

1D vs 3D subsidence modeling: appropriate simplification  
or do we need those extra two dimensions?

Jeremy White  
INTERA, Inc

The phrase "To Explain or to Predict" refers to the distinction in statistical modeling between understanding causal relationships (explanation) and forecasting future outcomes (prediction). Recognizing this difference is important for advancing scientific knowledge and applying statistical methods effectively.

# In an environmental modeling context

**Predictive env modeling:** predict the response on the hydro(geo)logic system to new/unseen forcings

- **Not all processes, physics, resolution are important - “it depends”**
- Learning from data is important
- Estimating reliability can be important

# Why predictive modeling?

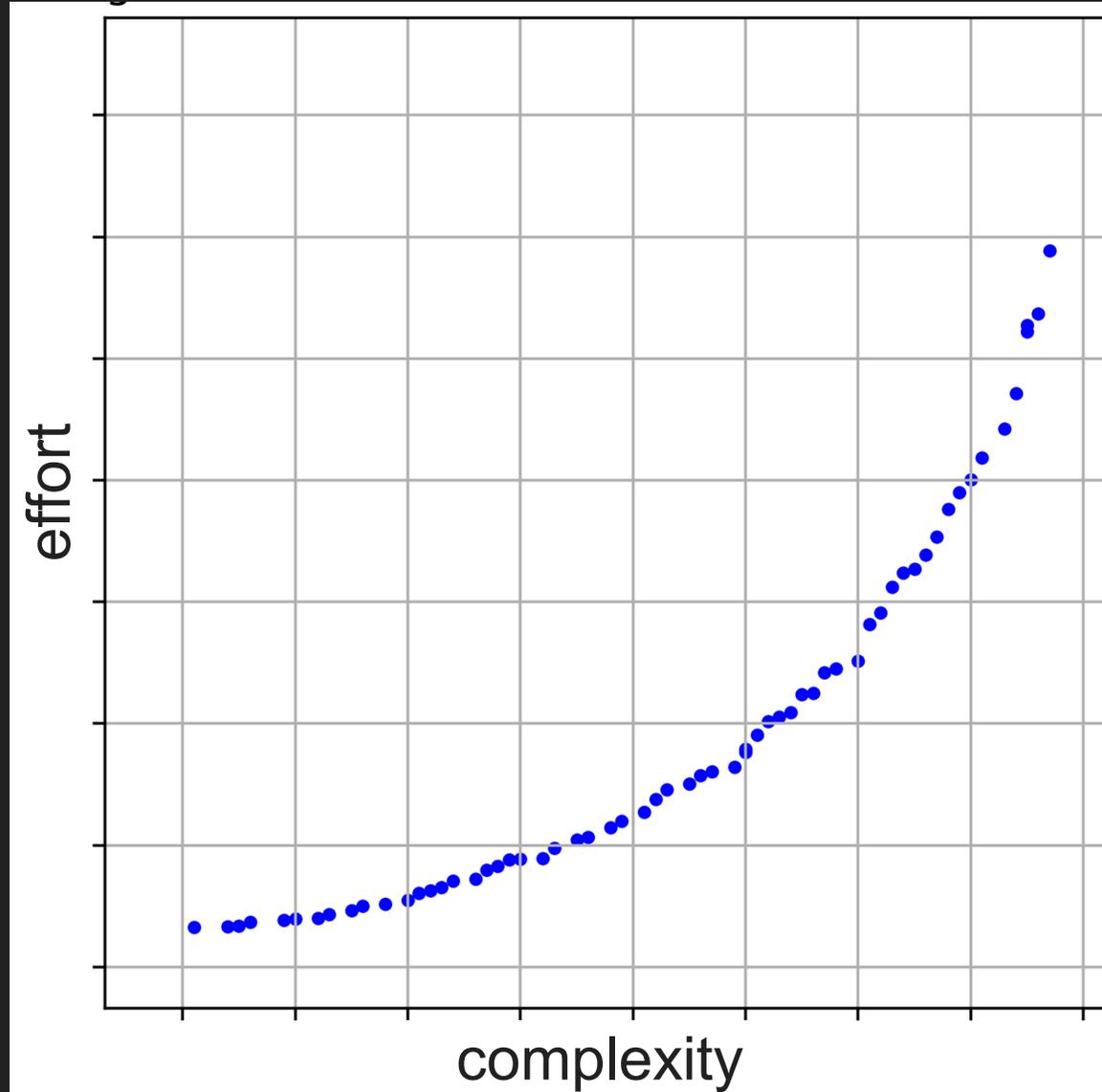
- Increasingly difficult tradeoffs
- **eg environment vs economy**
- Predictive modeling can help provide insights
- “What if we...”



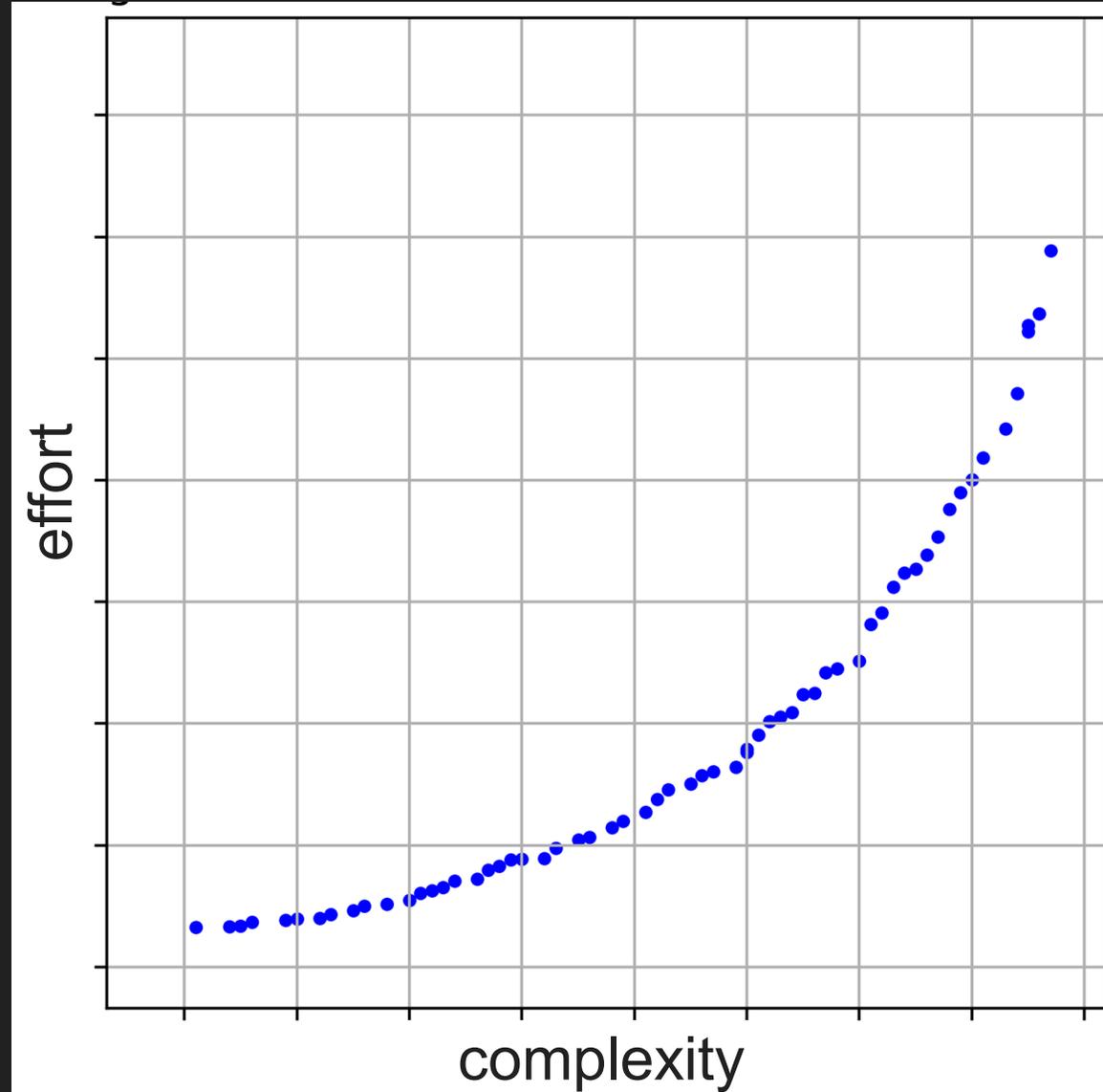
# In a perfect modeling world...”digital twin”

- All models would represent every process with high fidelity
- All models would have high spatial resolution
- All models would have high temporal resolution

