BRINGING IT ALL TOGETHER:

A PROTOTYPE FOR A PROBABILSITIC NATIONAL BLEND

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OUTLINE / SUMMARY

- **Role & relevance of NWP & SPP in forecasting**
  - NWP provides predictive information
  - SPP fixes NWP miscalibration - Potentially major user impact
- **Proposed framework for National Blend of Models (NBM)**
  - Combine & calibrate guidance for NWP prognostic variables
  - Derive user variables from calibrated prognostic variables
- **A prototype for probabilistic NBM**
  - Bayesian Processor of Ensemble (BPE)
    - Combines multiple ensemble / high res forecasts & obs/analyzed climate
    - Unified processing of all continuous variables
    - Comprehensive set of output variables
- **BPE status**
  - Algorithm, software developed
  - Ongoing transfer to MDL
  - Comparative test against EKDMOS next

STATISTICAL POST-PROCESSING (SPP) IN NWP

- **NWP is basis** of weather forecasting
  - Provides all predictive information beyond 6 hrs
    - Data assimilation, numerical model, ensemble approach
- **Systematic errors** limit utility of NWP
  - Forecasts are miscalibrated (mislabeled)
- Statistical Post-processing
  - **Re-labels** forecast information
- Traditional approach to SPP
  - **Process each NWP guidance product individually**
    - NAM-MOS, GFS-MOS, NAEFS-EKDMOS, etc
    - Multitude of products overwhelm forecasters
- Birth of NWS National Blend of Models (NBM)
  - **Merge & calibrate forecasts**

PROBLEMS WITH NWP FORECASTS

- **Drift of model solutions** from real to model world
  - 1st moment calibration
- **Uncertainty not captured well** by single/ens fcsts
  - 2nd moment calibration
- **Abundance of guidance products**
  - Fusing all predictive information

Lead-time dependent *behavior of*

NWP Model Prog Variables (MPV) ***on model grid***

- **Missing variables**
  - Limited model resolution in space, processes, variables

