Chaos and observability in variational data assimilation

CSGF Annual Review

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Outline

- Data assimilation

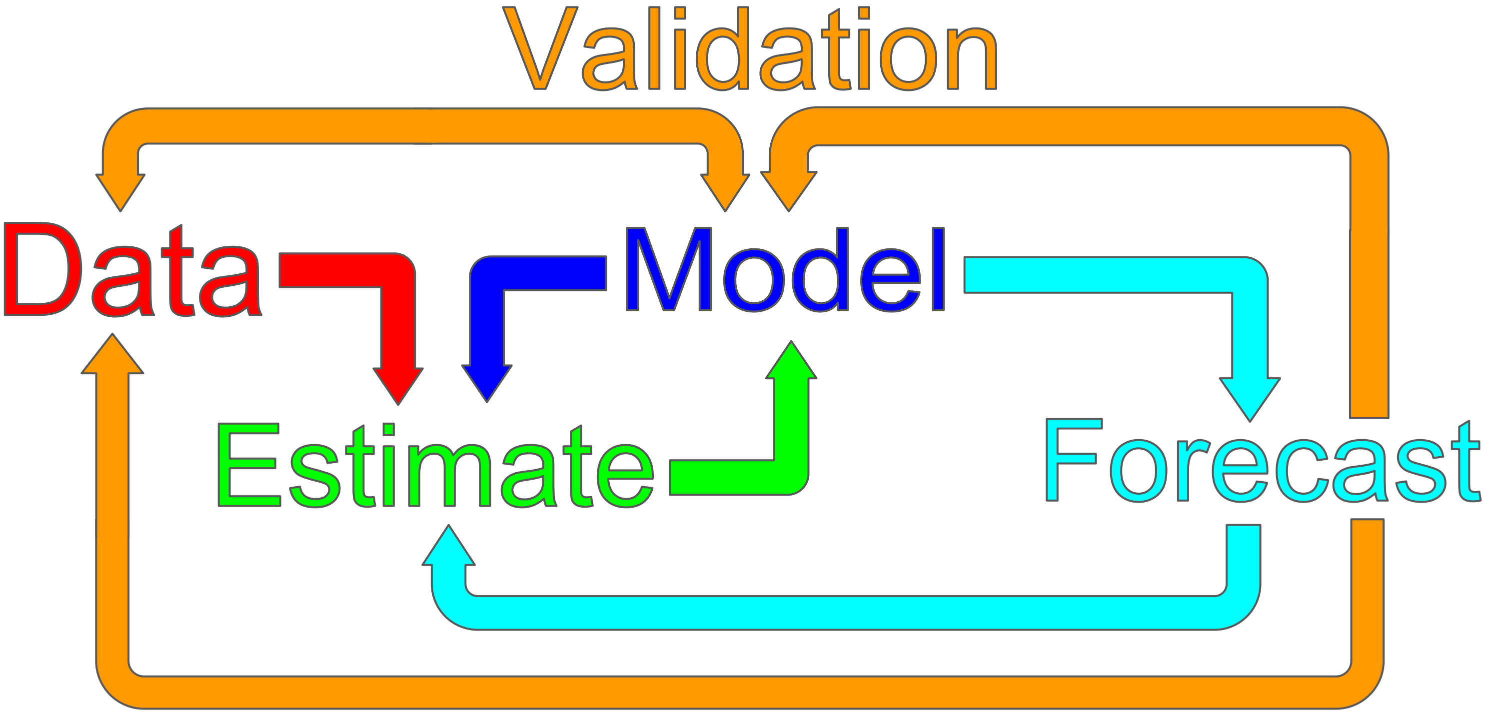
  --- blending data and models into dynamic forecasts

- Critical observability thresholds in chaotic systems

  --- how many observations do we need?

- Three DOE applications:
  - Coupled earth systems
  - Power generation networks
  - Biophysical problems

A schematic representation of data assimilation

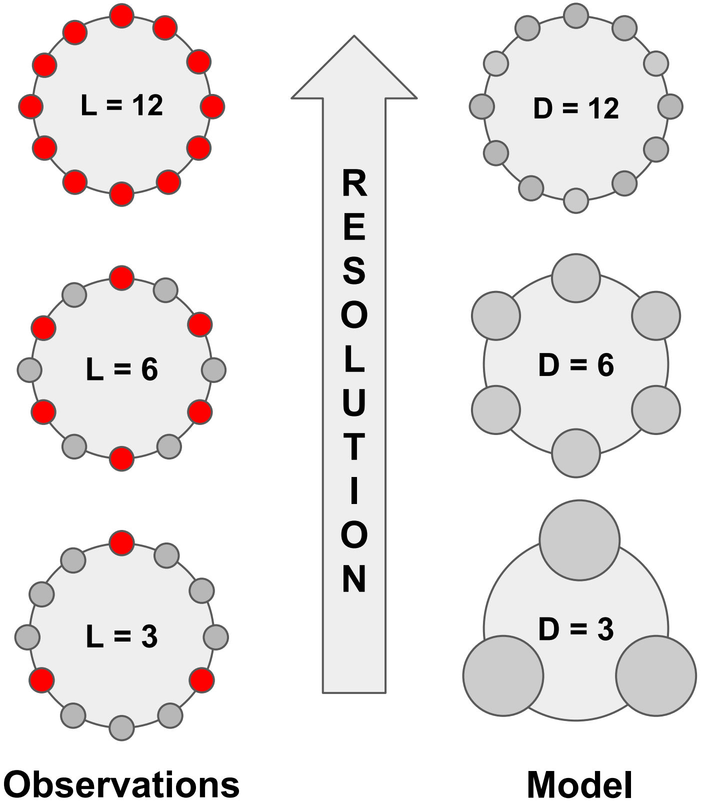


How many observations are needed?

