NOAA RESEARCH • ESRL • PHYSICAL SCIENCES DIVISION

Theme 3: Modeling the Physical System

Modeling the Climate System
Overview

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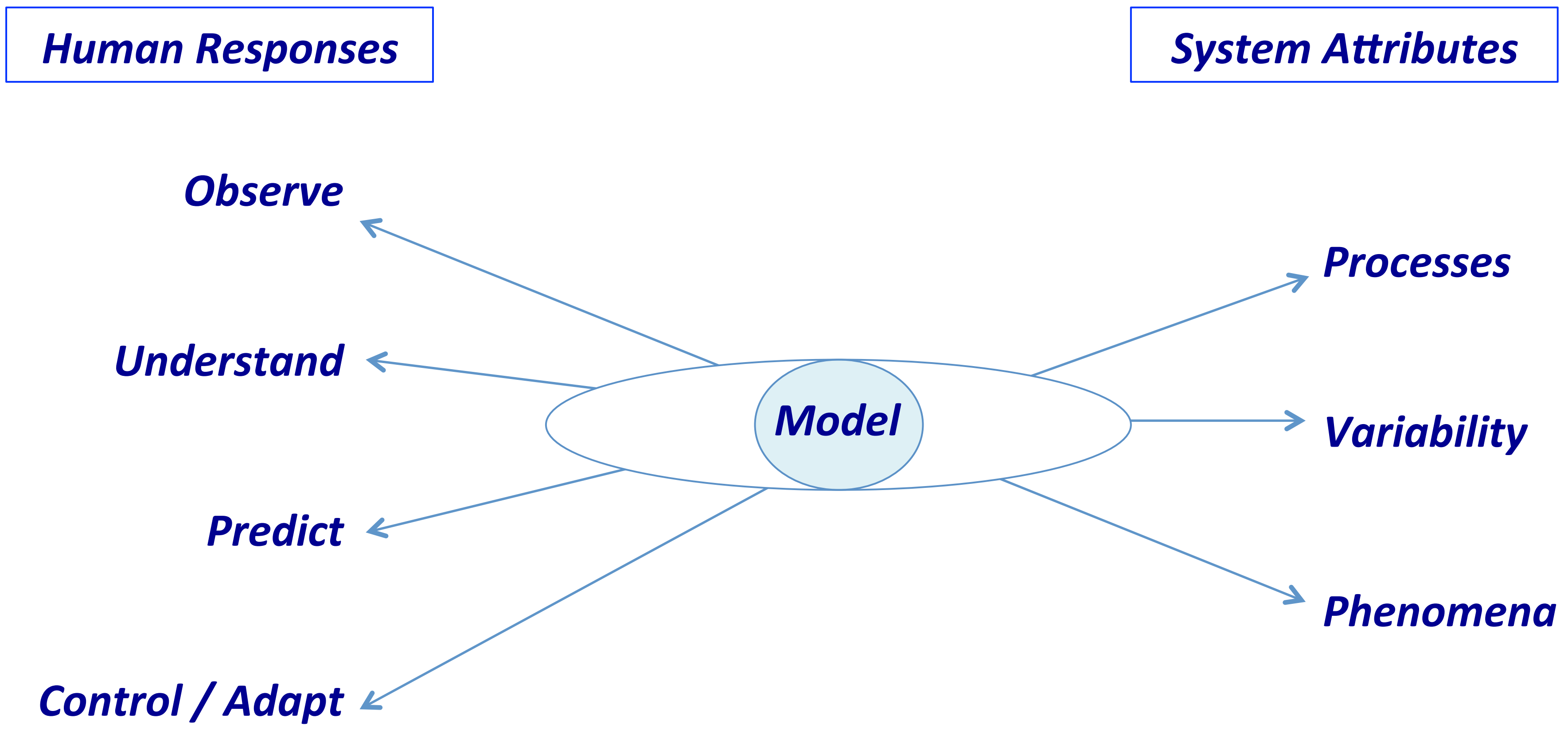
Science Review
12-14 May 2015
Boulder, Colorado