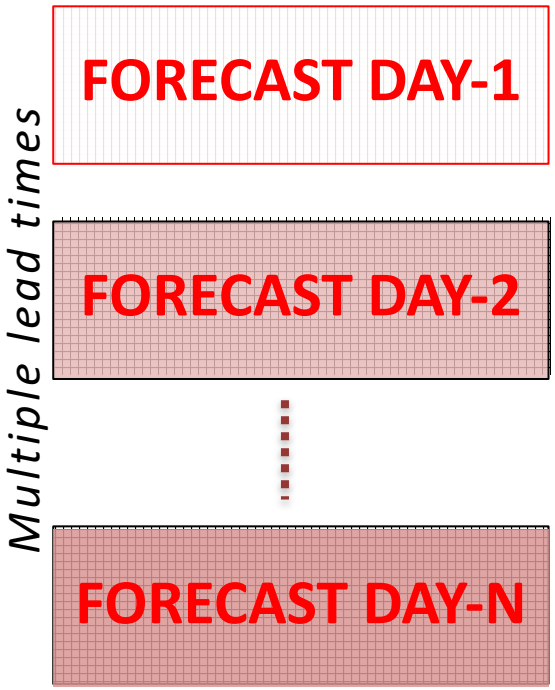
Simultaneous relationships *btw*

User Specific Variables on fine & *MPVs on model grid*

OBJECTIVE OF STATISTICAL POST-PROCESSING

Uncalibrated model variables

Calibrated user variables



Coarser model grid

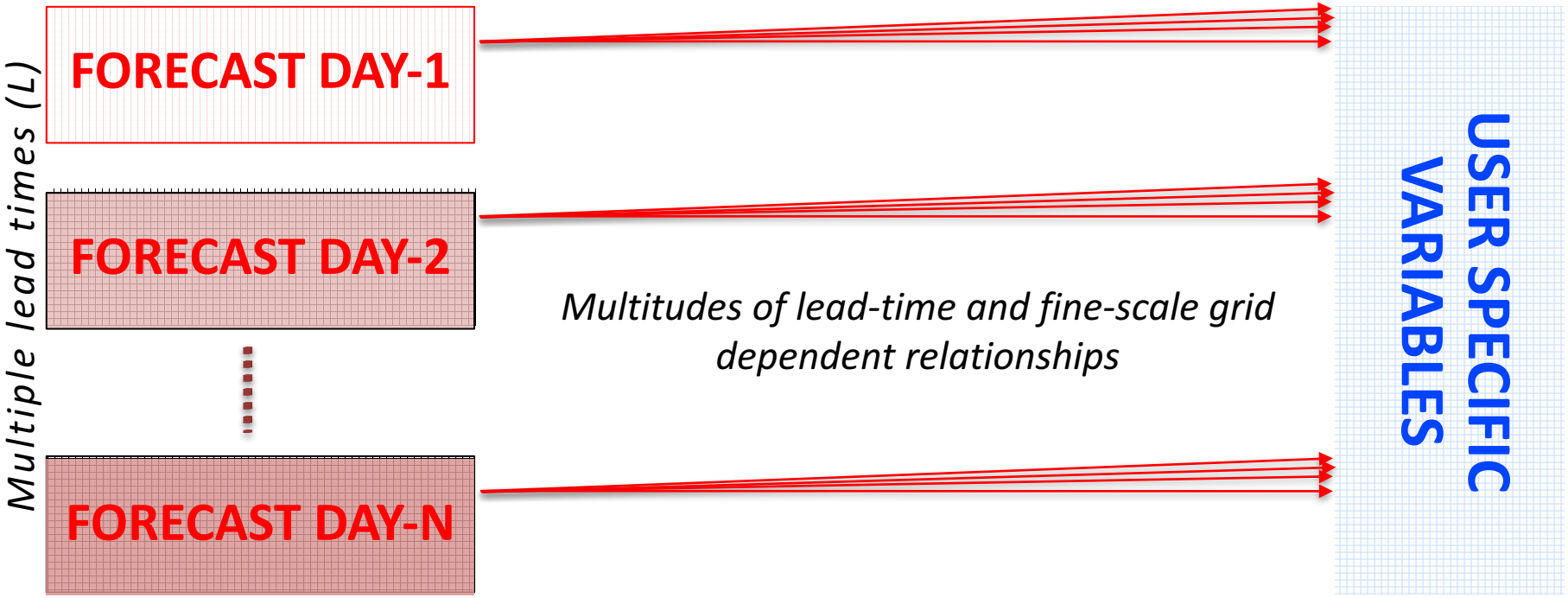
Fine scale grid

COMMON APPROACH TO POST-PROCESSING

1-Step, direct approach

Uncalibrated model variables ***Calibrated user variables***

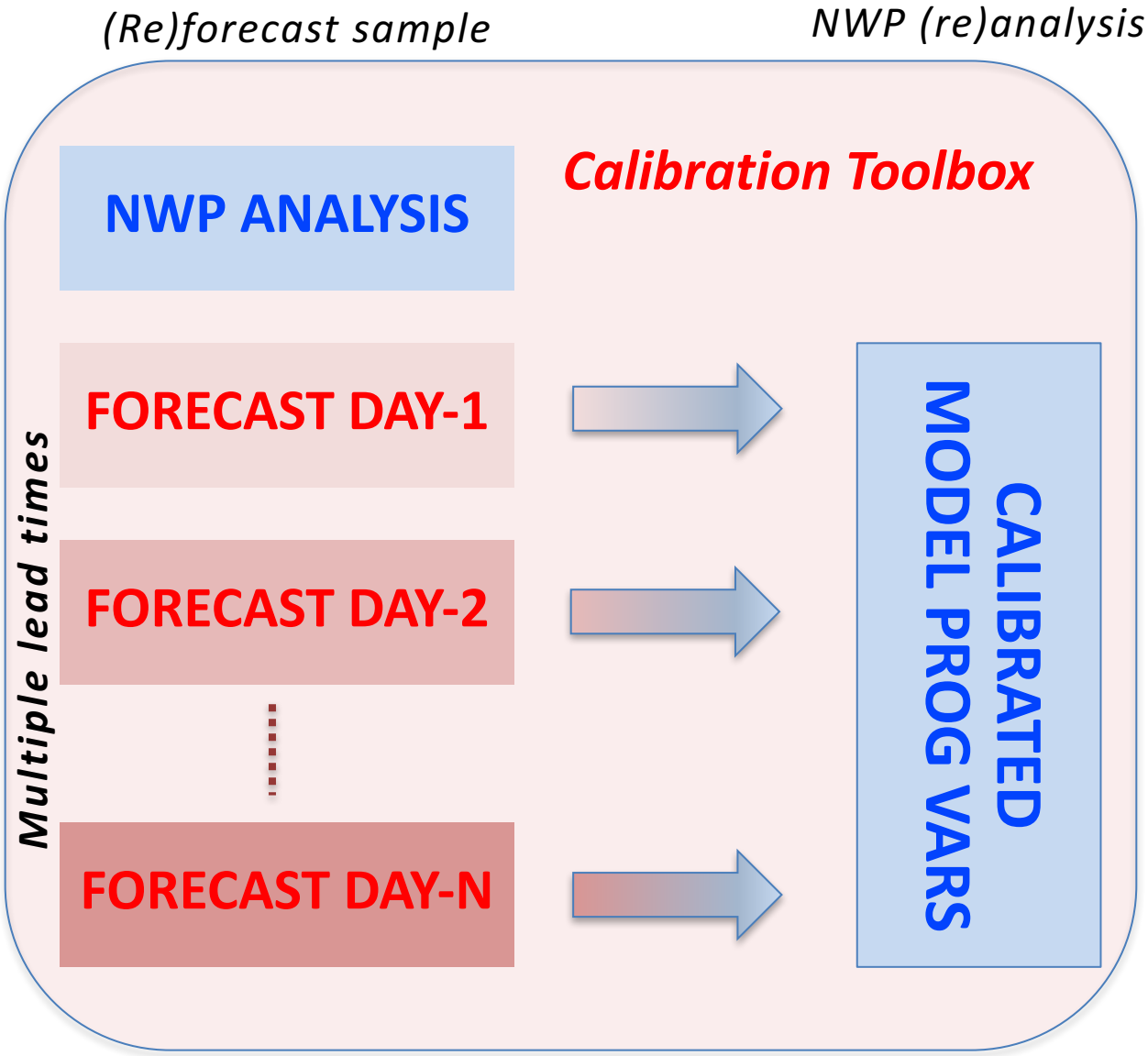
Cost: L x M x (N / M); Retrain for each model update



Model gridpoints (M) << (N) Fine scale gridpoints

O (10-100)

CALIBRATION OF MODEL PROGNOSTIC VARIABLES



Cost: L x M

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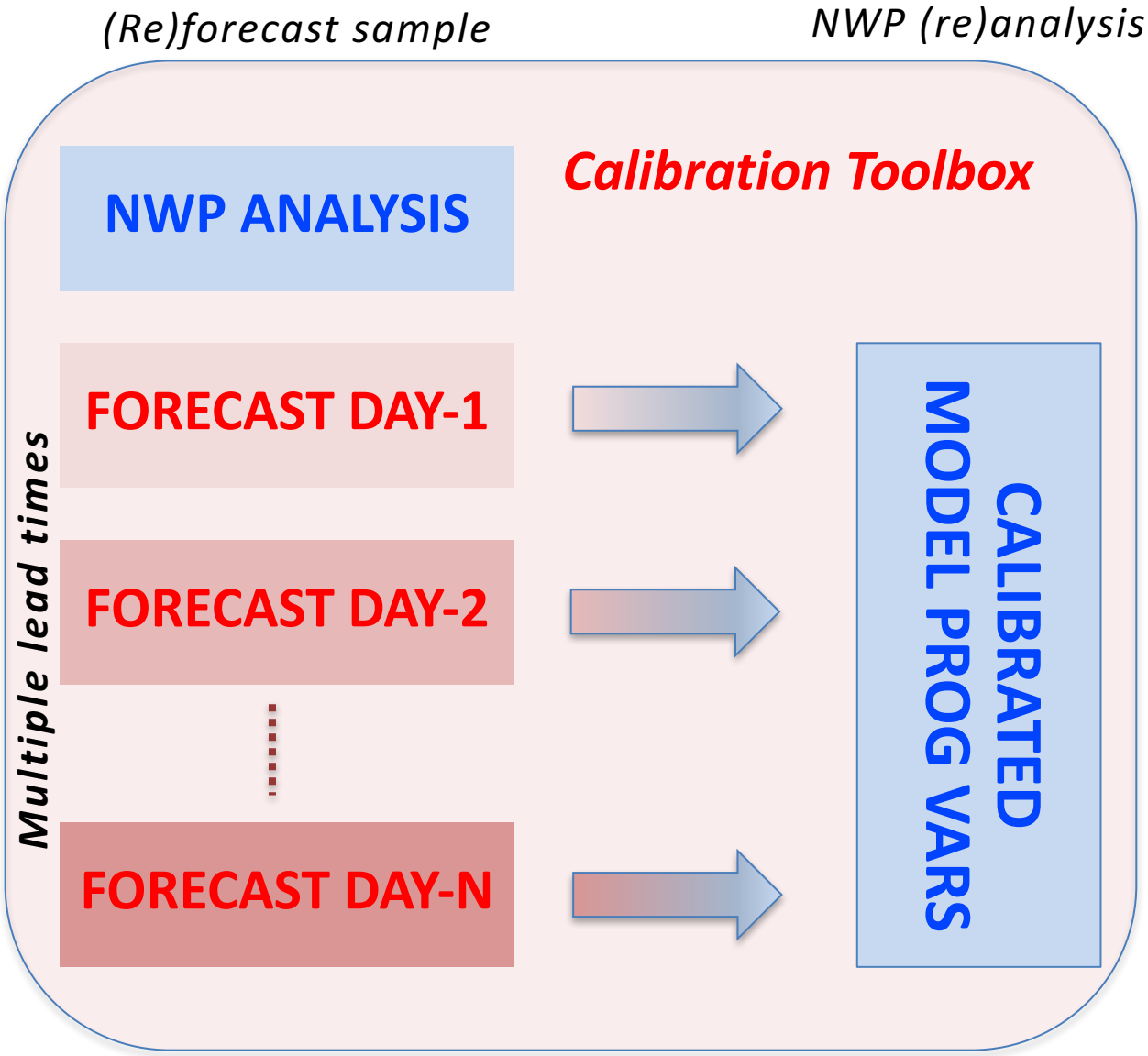

