simple Intuitions Violated:

Disagreement increases uncertainty??

We expect disparate errors to be negatively correlated \Rightarrow information in disagreement

- With conflicting results, one must be 'right', one must be 'wrong'??



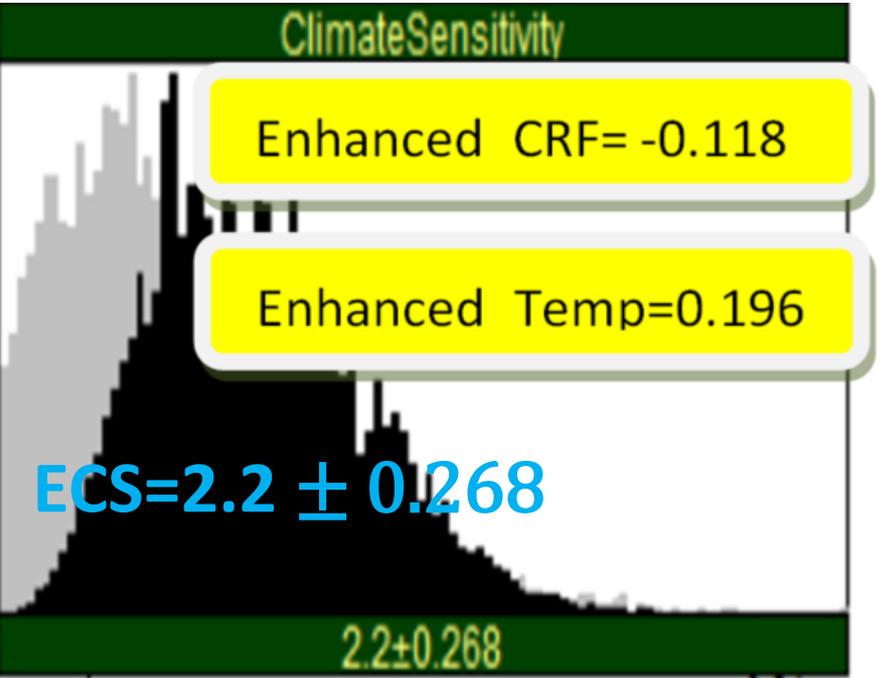
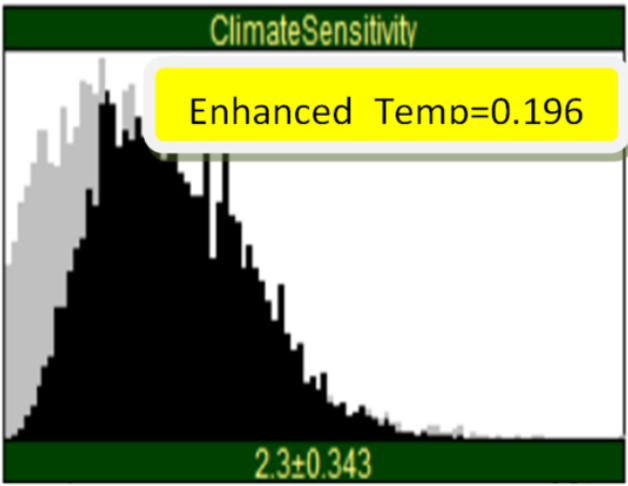
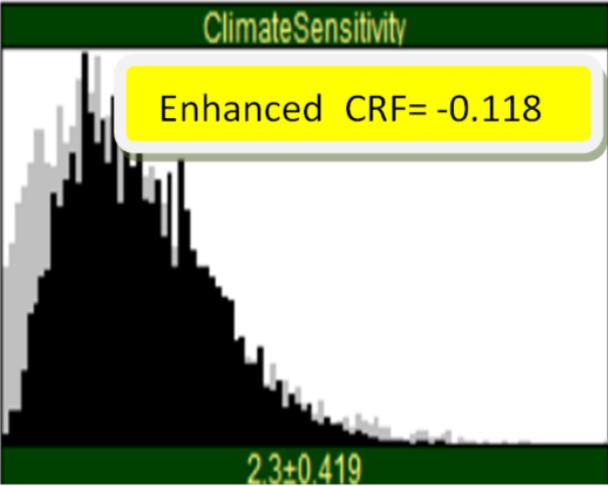
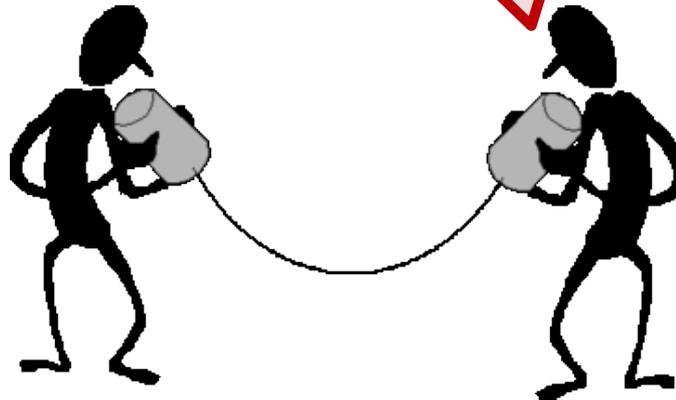
Ex Uno Plures (from one, many)

ECS=2.3 ± 0.419

ECS=2.3 ± 0.343

Discordant Unanimity

You get ECS=2.3, same as me. Lets combine our results and get ECS = 2.2



Simple Intuitions Violated:

Combining concordant measurements always strengthens confidence in the common result??

- Because prior bounded below, low measurements' variance can push the mean upward ...combining the measurements lowers their joint variance and allows the mean to drop.

average posterior standard deviation ECS (prior=1.24)		
GST	Current GST	0.96
	Enhanced GST	0.49
	Current & Enhanced GST	0.48
CRF	Current DRF	1.12
	Enhanced CRF	0.63
	Current & Enhanced CRF	0.62
OLD	CRF & GST	0.90
Enhanced	Enhanced GST & Enhanced CRF	0.41
ALL		0.40

Conclusions

1. Probabilistic thinking is often counter-intuitive because our intuitions are wrong
 1. Negative learning
 2. Discordant agreement
 3. Information in disagreement
 4. Discordant Unanimity
2. When the science 'isn't there yet', experts are **supposed** to disagree

The BN software employed here is UNINET, designed by the Department of Mathematics of the Delft University of Technology and licensed by LIGHTTWIST software. A free version is available for academic users at <http://www.lighttwist.net/wp/>. Initially developed for the Dutch Ministry of Transport, UNINET was designed for non-parametric continuous and discrete variables in very high dimensions (Ale et al 2009).

Video: <https://youtu.be/NBz5RirkXgw>