# Trade-offs in environmental modeling



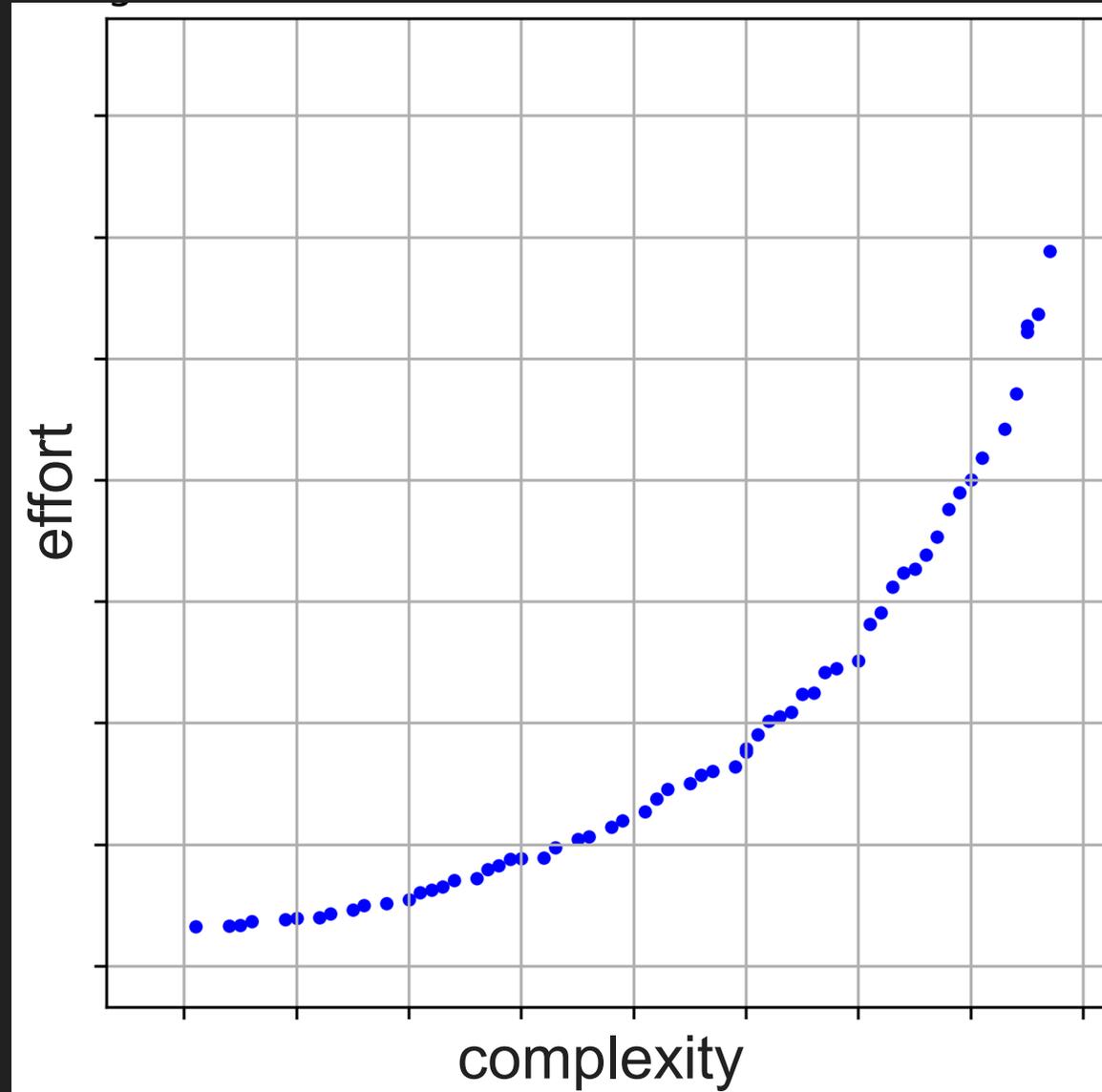
# Trade-offs in environmental modeling



Data  
driven

“Complete”  
physics

# Trade-offs in environmental modeling



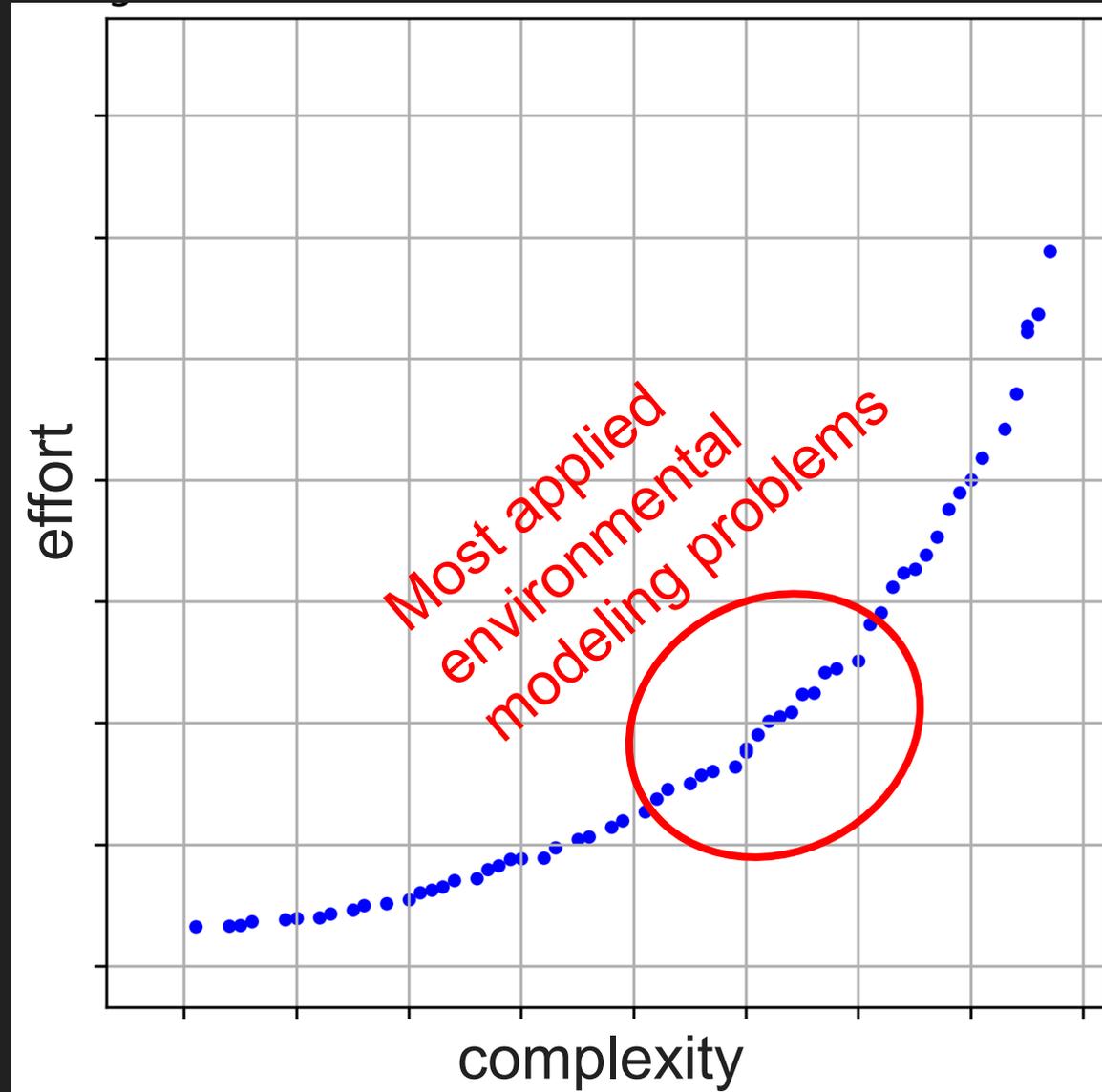
Predictions fully informed by available data