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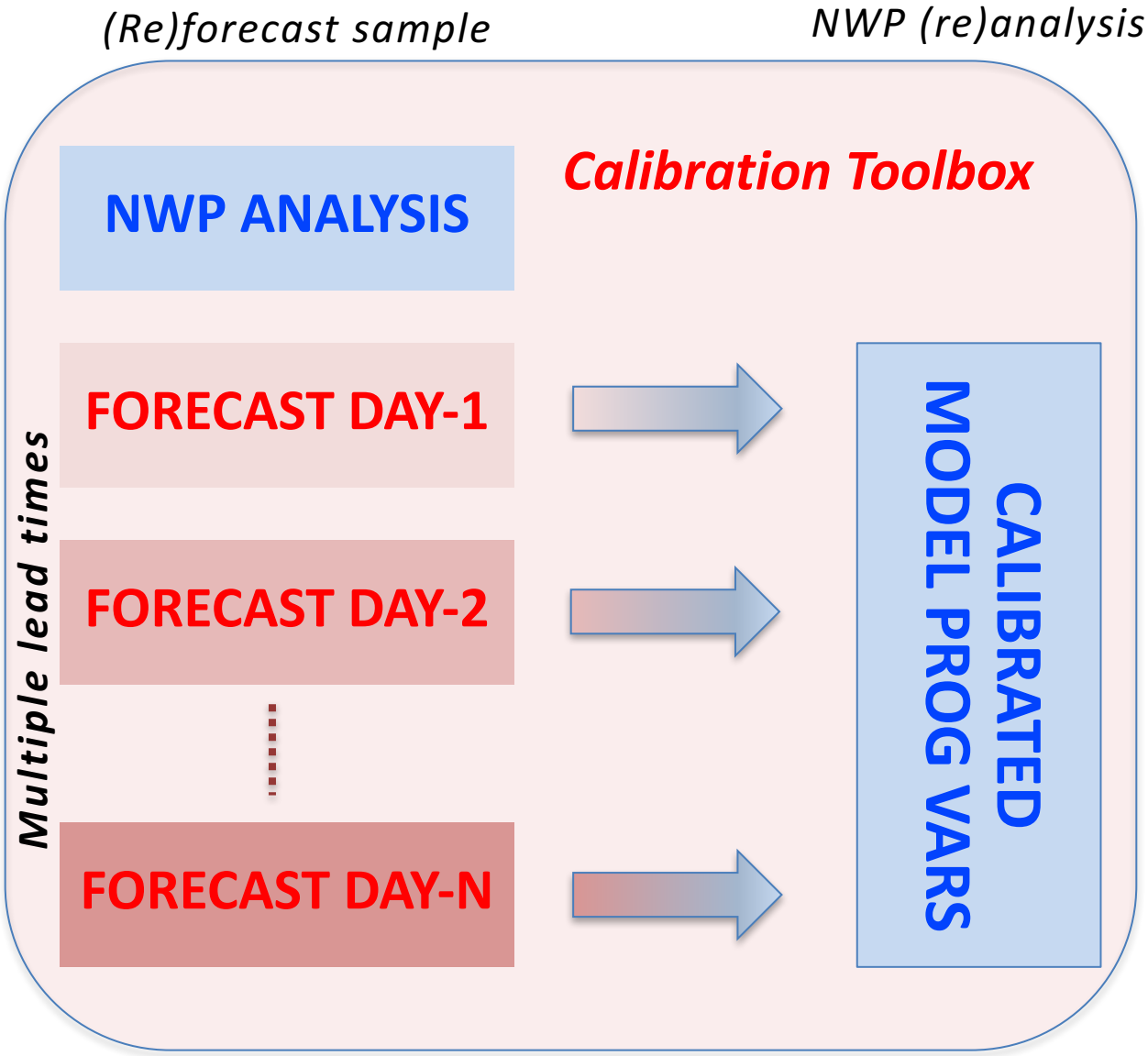
Lead-time dependent** behavior of NWP Model Prog Variables (MPV) **on model grid

CALIBRATION OF MODEL PROGNOSTIC VARIABLES



N / M savings from fixing model problems on model grid

DERIVATION OF USER VARIABLES

- **Missing variables**
  - Limited model resolution in space, processes, variables