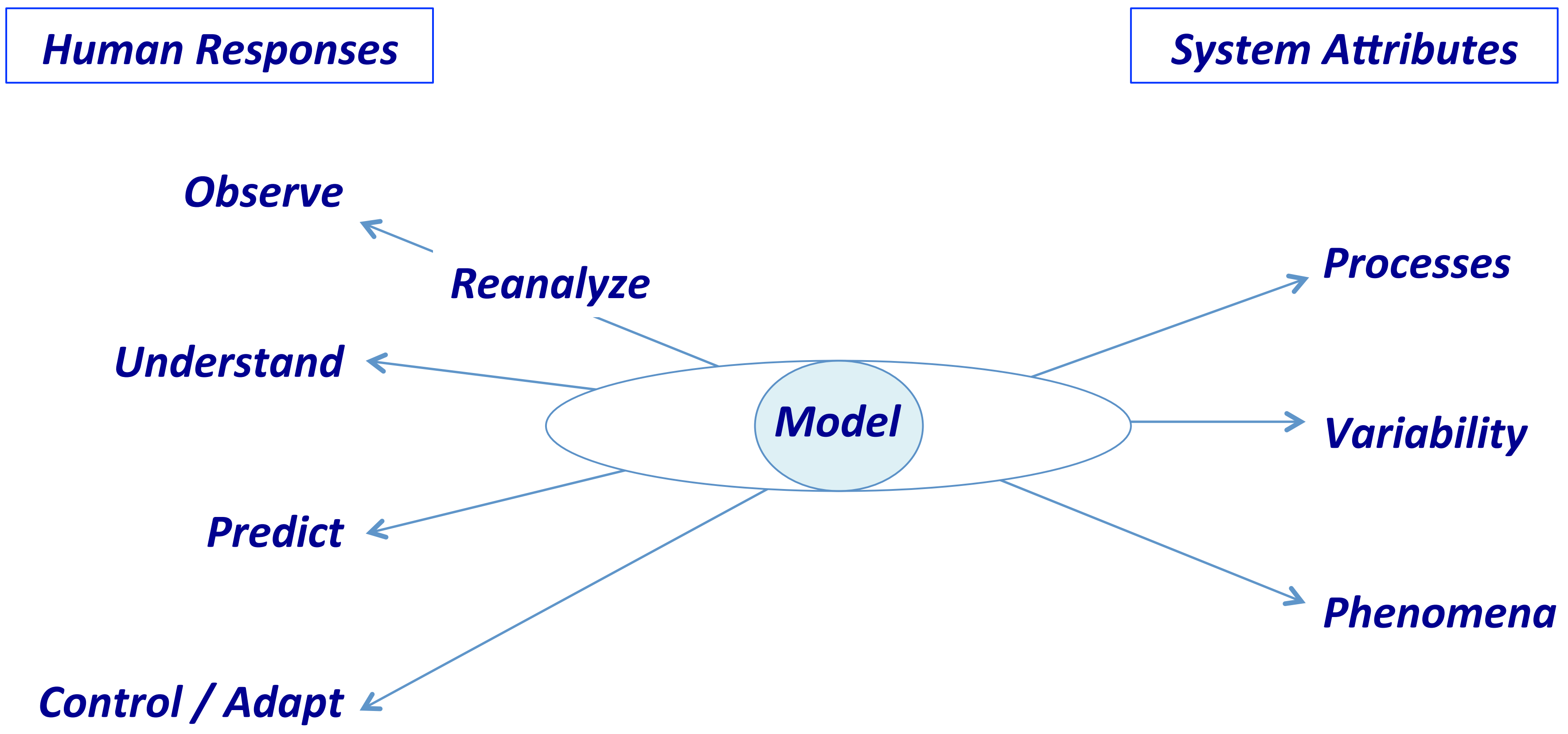
Human responses to complex chaotic systems

Human Responses	**System Attributes**
Observe	*Processes*
Understand	*Variability*
Predict	*Phenomena*
Control / Adapt	

Human responses to complex chaotic systems : Modeling is Key



Human responses to complex chaotic systems : Modeling is Key



PSD does not specifically develop Big Weather and Climate models

In other words, there is no "PSD GCM" (although there could be, if there is support)

Instead, we both run and analyze GCMs developed elsewhere to :

- *Diagnose the causes of weather and climate variations and extremes*
- *Identify regions of relatively large sensitivity and predictability*
- *Perform focused dynamical and physical process studies*
- *Help extend the climate record back to 1850 through Reanalysis*
- *Identify simulation and prediction errors that are systematic across models*

A distinctive PSD contribution is much simpler "Linear Inverse Models" (LIMs) derived directly from data, that are useful for many of the above (and several other) purposes.