Data driven

“Complete” physics

Available data have no predictive information

# Trade-offs in environmental modeling



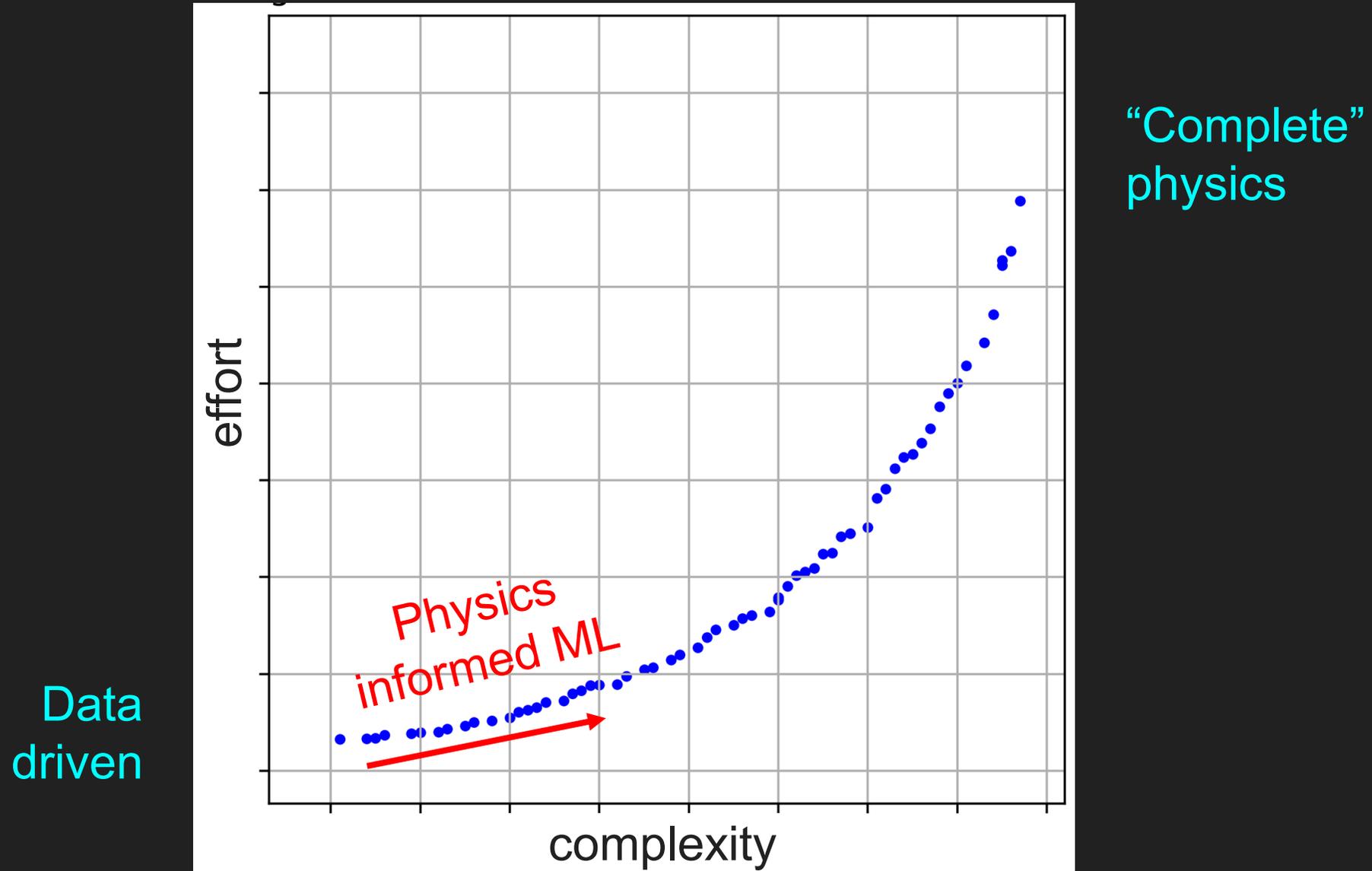
“Complete”  
physics

Available data have  
no predictive  
information

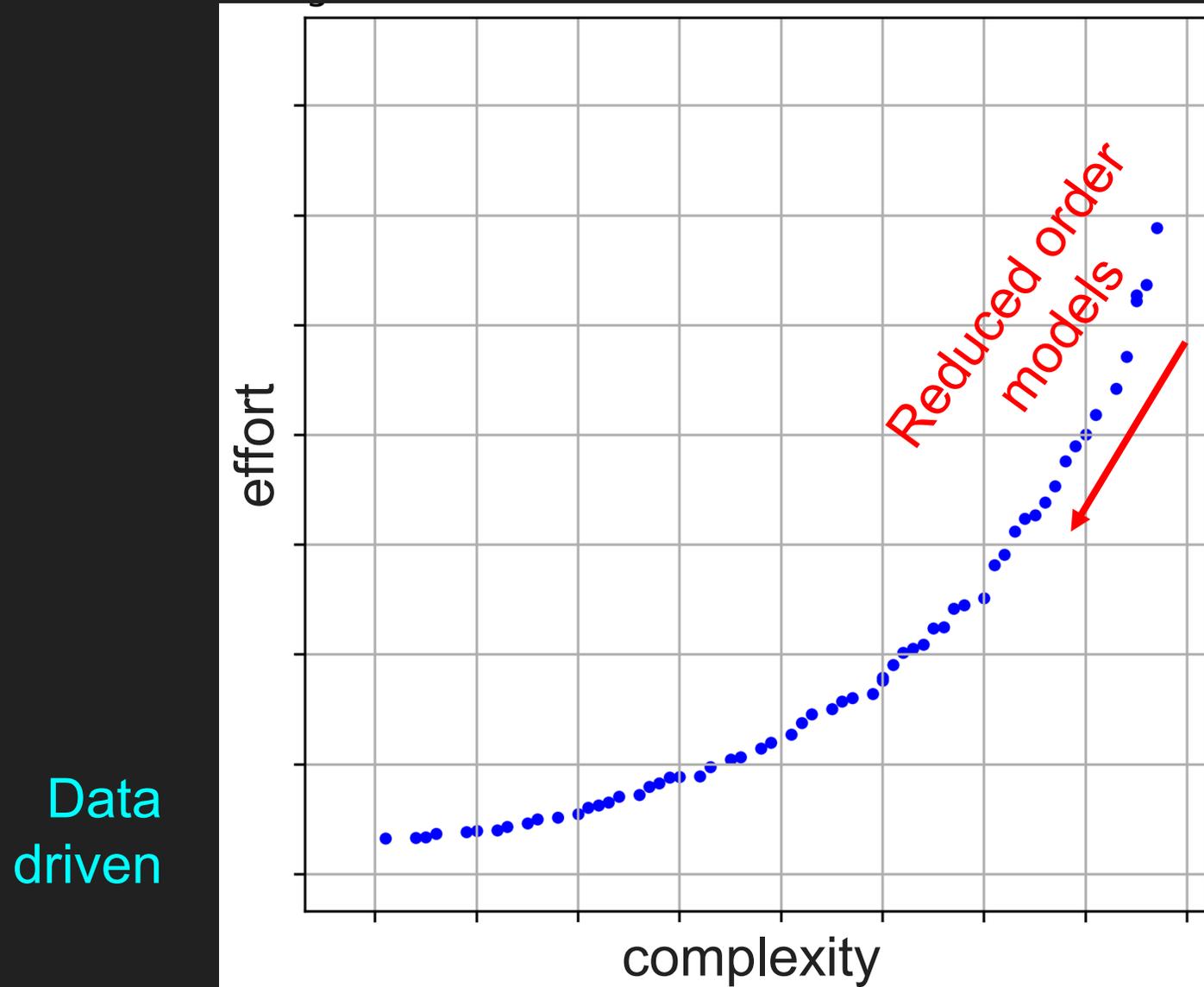
Predictions fully  
informed by  
available data

Data  
driven

# Trade-offs in environmental modeling



# Trade-offs in environmental modeling



Data driven

“Complete” physics

# Complex models

## Pros

- Easy to design
- Direct meaning for inputs
- **Optics**

## Cons

- Expensive to develop and update
- Computationally expensive
- Numerical instability



# Reduced order models

## Pros

- Cheap to develop and update
- Computationally efficient
- Numerically stable

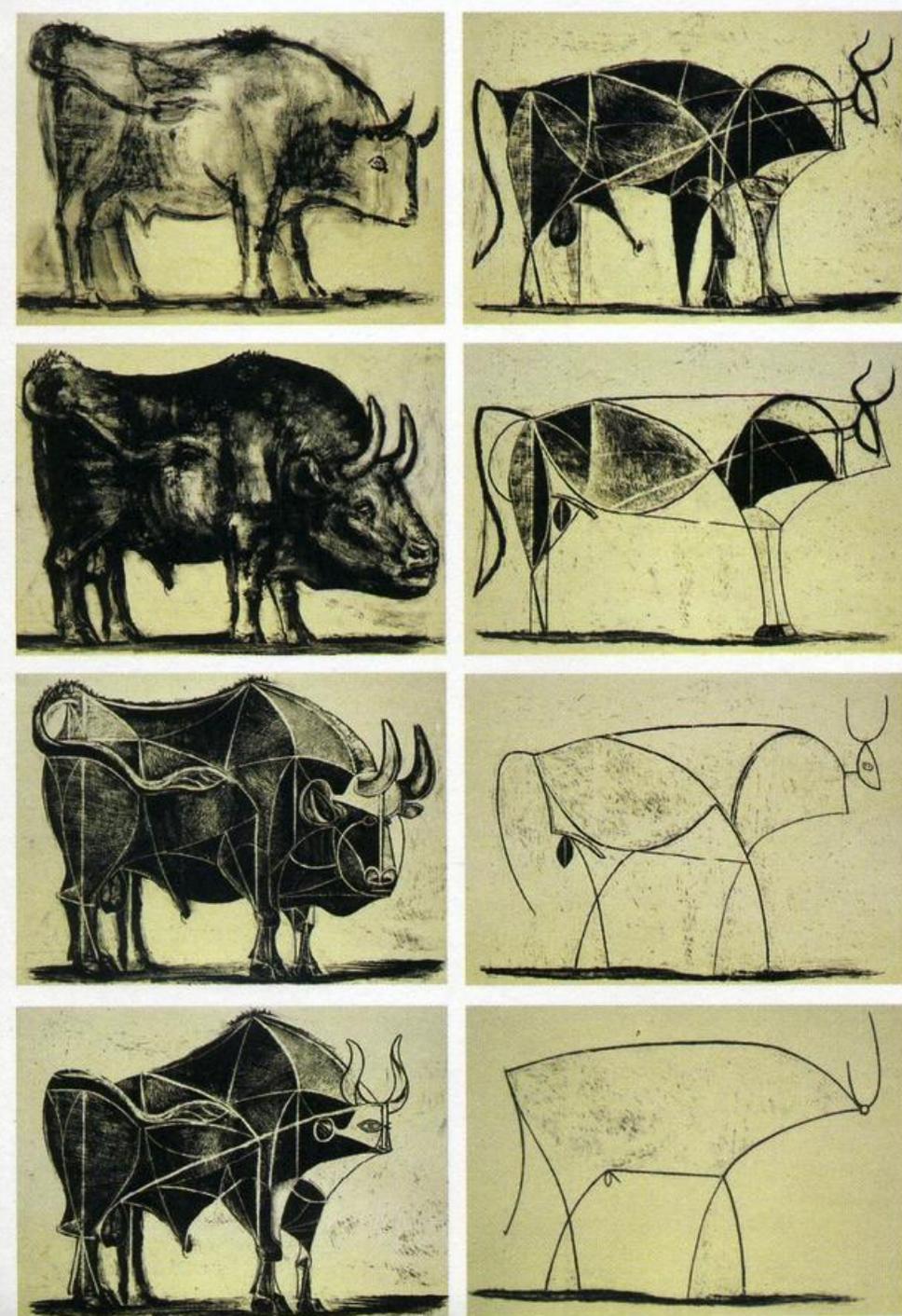
## Cons

- Can be hard to design
- “grey”/black box
- **Optics**



# Reduced order models

- **Reduce** the process complexity
  - SFR to RIV
  - MAW to WEL
- **Reduce** the resolution
  - Daily to Seasonal
  - 50m grid to 1km grid ;)
- **Reduce** the dimensions
  - Transient to steady-state
  - 3-D to 2-D (or 1D!)