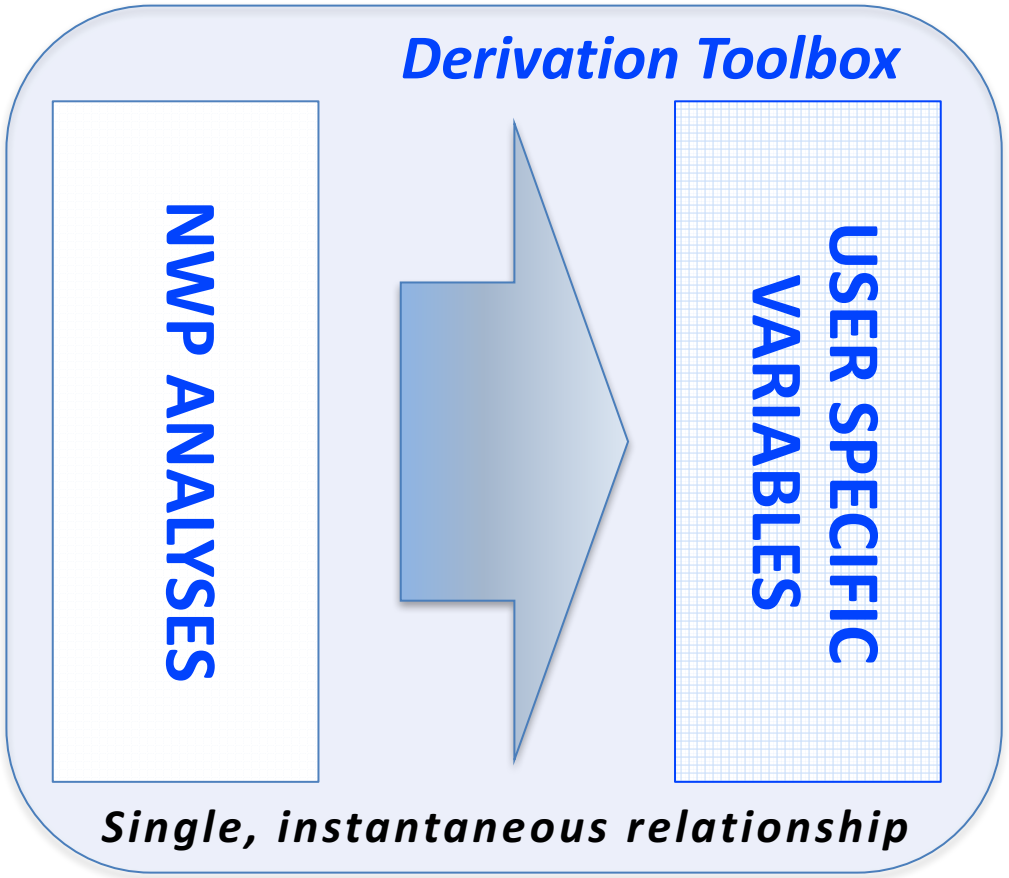
Simultaneous relationships btw

User Specific Variables on fine & MPVs on model grid

NWP reanalysis

Fine scale (re)analysis

No need for hindcasts



Model grid

Fine scale grid

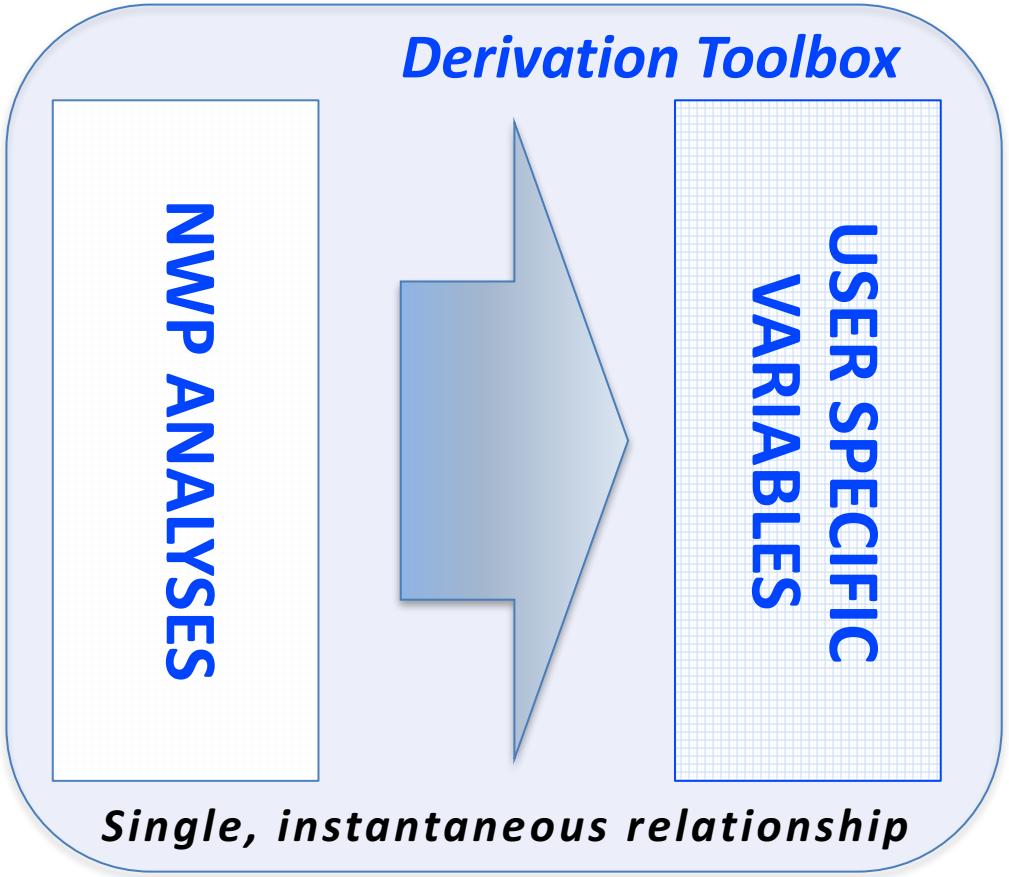
DERIVATION OF USER VARIABLES

NWP reanalysis

Fine scale (re)analysis

Cost: M x (N / M)
Retrain only for reanalysis update

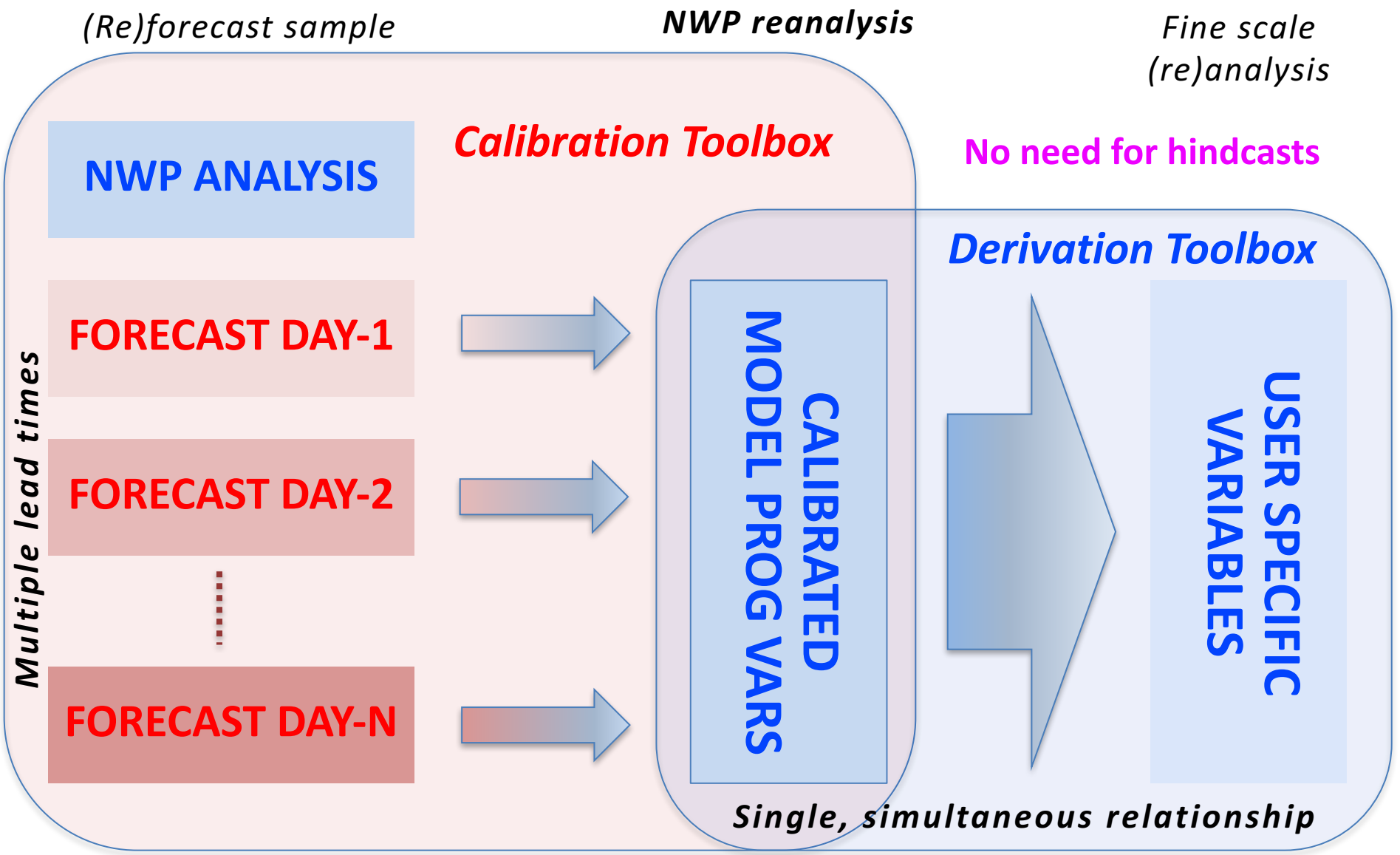
No need for hindcasts



Model grid

Fine scale grid

PUTTING IT TOGETHER: 2-STAGE POST-PROCESSING



Model grid

Fine scale grid

1-STEP vs 2-STAGE APPROACH TO POST-PROCESSING

- **Disadvantages of 1-step approach**
  - Addresses coarse scale model problem on fine scale grid – Redundancy
  - Separate derivation of user variables for each lead time - Redundancy
  - Requires hindcast sample

- **Benefits of 2-stage approach**
  - Addresses independent problems separately
    - Better understanding / separate metrics to focus on issues
  - Modular design eases community involvement, supports collaboration
  - Shared development of derivation tool box
    - Vast array of "perfect prog" tools available – UPP, DA forward models, satellite product generation, etc
  - Calibrated model variables can be used in downstream coupled appls
    - Liberates downstream users from ever changing model version specific biases
      - Develop and use reanalysis – based relationships
    - One-way coupled user models (eg, hydro) can be calibrated with reanalysis
  - Simplifies forecast editing – Modify calibrated model prog variables