Another distinctive development is simple physically based "Probability Models" of extreme anomalies, that are an attractive alternative to expensive ensemble GCM integrations.

Two approaches to multi-scale anomaly dynamics in the chaotically nonlinear climate system

Large scale components x_l | *Smaller scale components* x_s | *Unresolved components* x_u

GCM truncation

Truth

$$\frac{dx_l}{dt} = \mathcal{A}(x_l, x_s, x_u) + F$$

chaotic nonlinear — *forcing*

The large scale components are influenced by chaotically nonlinear interactions among all components

GCM approximation

$$\frac{dx_l}{dt} \approx A(x_l, x_s) + B(x_l, x_s)\,\eta + F$$

chaotic nonlinear — *stochastic* — *forcing*

The need for additional accurate "Stochastic parameterizations" has only gradually become apparent.

Linear Stochastically Forced (LSF) approximation

$$\frac{dx_l}{dt} \approx A_0 x_l + (B_0 + B_1 x_l)\,\eta + F$$

linear (predictable) — *stochastic (unpredictable)* — *forcing*

This approximation underlies ALL diagnoses and predictions of anomalies (and errors) based on correlations and linear regressions

The LSF approximation provides an explicit separation of the predictable and unpredictable large scale anomaly dynamics, and an efficient characterization of all linear feedbacks and interactions among system components

The Linear Stochastically Forced (LSF) Approximation is relevant, and useful

$$\frac{dx_l}{dt} \approx \underbrace{A_0 x_l}_{\substack{\text{linear} \\ \text{(predictable)}}} + \underbrace{(B_0 + B_1 x_l)\,\eta}_{\substack{\text{stochastic} \\ \text{(unpredictable)}}} + \underbrace{F}_{\text{forcing}}$$

The linear feedback and stochastic forcing matrices can be estimated directly from data through Linear Inverse Modeling (LIM) (Penland and Sardeshmukh 1995, and many other PSD publications)

Useful for :

- ***Highly competitive predictions*** *on weekly and longer time scales. Useful for benchmarking GCM forecast skill.*
- ***Explicit separation of predictable and unpredictable anomaly dynamics,*** *in general as well as in individual cases.*
- ***Identification of sources of predictive skill,*** *as well as of forecast "derailment".*
- ***Diagnosis of climate variability,*** *through analysis of the linear feedback and stochastic forcing matrices.*
- ***Diagnosis of GCM errors,*** *through comparisons of the corresponding feedback and stochastic forcing matrices.*
- ***Diagnosis of extremes,*** *through Monte Carlo simulations and the associated "SGS" probability distributions.*

Many papers by Penland, Sardeshmukh, Newman, Compo, Shin, Pegion, Alexander, Solomon, Hartten, Capotondi

Our modeling activities address the following NOAA, OAR, and PSD Goals and Objectives :

NOAA Strategic Goals:
Climate Adaptation and Mitigation: **an informed society** anticipating and responding to climate and its impacts.
Weather Ready Nation: society is prepared for and responds to weather-related events.

NOAA Strategic Objective:
Improved scientific understanding of the changing climate system and its impacts.

NOAA 5-yr plan R&D Objectives:
Identify the causes of climate trends and their regional implications.
Improved predictive guidance.
Produce best-quality reference data (reanalysis)

OAR Science Questions:
What is the state of the climate system and how is it evolving?
What causes climate variability and change on global to regional scales?
How does climate affect seasonal weather and extreme weather events?

PSD 2010 Strategic Goal:
Understand, attribute and predict extremes in a variable and changing climate.

PSD 2015 Overarching Science and Priority Research Goals:
Develop new knowledge and capabilities to explain observed weather and climate extremes, variations, trends.
Rigorously characterize and predict weather, water, and climate extremes and their uncertainties to inform decision-making.

The 4 Talks in this Session

1. Cécile Penland
   The Stochastic Framework for Understanding Climate
   A magical mystery tour of stochastics

2. Prashant Sardeshmukh
   Challenges in modeling extremes
   Tails of the Unexpected, and how they can be muddled

3. Amy Solomon
   Filling conceptual gaps in Arctic Cloud Processes with focused model studies
   Clearing up some cloudy Arctic issues

4. Gil Compo
   The 20th Century Reanalysis project version 2c (1851-2011)
   How to Reanalyze it all. Again.