# A concrete example

- Central valley, subsidence, blahblahblah
- Several existing groundwater models
  - **Most are (very) complex IMO**
- Generally:
  - Large spatial extent
  - 3-D (heaps of layers!)
  - Transient
  - Advanced processes/physics
  - **In development for years**



# Subsidence Data and Decision Making

**What matters for decision making and resource mgmt?**

# Subsidence Data and Decision Making

## What matters for decision making and resource mgmt?

- **Current critical level**
  - Present day GW level where (inelastic) subsidence will resume
  - Current “freeboard” above critical level

# Subsidence Data and Decision Making

## What matters for decision making and resource mgmt?

- **Current critical level**
  - Present day GW level where (inelastic) subsidence will resume
  - Current “freeboard” above critical level
- **Interbed properties** (kv, storage)
  - Temporal compaction response to changes in critical level
  - Any delayed compaction in the near term

# Subsidence Data and Decision Making

**What matters for decision making and resource mgmt?**

Current critical level, Interbed properties

“Current” implies the most recent observations are more important

Interbed properties cannot be measured - they must be learned

# Reduced-order Subsidence modeling

- Key: use observed GW levels as inputs

# Reduced-order Subsidence modeling

- Key: use observed GW levels as inputs

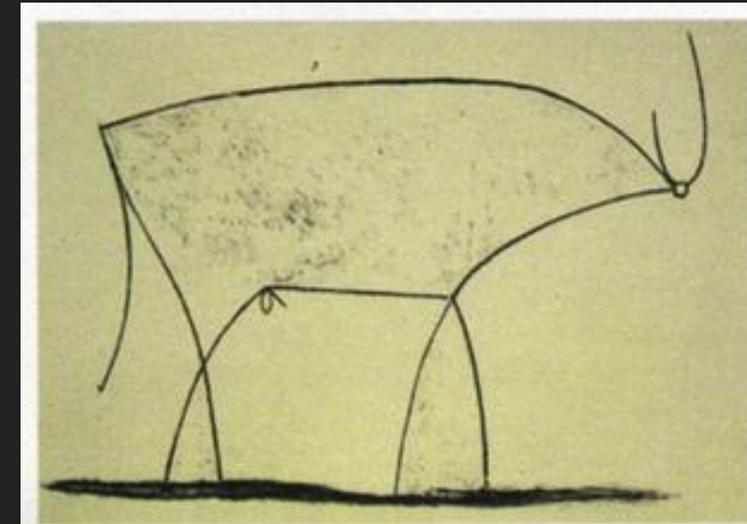
complexity



modeler

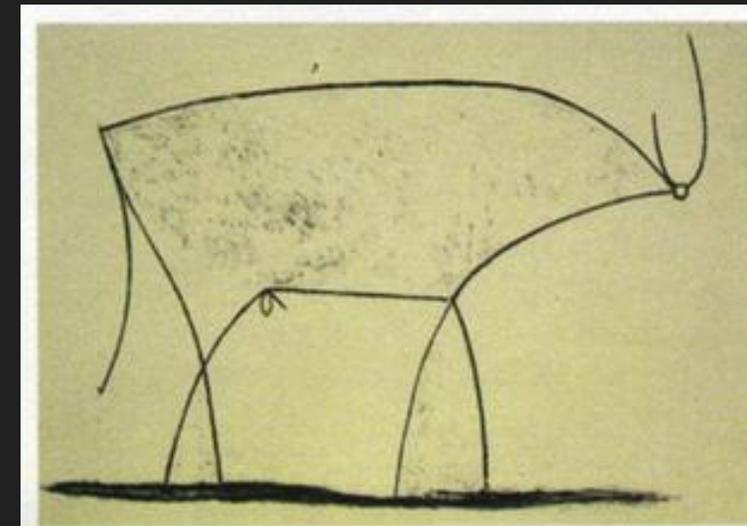
# Reduced-order Subsidence modeling

- **Key: use observed GW levels as inputs**
- 1D vertical column models
  - It's been done before!
- MF6 + CSUB (Hughes and others, 2022)
- 2 to 5 computational layers
- **Full period of record**
- Clay thickness characteristics from lith logs
- Effective stress formulation
- Delay formulation



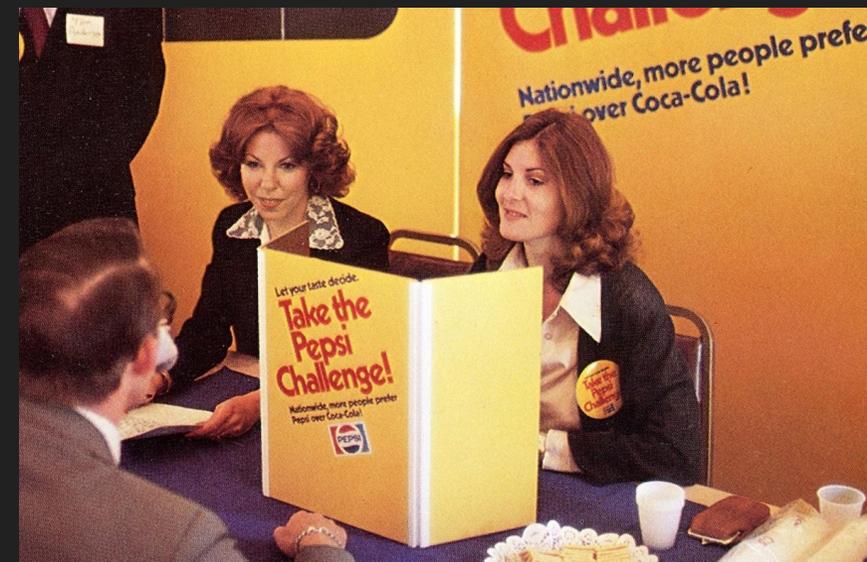
# Reduced-order Subsidence modeling

- Ensemble methods for history matching
  - **We need to learn from data**
  - Estimating all unknowns (more on this later)
- Fully automated process
- Zero to hero : 30mins on a laptop
- Scenarios in terms of GW levels
  - not water use and/or climate