    - Multitude of consistent user variables automatically derived w/o addition. edits
  - Thorough analysis of systematic model errors for model developers

RECOMMENDED APPLICATION

- **Calibrate all model prognostic variables**
  - Lead-time dependent behavior eliminated
    - NWP (re)analysis as proxy for truth
    - Calibrated forecasts statistically behave like analyses
    - Systematic error estimates useful for model developers
  - NWP-based predictive info fused on model grid
  - Scales with number of **model gridpoints x leadtimes**

- **Derive additional user variables**
  - Fine scale analysis as proxy for truth (RUA)
  - Instantaneous relationships between analyses of
    - Model Prog Vars (MPV) & User Specific Variables (USV)
      - No lead-time dependency - No need for hindcasts
  - Toolbox with various types of routines
    - UPP, DA forward models and other physical & statistical methods
  - Scales with number of **fine scale gridpoints**

Model Prognostic Variables — **Fine Scale User Var.**

REAL TIME NWP FORECAST — *HISTORICAL DATA*

Ensemble, High Res. Control — Hindcast, (Re)analysis — Reanalysis

NOAA — National Oceanic and Atmospheric Administration — U.S. Department of Commerce

Calibrate & Consolidate NWP Output

Derive Fine Scale User Vars.

PROBABILISTIC FORECAST SERVICES

NWS FORECASTERS

Forecast Editor

Calibrated Model Prog Variables

Calibrated User Variables

6D-DATACUBE

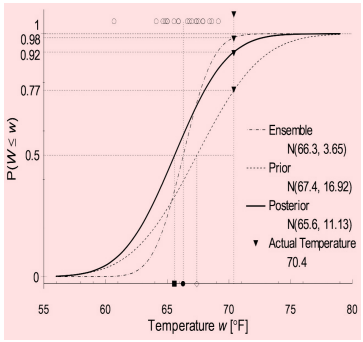
Climate & Forecast Distributions

Ensemble Scenarios

Coupled Models

3rd Party Appls.

