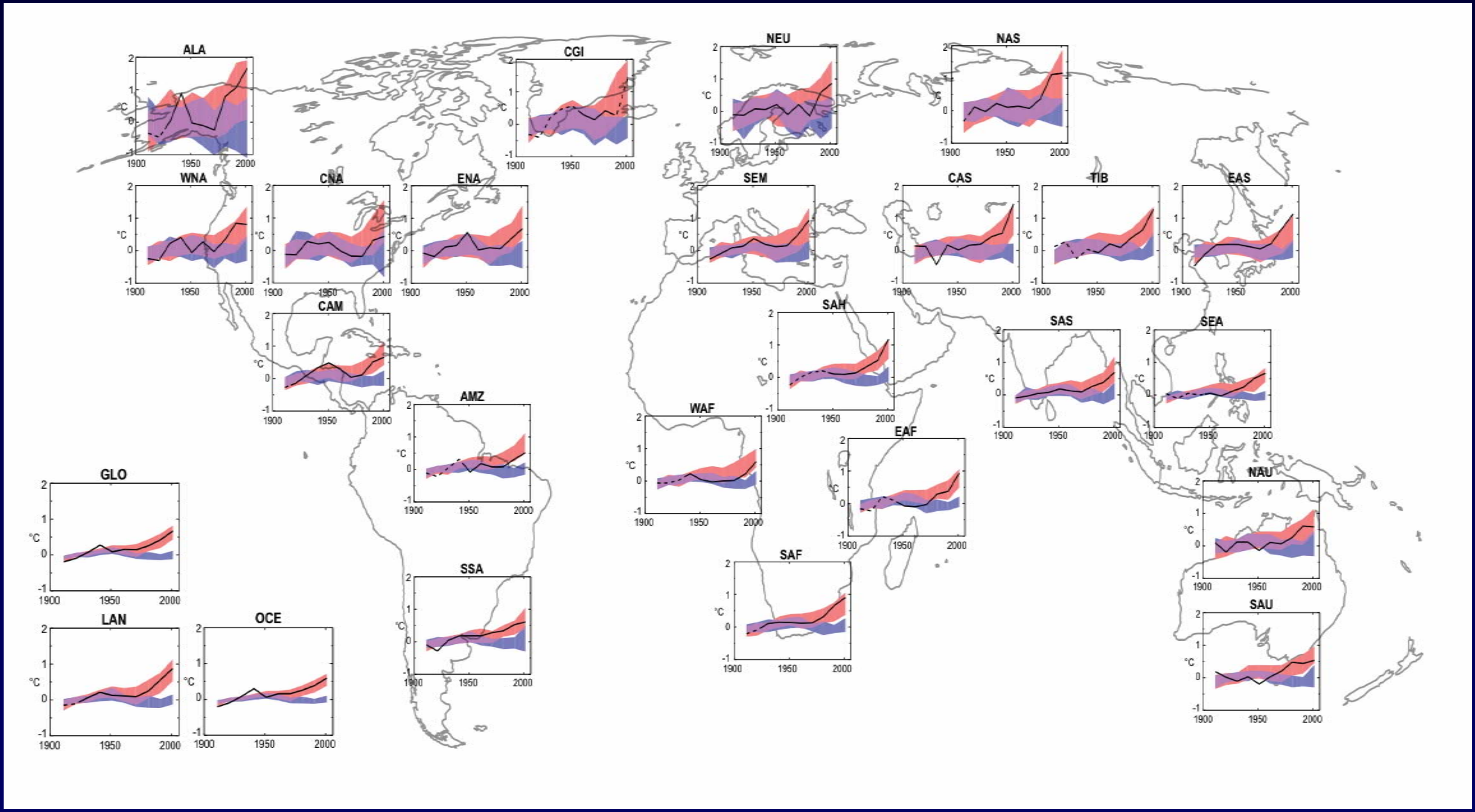
CLARREO and Climate Scalar Prediction

Stephen Leroy
(Anderson Group)

April 30, 2008

Scalar Prediction



Hegerl et al., IPCC AR4 Chapter 9

Bayesian Ensemble Prediction Theory

- Fluctuation-dissipation theorem suggests strong relationships between trends and second moments of climate, not mean state.
- Overall (transient) sensitivities of models might vary, but patterns of change are more robust.