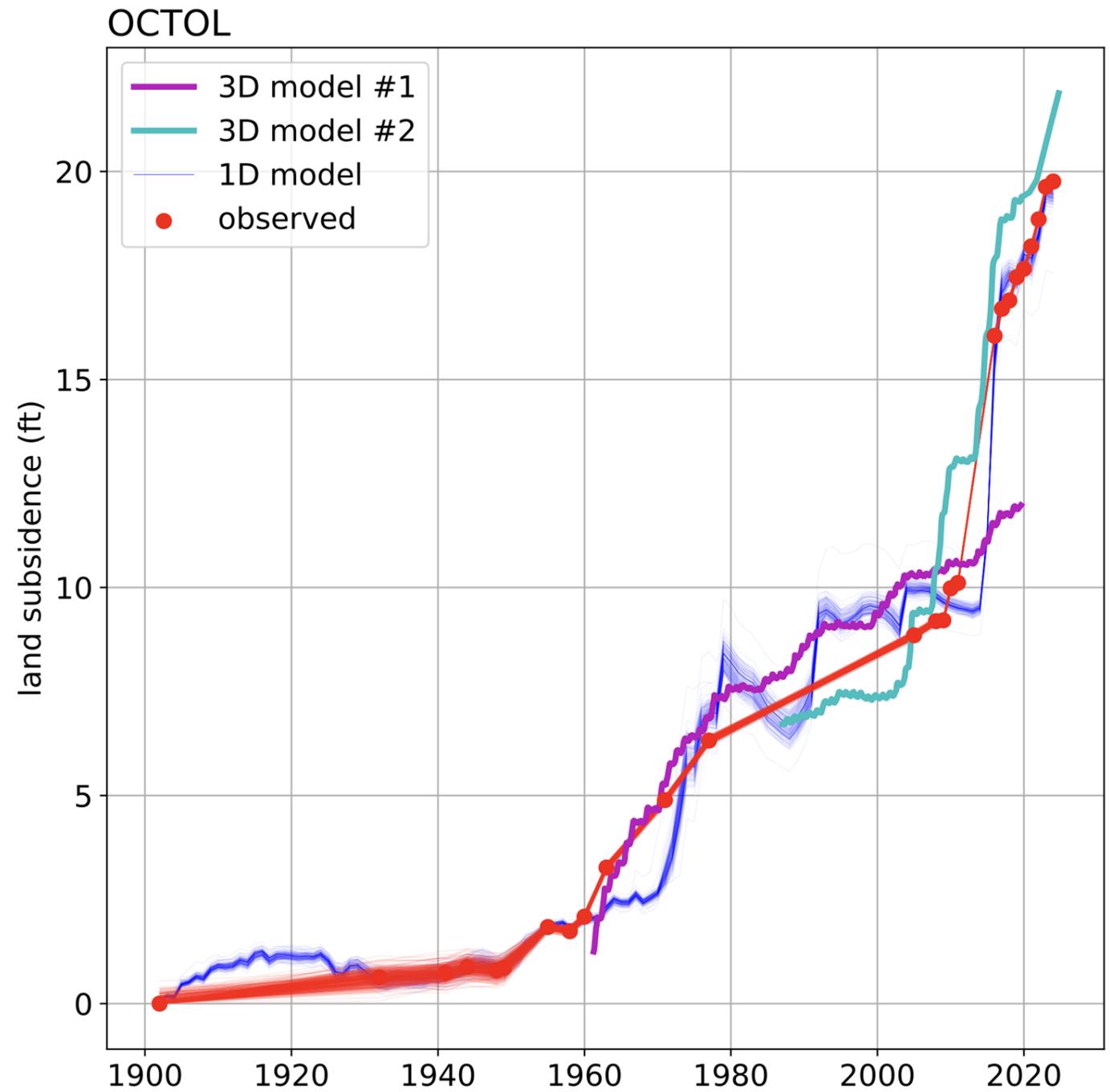


# “The 3-D model is really good..RMSE! RMSE!”

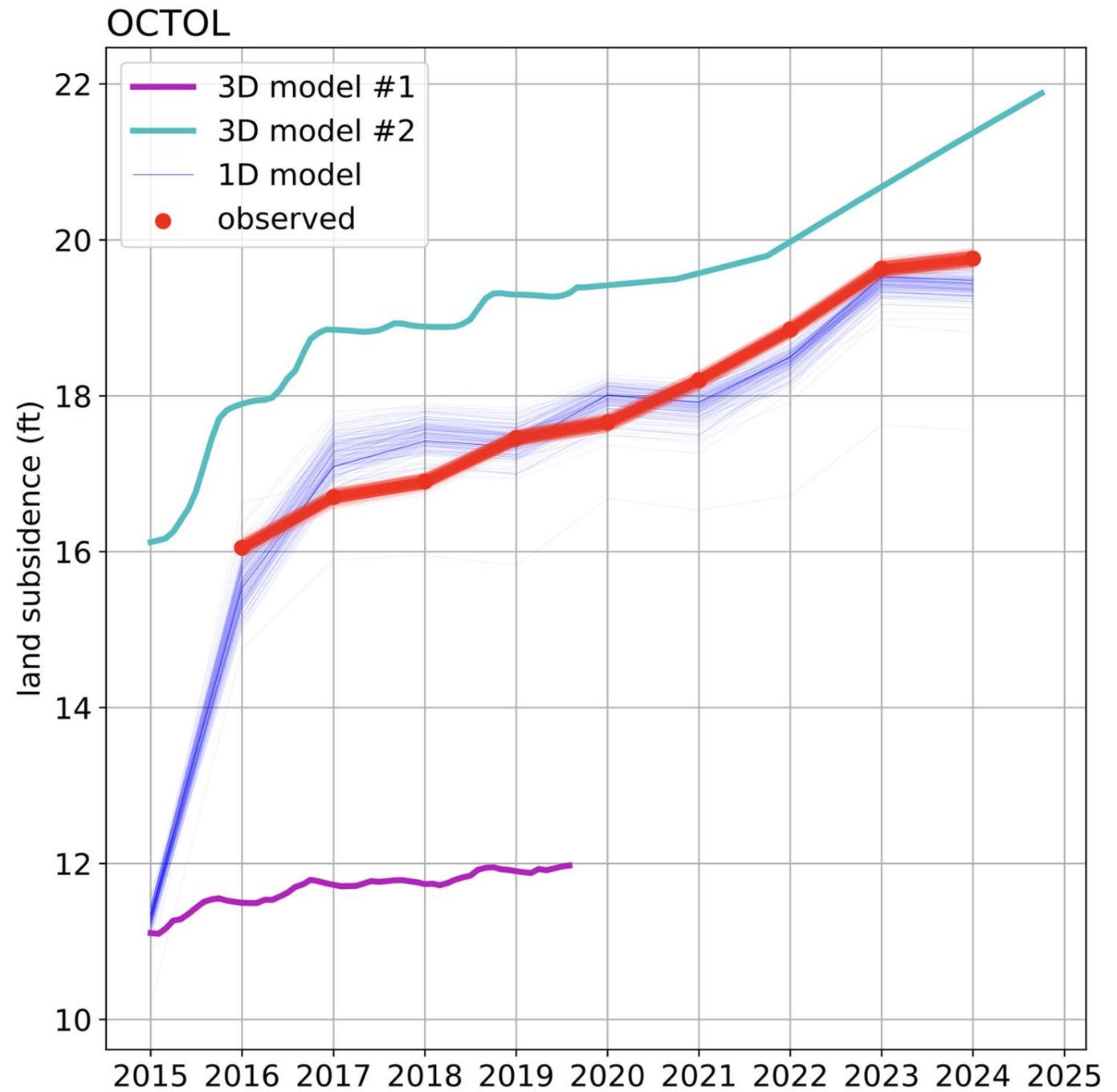
- Let's have a go with two unnamed 3D models
- 3-D model #1: regional scale
- 3-D model #2: 1 sub-regional scale
- One caveat: the 3-D models don't cover the full historic period
- ...Anchored them to the nearest 1-D simulated value