EXTERNAL USERS



Product Generator

Pregenerated Products, Interactive Services

Model Prognostic Variables — *REAL TIME NWP FORECAST* — Ensemble, High Res. Control

Fine Scale User Var. — *HISTORICAL DATA* — Hindcast, (Re)analysis — Reanalysis

NOAA — National Oceanic and Atmospheric Administration — U.S. Department of Commerce

Bayesian Processor of Ensemble

*Planned Bays. Deriv., **UPP**, etc*

PROBABILISTIC FORECAST SERVICES

NWS FORECASTERS

*Proposed **iEdit***

Calibrated Model Prog Variables

Calibrated User Variables

Coupled Models

6D-DATACUBE
Climate & Forecast Distributions
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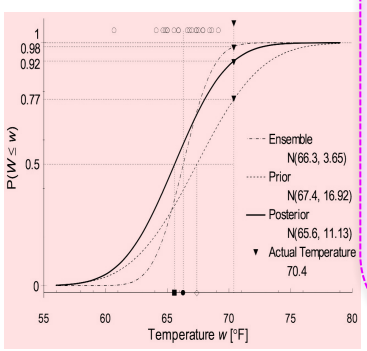
3rd Party Appls.

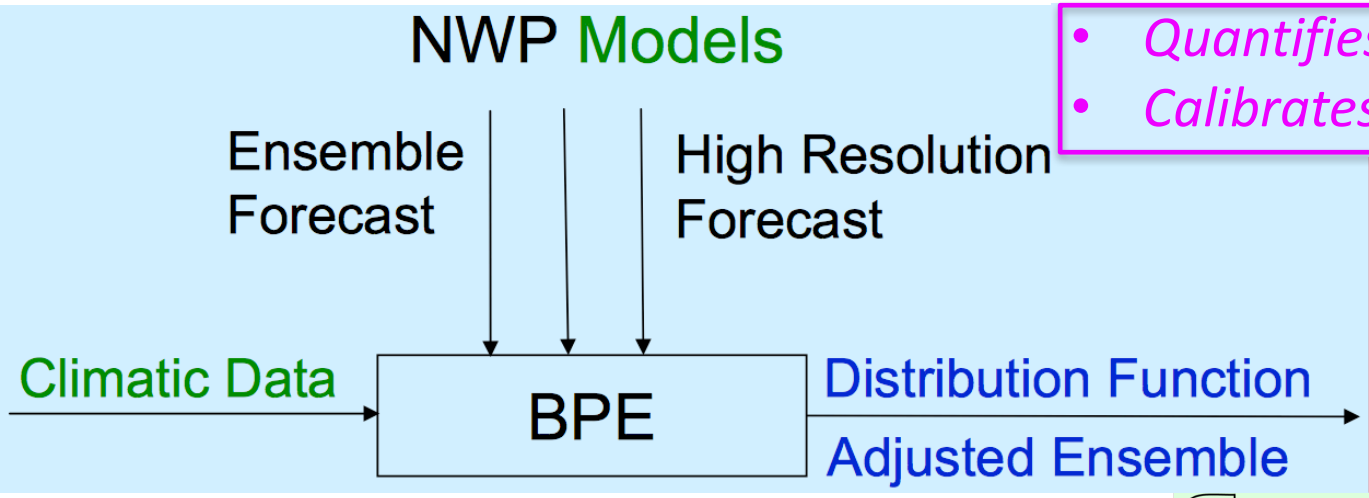


***BPE Product Generator**, other tools*

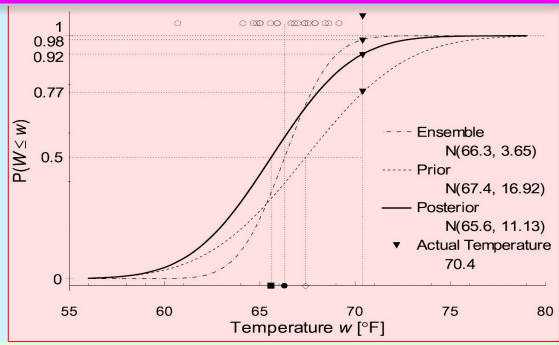
Pregenerated Products, Interactive Services