$$P(d\alpha/dt \mid D, M) \propto \sum_i p(d\alpha/dt \mid D, m_i)\; p(m_i)$$

$$\forall m_i : \frac{d\mathbf{d}}{dt} = \left.\frac{d\mathbf{d}}{d\alpha}\right|_{m_i} \frac{d\alpha}{dt} + \frac{d}{dt}\delta\mathbf{n}$$

Generalized Scalar Prediction

$$\mathbf{F} = \left(\mathbf{\Sigma}_{\text{var}} + \mathbf{\Sigma}_{d\mathbf{d}/d\alpha}\right)^{-1}\mathbf{S}\ \left[\overline{\mathbf{S}}^T\left(\mathbf{\Sigma}_{\text{var}} + \mathbf{\Sigma}_{d\mathbf{d}/d\alpha}\right)^{-1}\overline{\mathbf{S}}\right]^{-1}$$

$$\mathbf{s}_i = d\mathbf{d}/d\alpha_i\,, \quad \mathbf{\Sigma}_{d\mathbf{d}/d\alpha} = \sum_{i,j}\left\langle \frac{d\alpha_i}{dt}\frac{d\alpha_j}{dt}\delta\mathbf{s}_i\delta\mathbf{s}_j^T \right\rangle_{\text{models}}$$

$$\frac{d\boldsymbol{\alpha}}{dt} = \frac{d}{dt}\left(\mathbf{F}^T\mathbf{d}(t)\right)$$

Extrapolate from the past, searching for external indicators that are…

- **Physically robust**—there is significant agreement between models that the indicator’s trend is strongly related to the target scalar’s trend, and
- **Naturally quiet**—they are associated with minimal naturally occurring inter-annual variability.

Generalized Scalar Prediction

$$\mathbf{F} = \left(\mathbf{\Sigma}_{\text{var}} + \mathbf{\Sigma}_{d\mathbf{d}/d\alpha}\right)^{-1} \mathbf{S} \left[\overline{\mathbf{S}}^T \left(\mathbf{\Sigma}_{\text{var}} + \mathbf{\Sigma}_{d\mathbf{d}/d\alpha}\right)^{-1} \overline{\mathbf{S}}\right]^{-1}$$

“Contravariant fingerprint”

$$\mathbf{s}_i = d\mathbf{d}/d\alpha_i, \quad \mathbf{\Sigma}_{d\mathbf{d}/d\alpha} = \sum_{i,j} \left\langle \frac{d\alpha_i}{dt} \frac{d\alpha_j}{dt} \delta\mathbf{s}_i \delta\mathbf{s}_j^T \right\rangle_{\text{models}}$$

“Fingerprint”

$$\frac{d\boldsymbol{\alpha}}{dt} = \frac{d}{dt}\left(\mathbf{F}^T \mathbf{d}(t)\right)$$