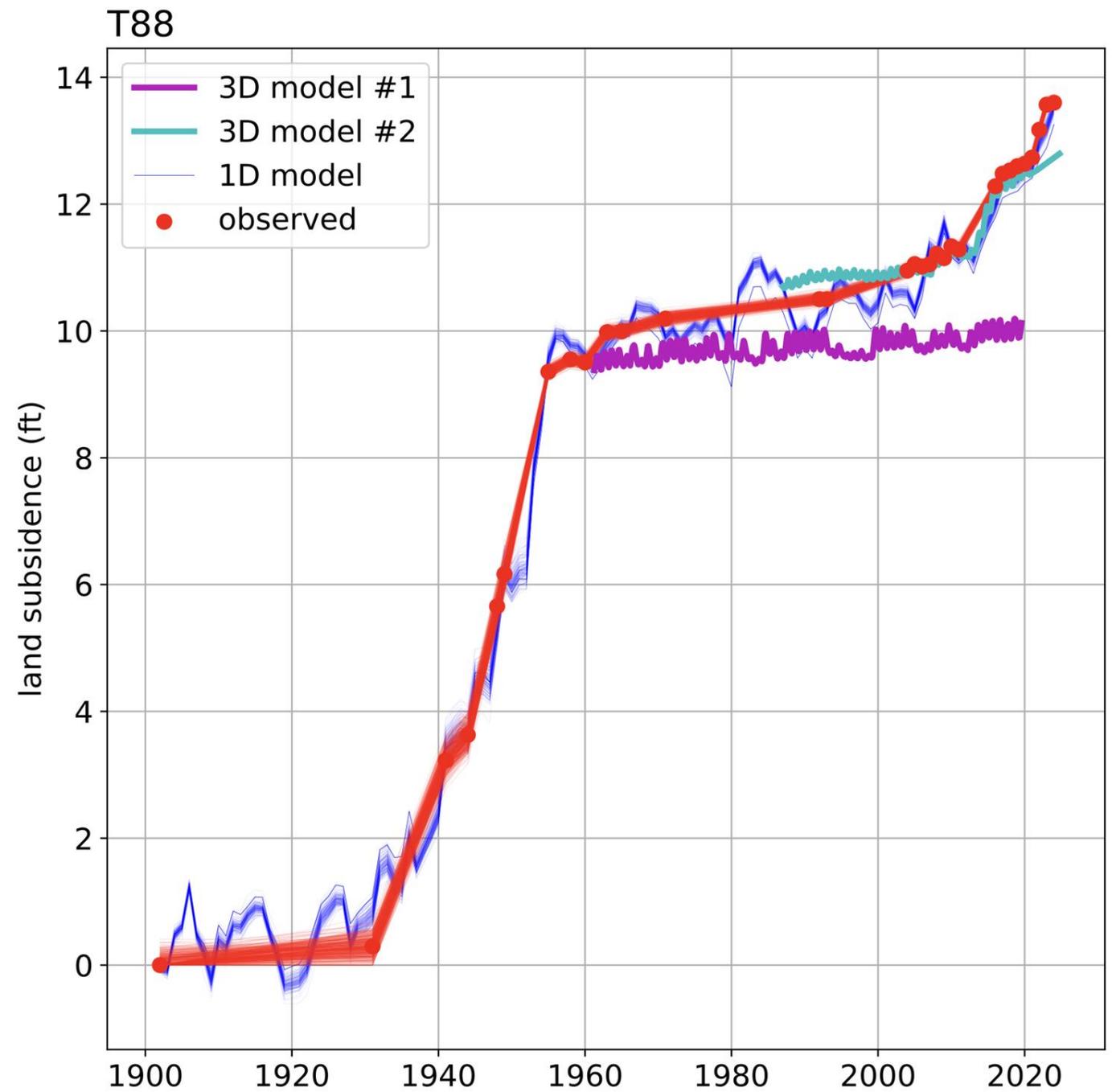
# Pepsi challenge site #1



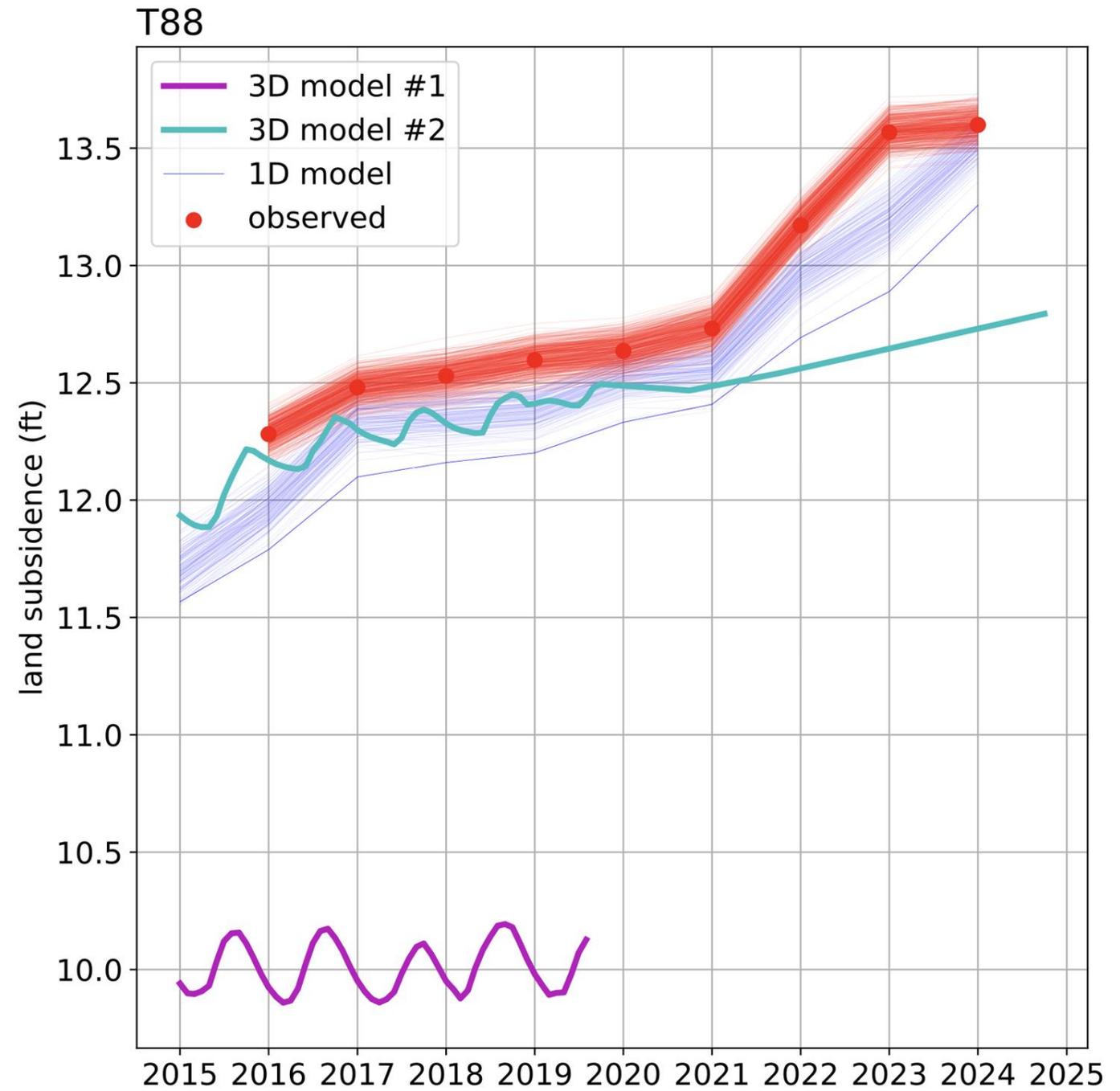
# Pepsi challenge site #1



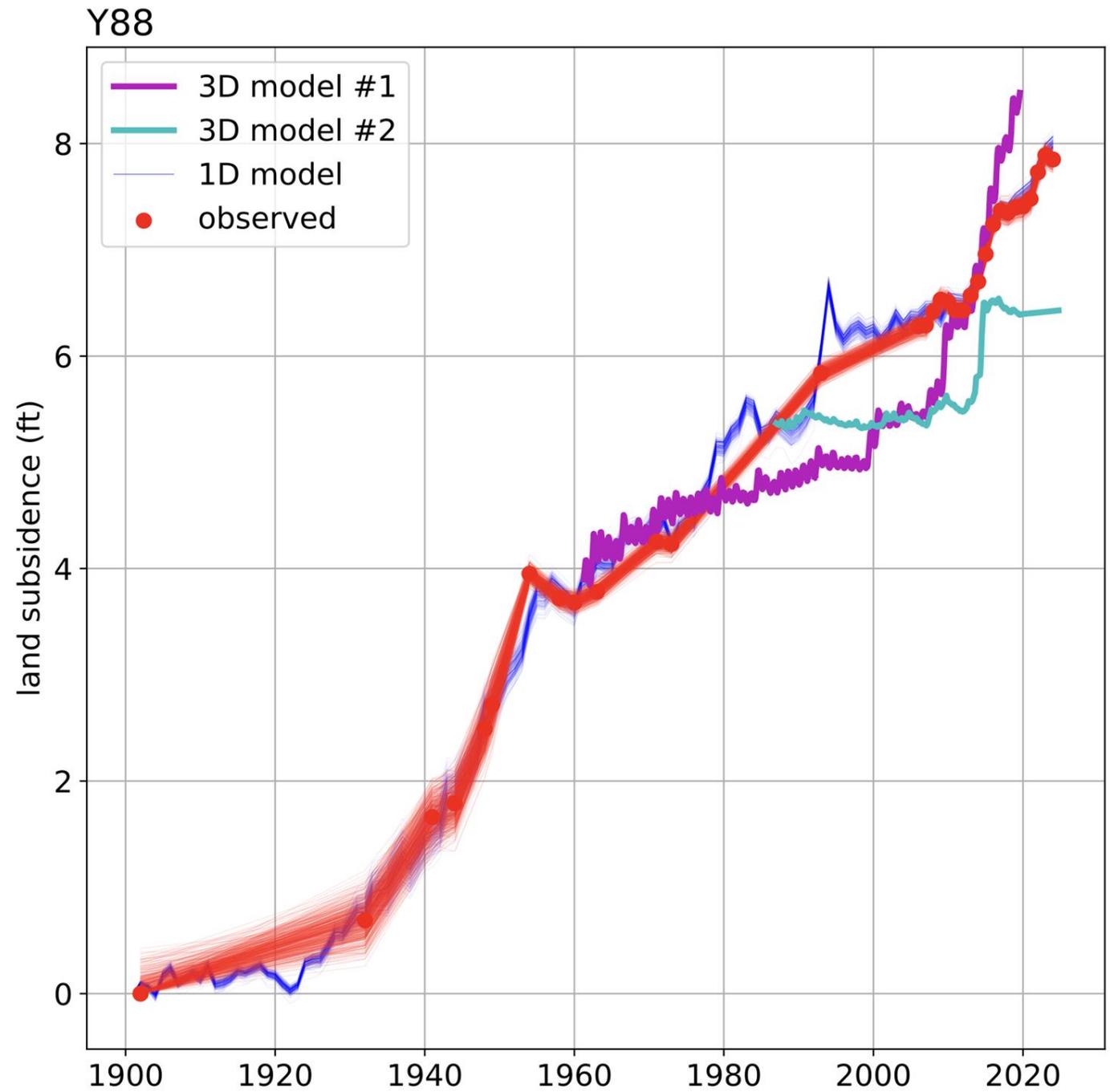
# Pepsi challenge site #2



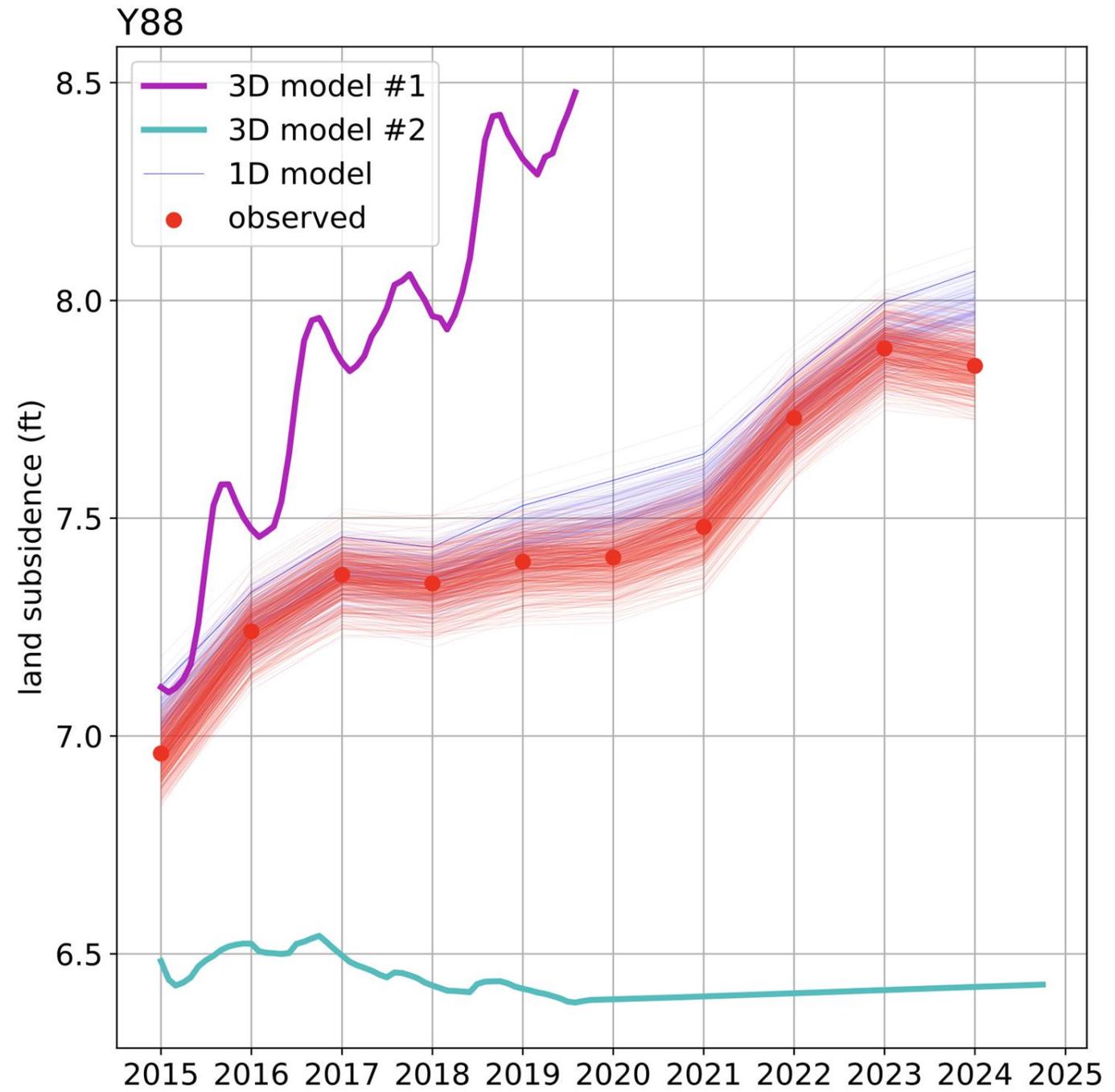
# Pepsi challenge site #2



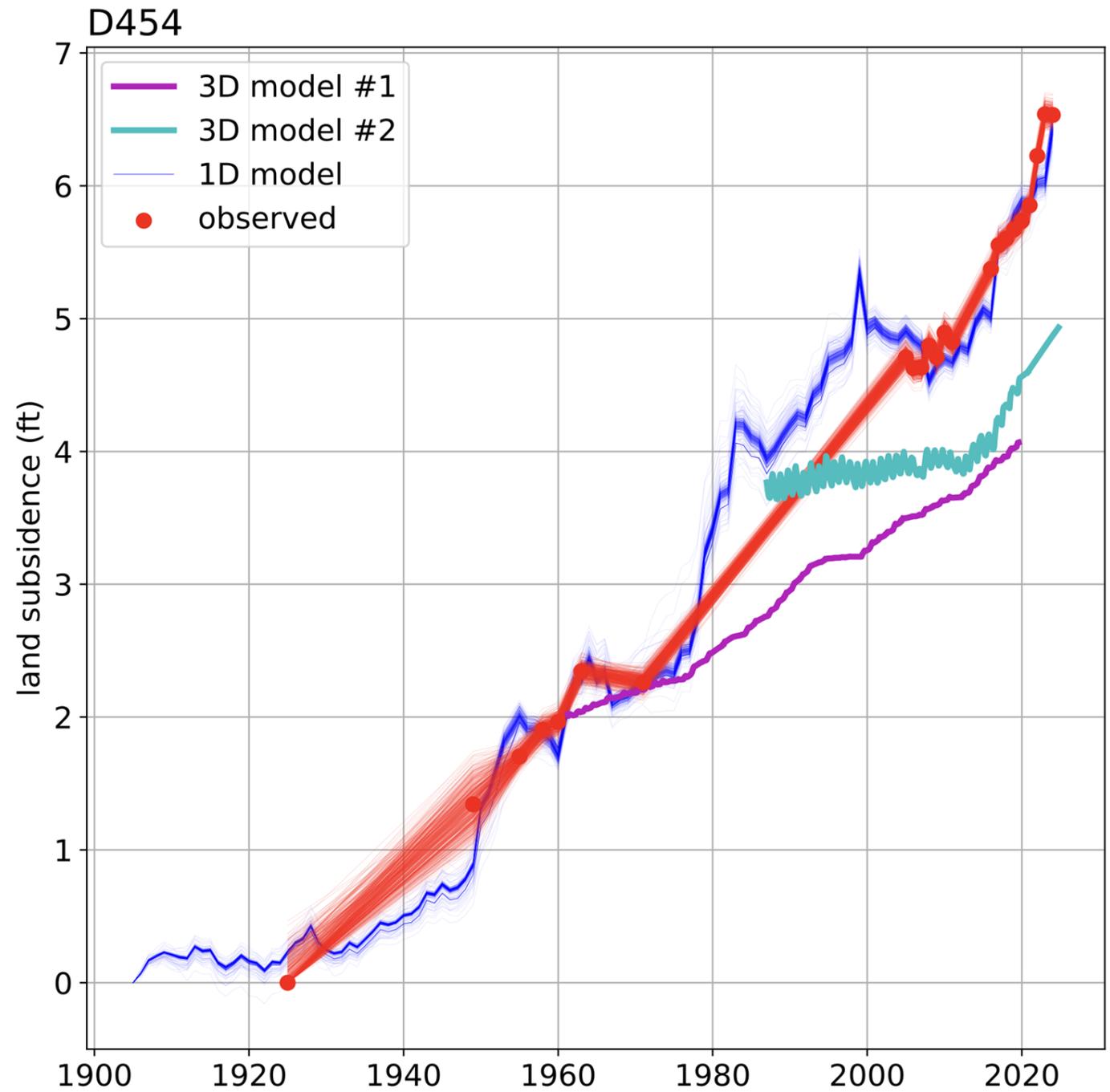
# Pepsi challenge site #3



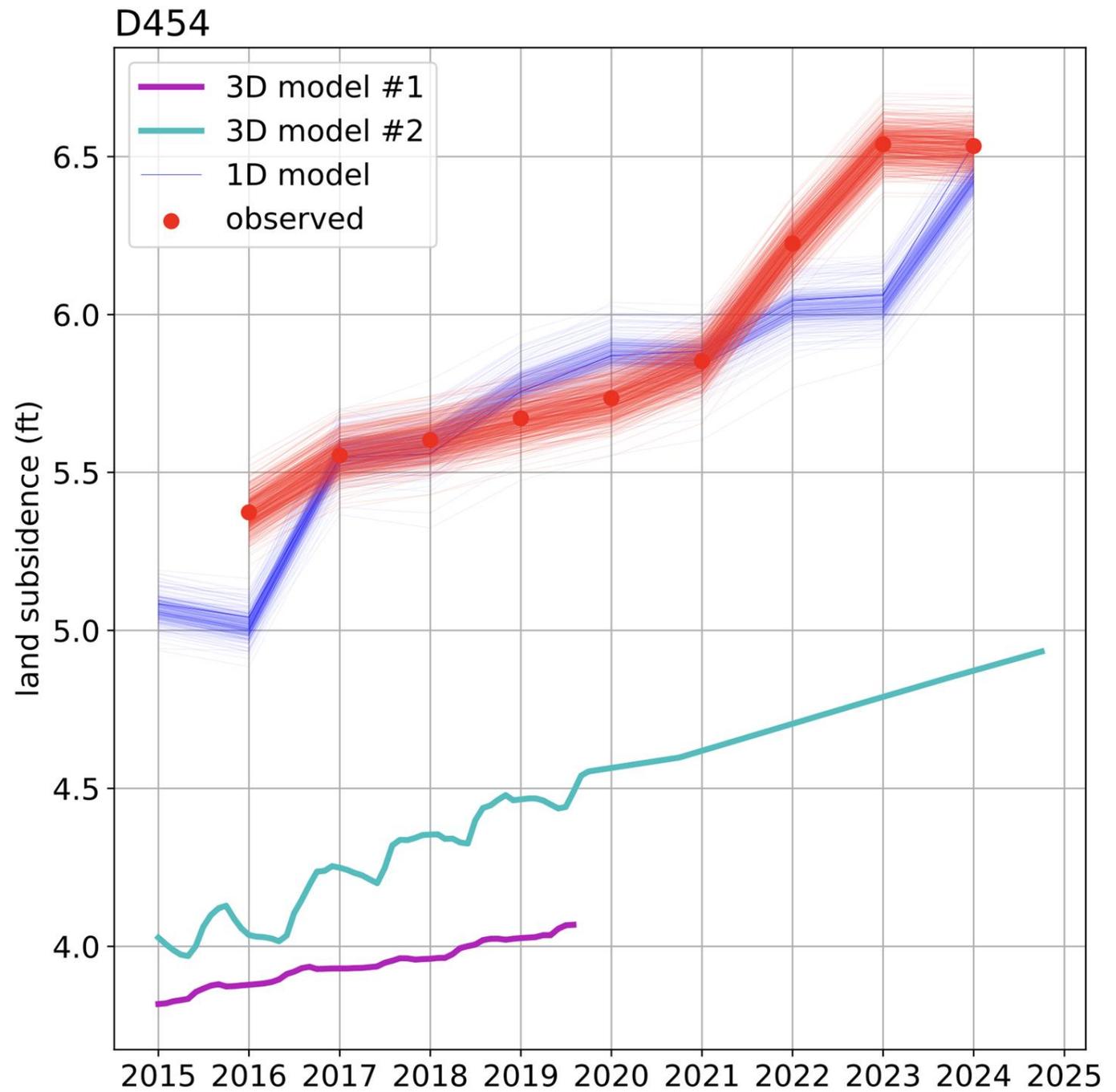