EXTERNAL USERS

BAYESIAN PROCESSOR OF ENSEMBLE - BPE



- *Quantifies & reduces uncertainty*
- *Calibrates (de-biases) ensemble*

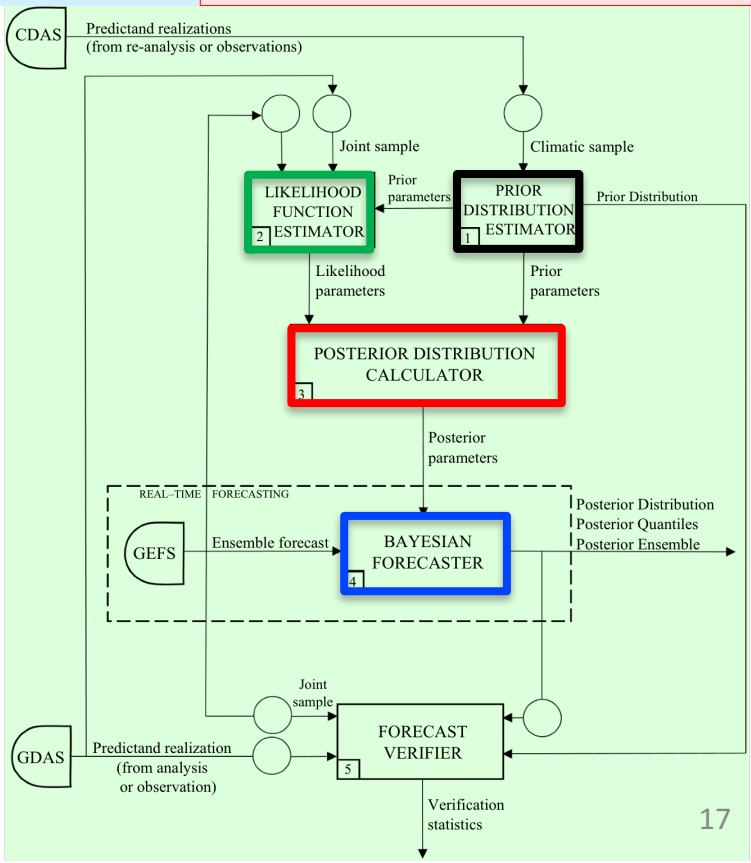


1) Estimate climate distribution

2) Assess skill in & combine all predictors

3) Cast forecast in climate context

4) Offer multiple output formats



Krzysztofowicz & Toth 2008, Krzysztofowicz 2010

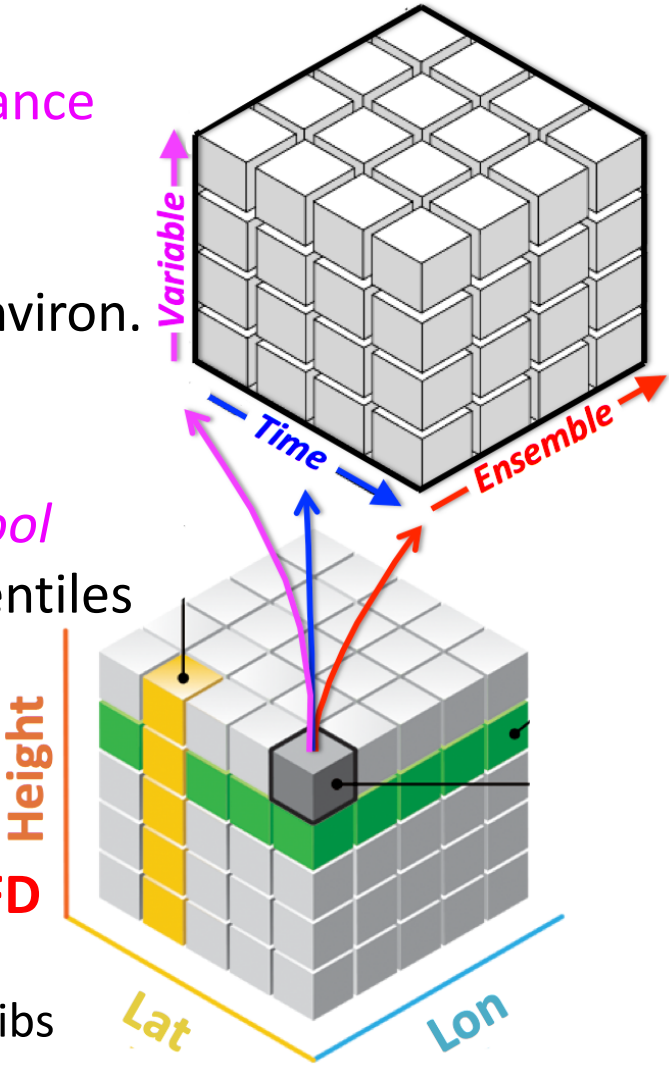
BAYESIAN PROCESSOR OF ENSEMBLE (BPE) BASICS

- Use **climatology as basis** – link w climate prediction
  - Fit **parametric distribution** to large climate sample
    - Calibration ensured, extremes handled gracefully w/o large hindcast
  - Express forecasts as anomalies from climate
    - No need for large hindcast sample to define obs. Climatology
- Transform each variable into **normal space**
  - Unified approach for ALL continuous variables
- Assess **predictive information** in guidance products
  - Multilinear regression, 1st & 2nd moments as predictors
    - Well established technology (MOS); Forecast information maximized
- Process **current forecast**
  - Calibrated forecast as modified climate distribution (percentiles)
    - Most economic storage – 2 modified pars of climate distribution
  - Prob. dist., quantiles, posterior ensemble (scenarios / joint prob)

6D NDFD – CENTRAL TENET OF FORECAST PROCESS

Connects NWP output w. users via value added steps

- **Role**
  - Repository of authoritative probabilistic guidance
    - Forecaster modification via *editor tool*
- **Function**
  - Holds answer to all questions about future environ.
    - Access info via *interrogator tool*
- **Content**
  - Calibrated **prog. vars.** from *post-processing tool*
  - Calibrated **user variables** – incl. climate percentiles
- **Format**
  - **6D** - Space (3), time, variables, uncertainty
- **Implementation**
  - Phase 1 – **Only 2-fold expans. of current NDFD**
    - Climatological distributions – negligible cost
    - 2 BPE posterior parameters to describe fcst distribs
  - Phase 2
    - Ensemble members for joint probabilities & scenarios



NATIONAL BLEND OF MODELS – BRINGING ALL THE PIECES TOGETHER

- Modular/comprehensive/expandable **framework**
- Academic **research &** NOAA **operations**
- Array of theory based **techniques**
- End-to-end **workflow** w up-to-date software
- Variety of **forecast products** & climate info
- **All model prog vars** processed in unified way
- **Calibrated and informative** guidance
- Comprehensive array of **output formats**
- Serving diverse **applications**