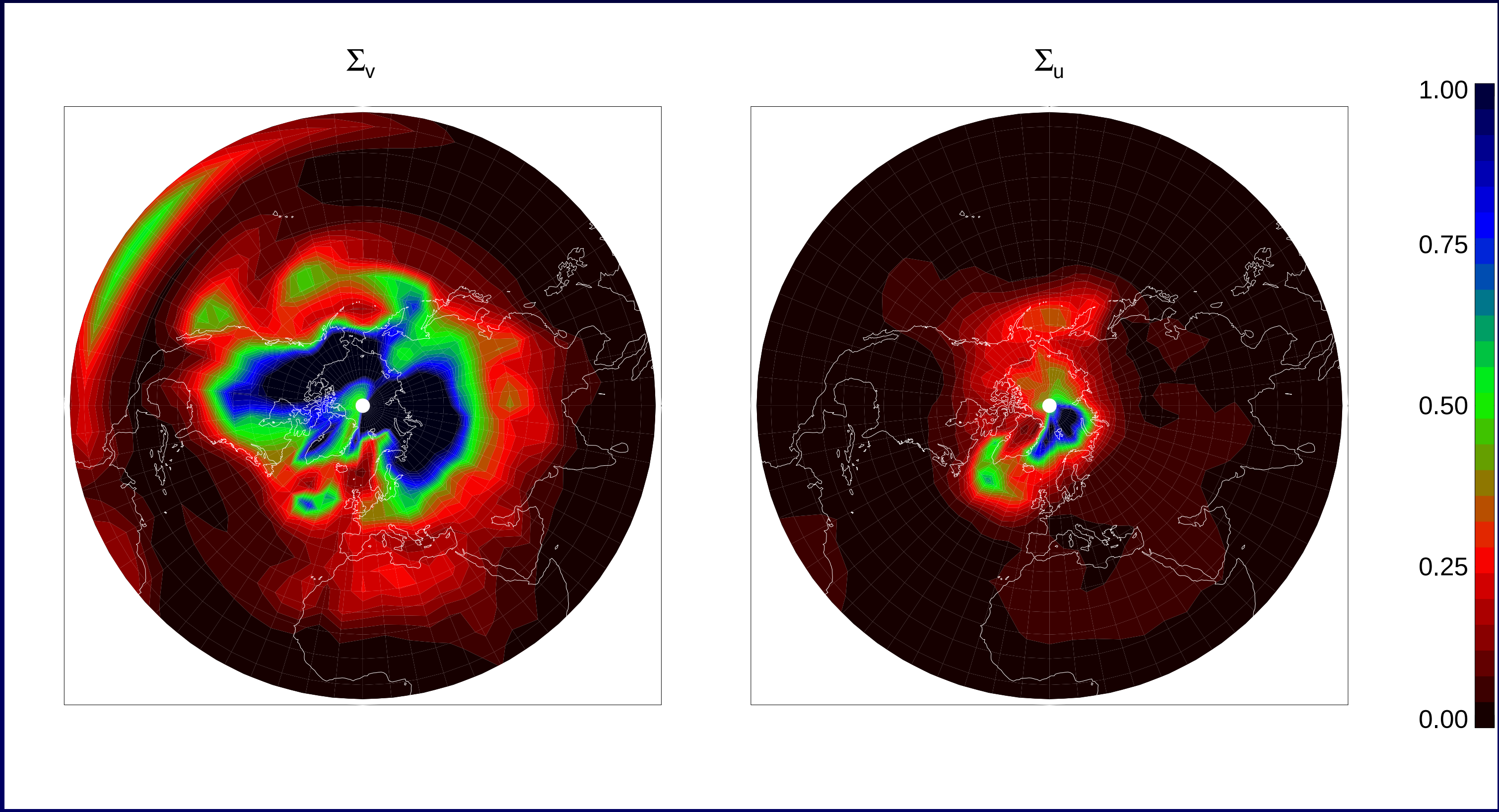
“Detectors”

Extrapolate from the past, searching for external indicators that are…

- **Physically robust**—there is significant agreement between models that the indicator’s trend is strongly related to the target scalar’s trend, and
- **Naturally quiet**—they are associated with minimal naturally occurring inter-annual variability.