# Pepsi challenge site #3



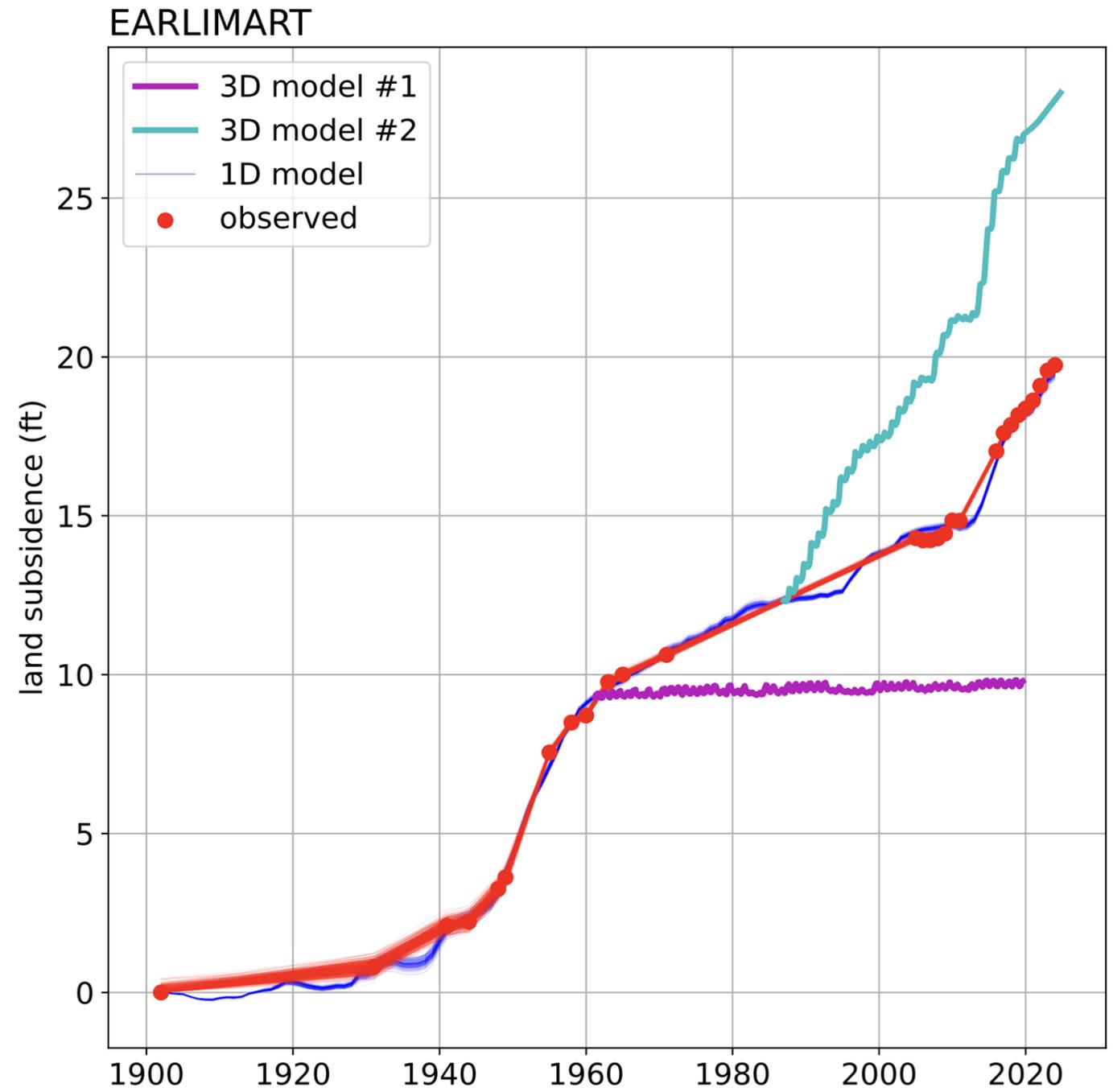
# Pepsi challenge site #4



# Pepsi challenge site #4



# Pepsi challenge site #5



# An aside on parameterization

- The 1-D models have between 2-5 active cells
  - 2-5 layers
- The 3-D models have 1e5 to 1e6+ active cells
  - 8+ layers
- The 1-D models used more parameters for history matching than either of the 3-D regional models.