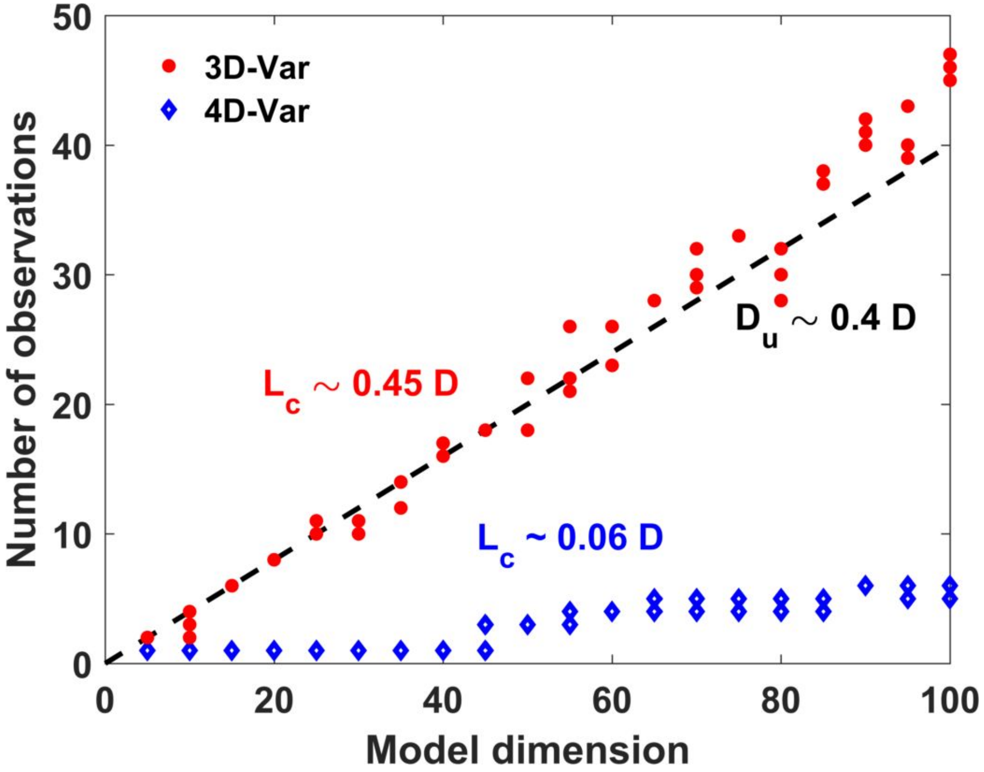
- Develop analysis tools to identify critical observability thresholds
  --- below which estimates and forecasts become unreliable
- Analyze how these limits scale with properties of the problem
  --- the models, the data, and the estimation algorithm
- Validate the design of the coupled observe-analyze-forecast system
  --- and suggest improvements

Identifying the limits of computational observability

- Lorenz 1996 model
  - Atmosphere-like model on a periodic lattice
  - Chaos scales extensively with model dimension
- Simulated data
  - Uniformly distributed observations
  - Random observation errors
  - *No model error*
- Perform estimates in parallel
  - Vary resolutions of the model and observations
  - Each trial either succeeds or fails
  - Identify computational limits in observability

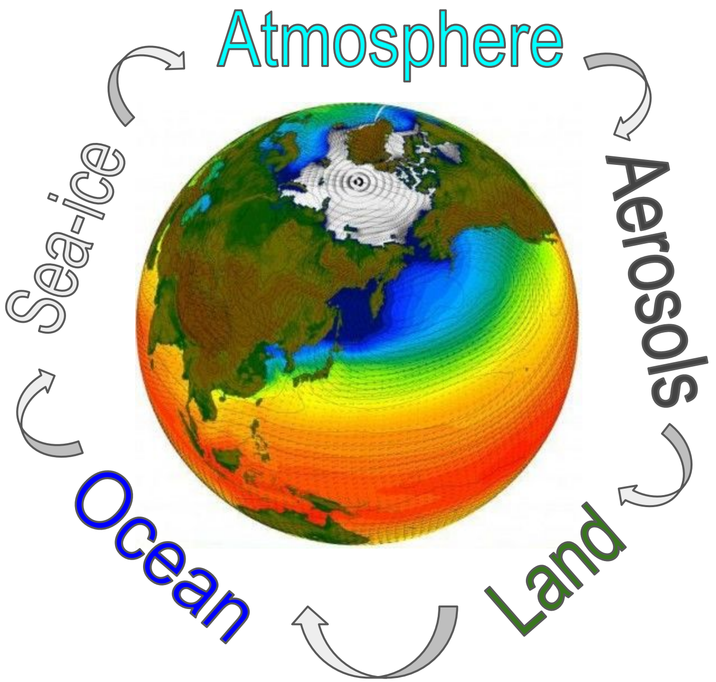


Observability limits of the Lorenz 1996 model



Applications to existing DOE work

- Coupled earth systems models
  - Shallow water equations require observing roughly ⅔ of the system states
  - Time extended measurements reduce this requirement by over half
- Power systems models
  - Control short term instabilities introduced by renewable resources
  - Identify conditions leading to network-wide voltage collapse
- Biophysical applications
  - The BRAIN initiative
  - Combining data assimilation with machine learning



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