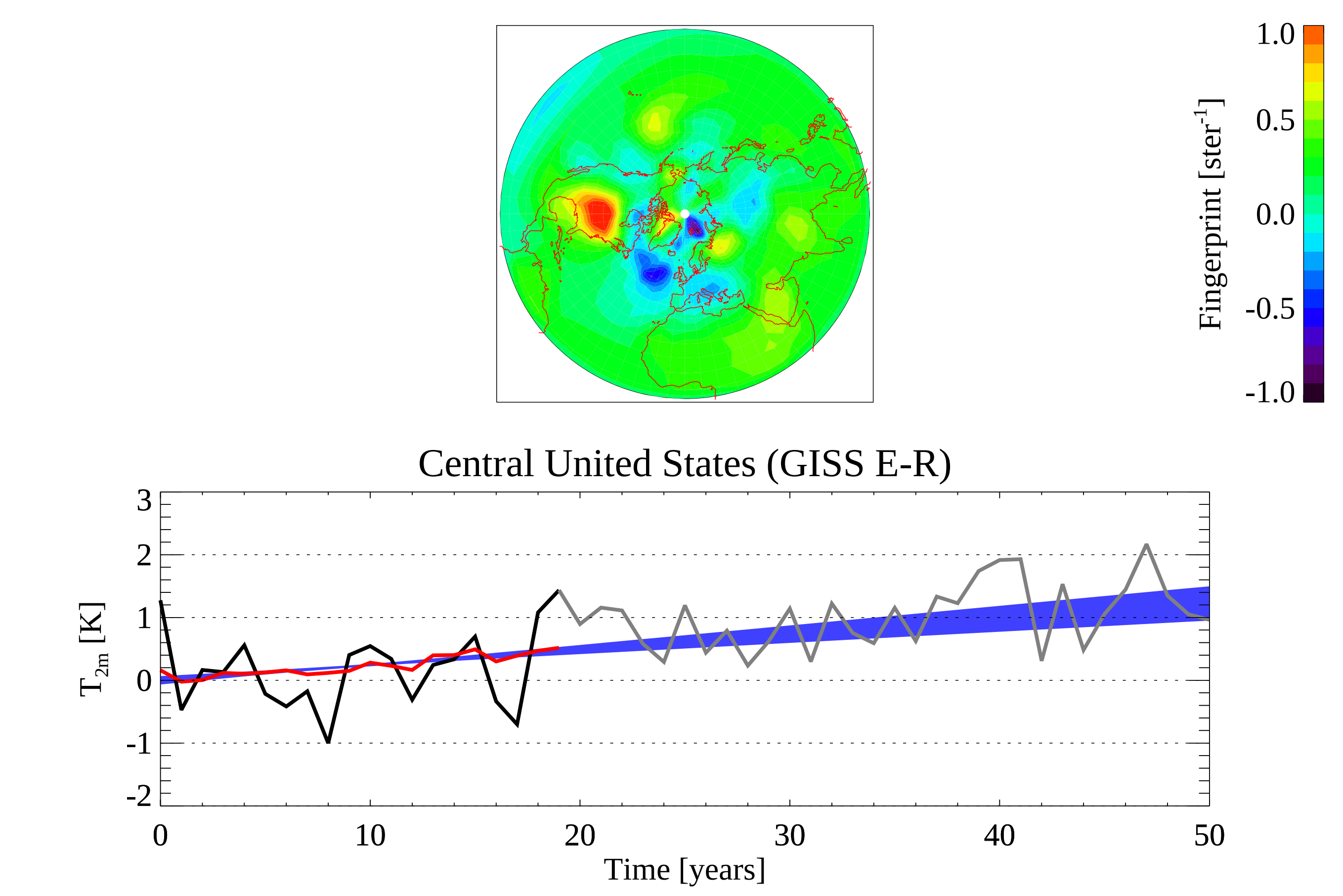
Test of Technique: Central U.S. (1)

α = Central U.S. surface air temperature, ***d*** = NH surface air temperature maps



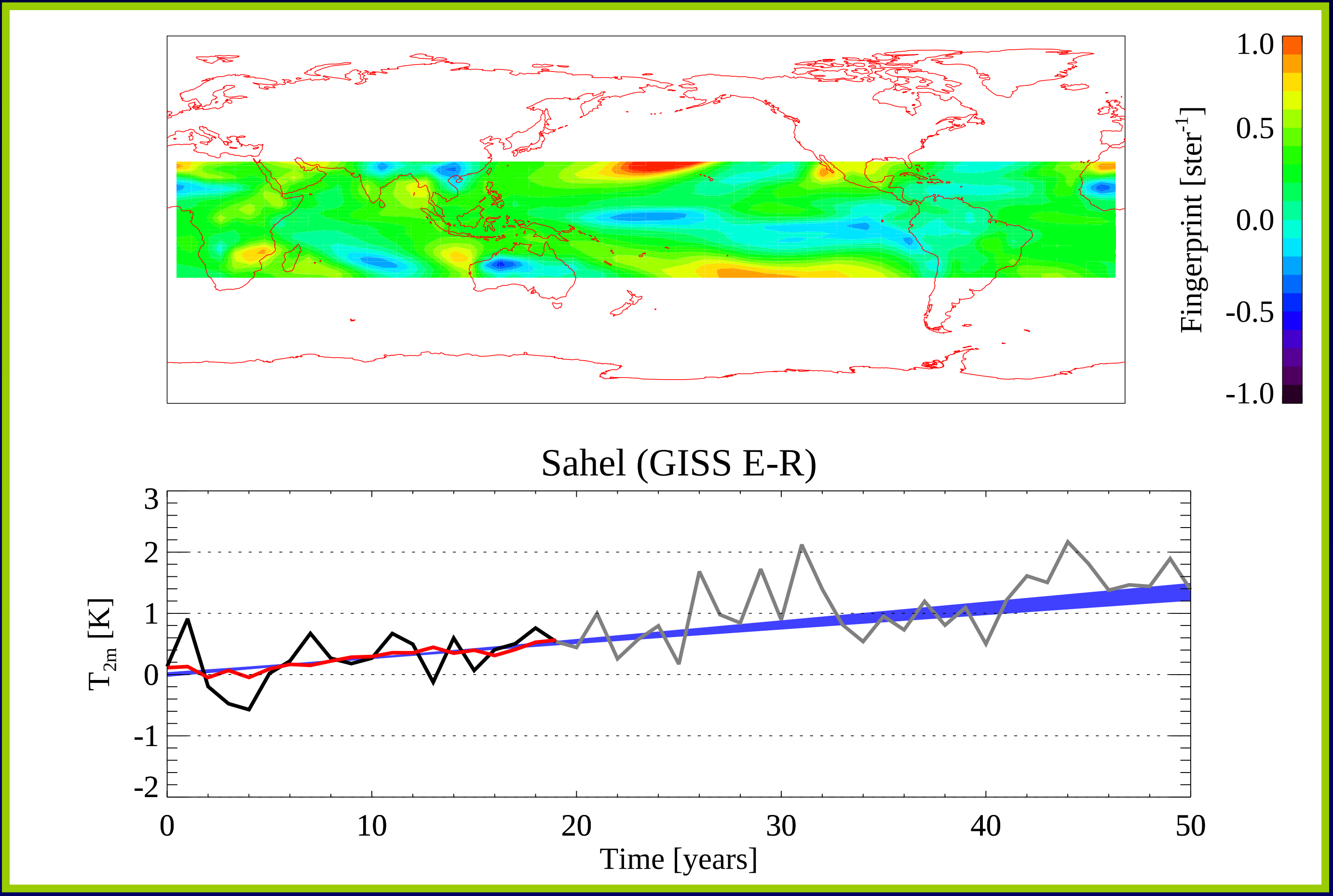
Test of Technique: Central U.S. (2)