BACKGROUND

OUTLINE / SUMMARY

- **Role & relevance of NWP & SPP in forecasting**
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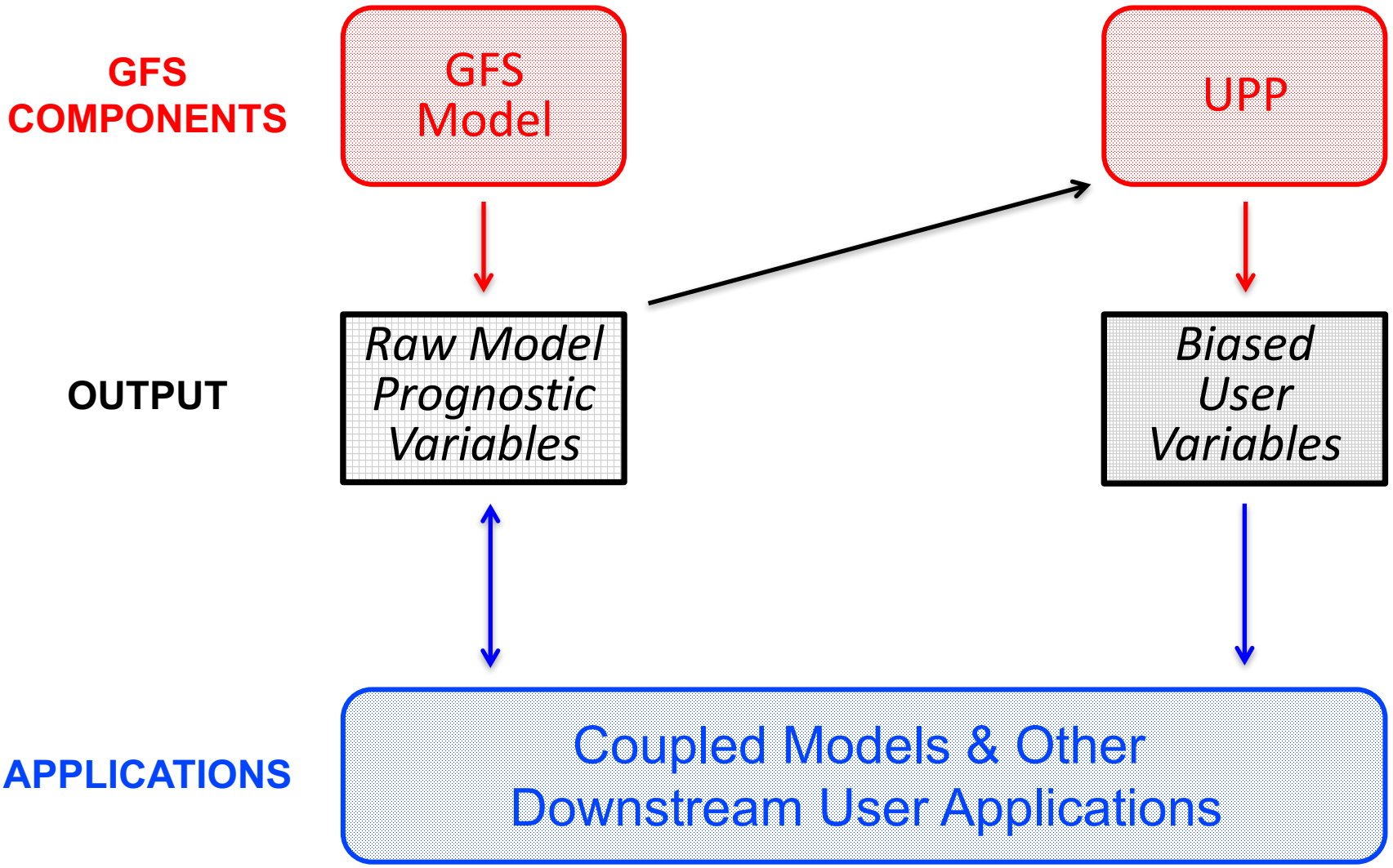
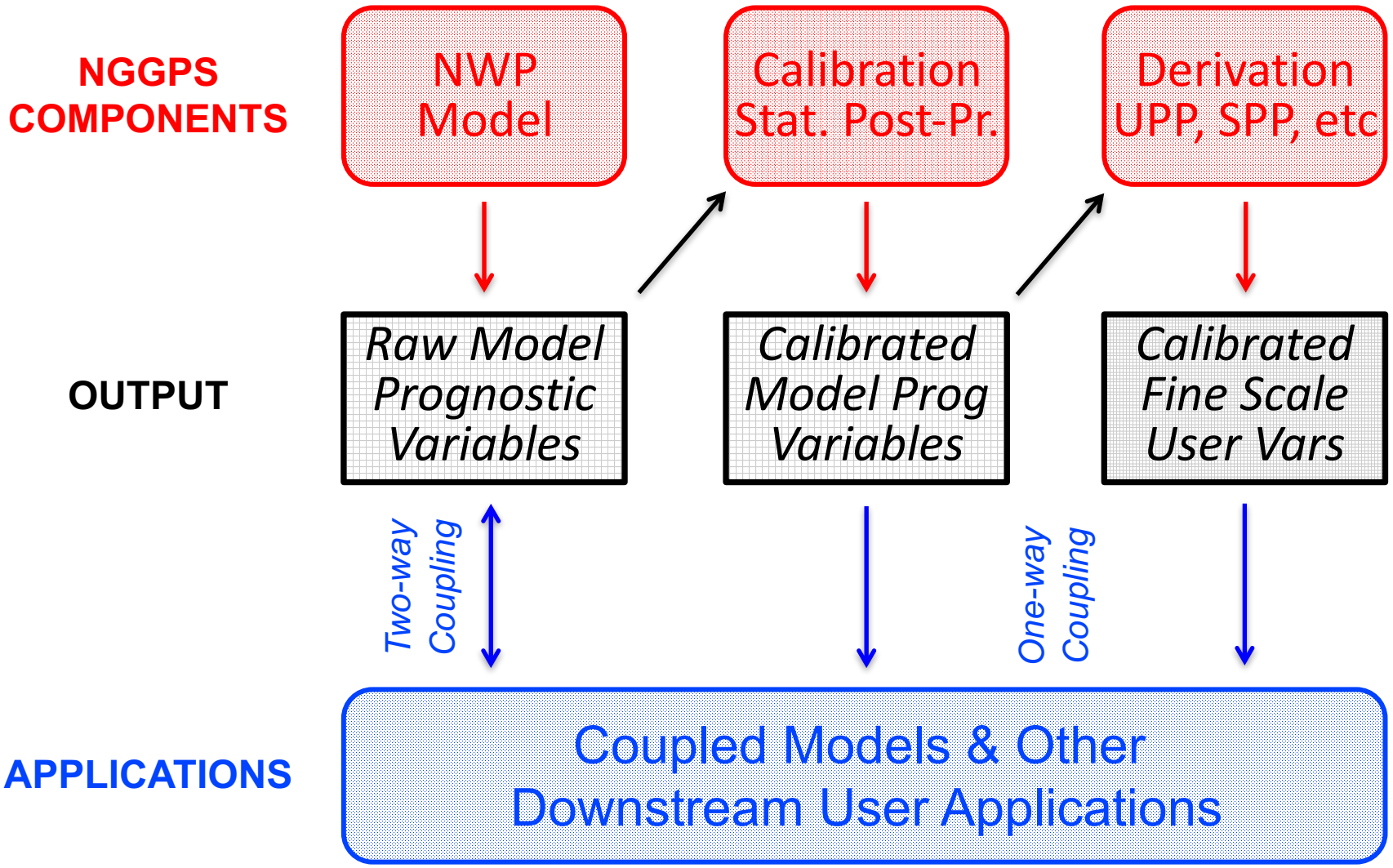
CURRENT GFS CONFIGURATION



NGGPS SYSTEM DESIGN CONSIDERATIONS

Component functionalities, links, software infrastructure



BPE PROJECT STATUS

- **OMM version** - One ensemble, Multiple control & Multiple auxiliary predictors
  - Algorithm & documentation complete (U. Va)
  - Codes complete (GSD)
  - Off-line testing (GSD, ongoing)
  - Transition to MDL (Oct16)
  - Testing at MDL (Nov16)

- **MMM version** – Multiple ensembles added
  - Algorithm & documentation (U. Va, Sep16)
  - Codes complete (GSD, Nov16)
  - Off-line testing (GSD, Jan17)
  - Comparison w EKDMOS

    in operational environment (MDL, Mar17)
    - Assess quality & computational speed at observation sites

- **Final report** (All, May 2017)