α = Central U.S. surface air temperature, ***d*** = NH surface air temperature maps



Sahel Surface Air Temperature

α = Sahel surface air temperature, ***d*** = Tropical surface air temperature maps



Climate OSSE: The Science of a Benchmark

Benchmark Measurement

- Traceable to international standards
- Minimize sampling error

Climate OSSE

- Simulate trends in observable as produced by a perturbed physics ensemble of runs of a climate model
- Explore information content with various contravariant fingerprints

Climate Uncertainty

- Shortwave forcing
- Longwave forcing
- Climate feedbacks & sensitivity
- Ocean heat storage

Climate OSSE Results

- Detection time and accuracy requirements
- How measurement constrains climate predictability
- Relative redundancy with other benchmark data types

CLARREO Conceptually

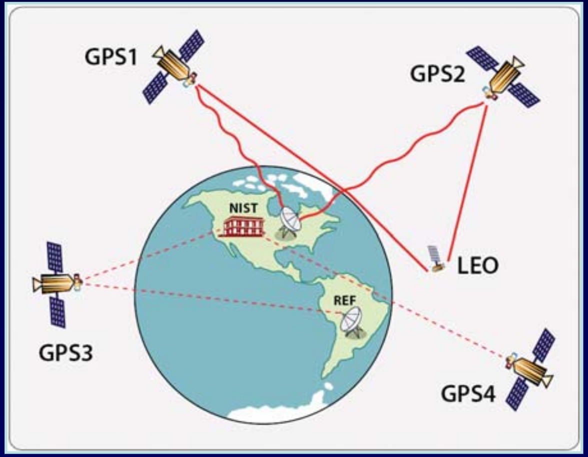
GNSS radio occultation measurements

Absolute spectrally resolved radiance in the thermal infrared

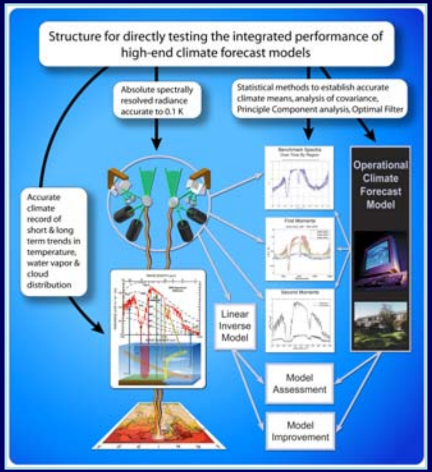
Solar irradiance: Incident and reflected

Thermal Infrared Spectra

GPS Occultation: The Time Standard



- GNSS occultation is tied to ground-based atomic clock standards by double-differencing technique.
- NIST F1 measures time with fractional error of 1.7•10-15 (as of 1999).



SSEC

Southwest Research Institute

aer Atmospheric and Environmental Research, Inc.

University of Michigan

University of Maryland