Effectively learning from data starts with expressing what you don't know...

...And parameters provide that opportunity

# Play to your strengths

## Complex model pros

- Easy to design
- Direct meaning for inputs
- **Optics**

## Reduced-order model pros

- Cheap to develop and update
- Computationally efficient
- Numerically stable

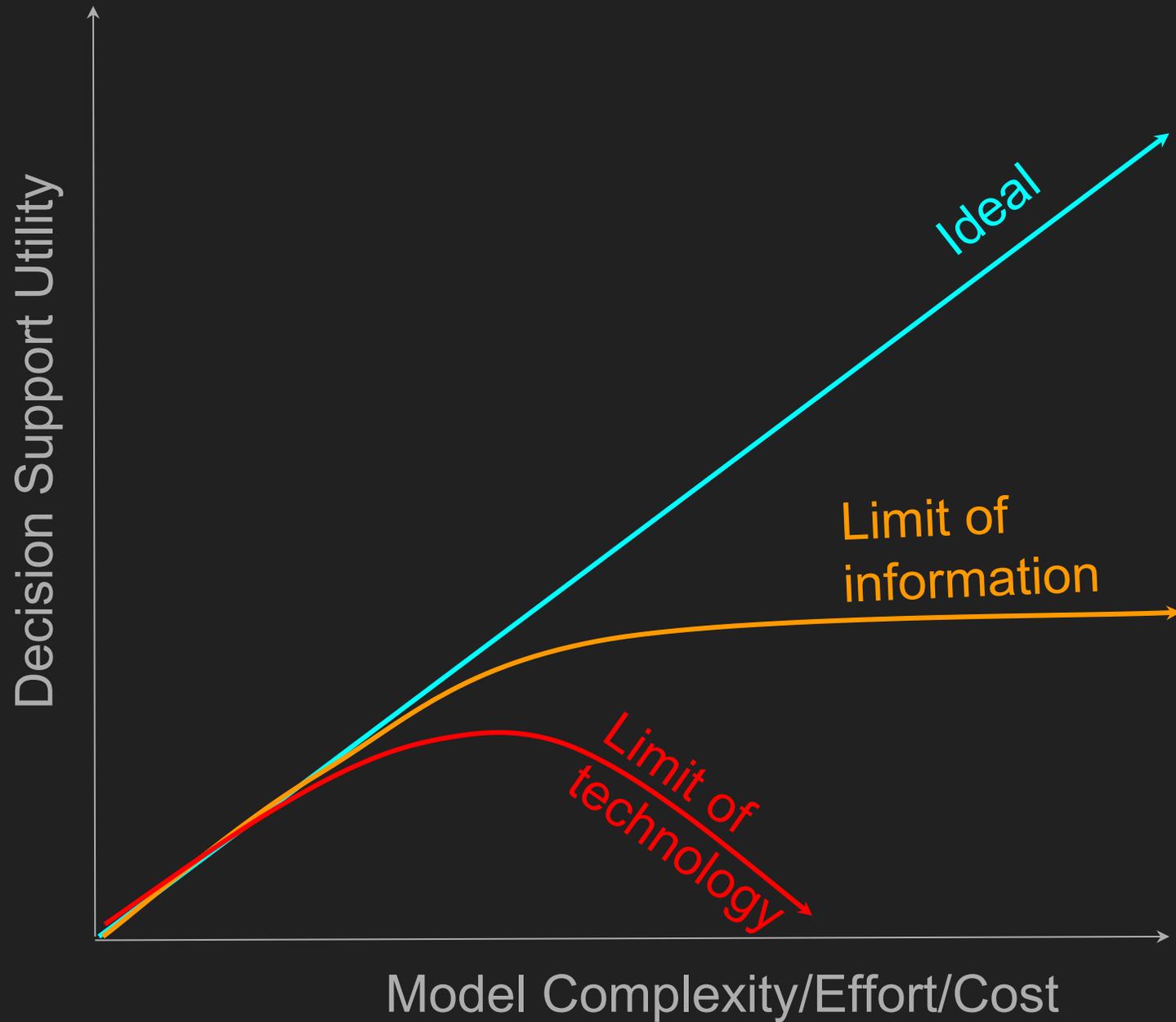
# Closing remarks

- Regional complex 3-D models: Jack of all trades...master of none
- Reduce order 1-D subsidence modeling: only one purpose
- **Optics**

complexity



modeler



what is the best way to improve a groundwater model?



All Images Videos News Maps Shopping

Assist

Chat



Always private

US (English)

Safe search: moderate

Any time

Assist



The best way to improve a groundwater model is to conduct uncertainty analysis, which helps identify and adjust the parameters that influence model outcomes, ensuring more accurate predictions. Additionally, incorporating high-quality data and continuously testing assumptions can enhance the model's reliability and performance.

westyost.com

Science Friday

Auto-generated based on listed sources. May contain inaccuracies.

Ask a follow-up question

Chat

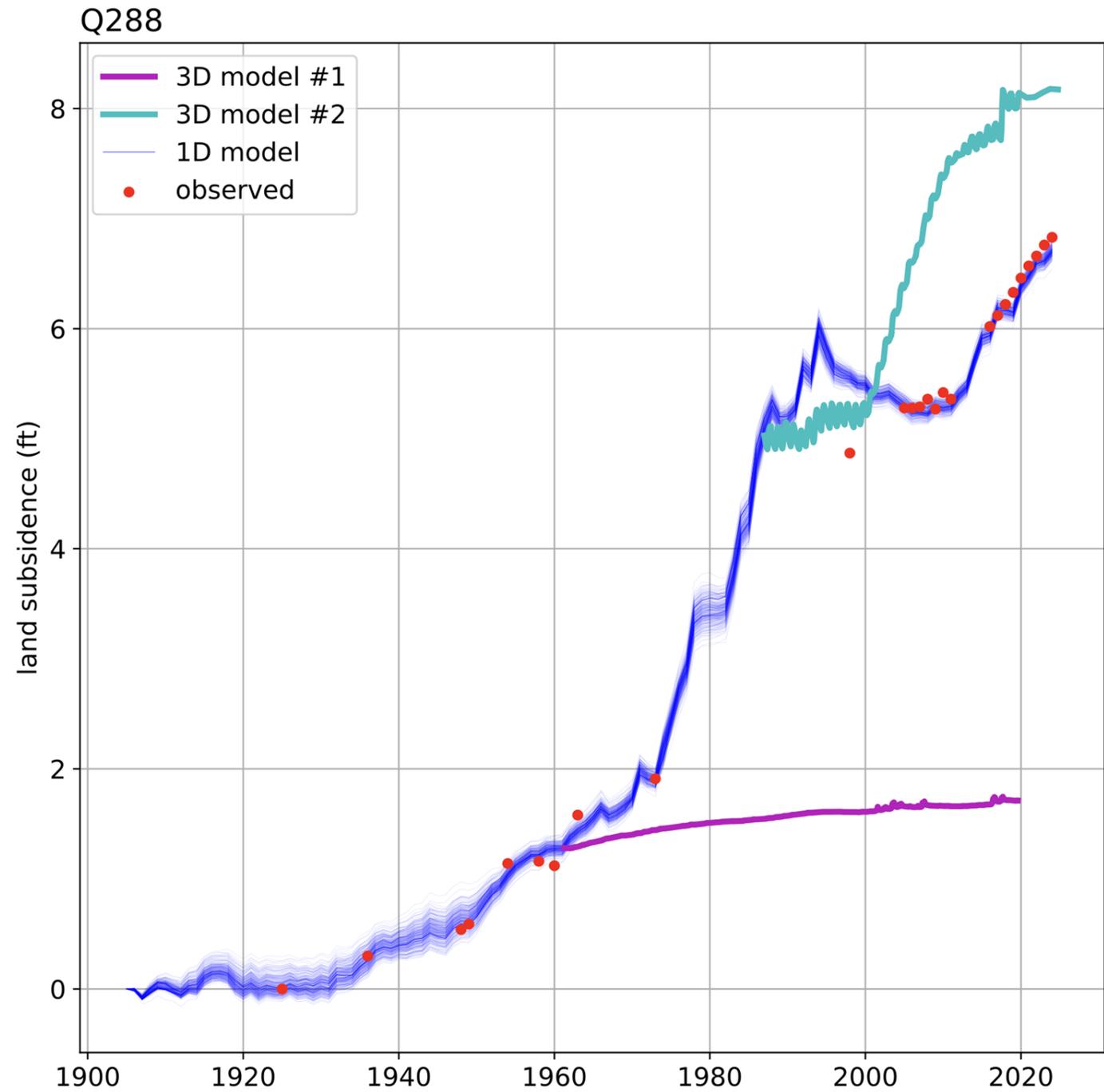
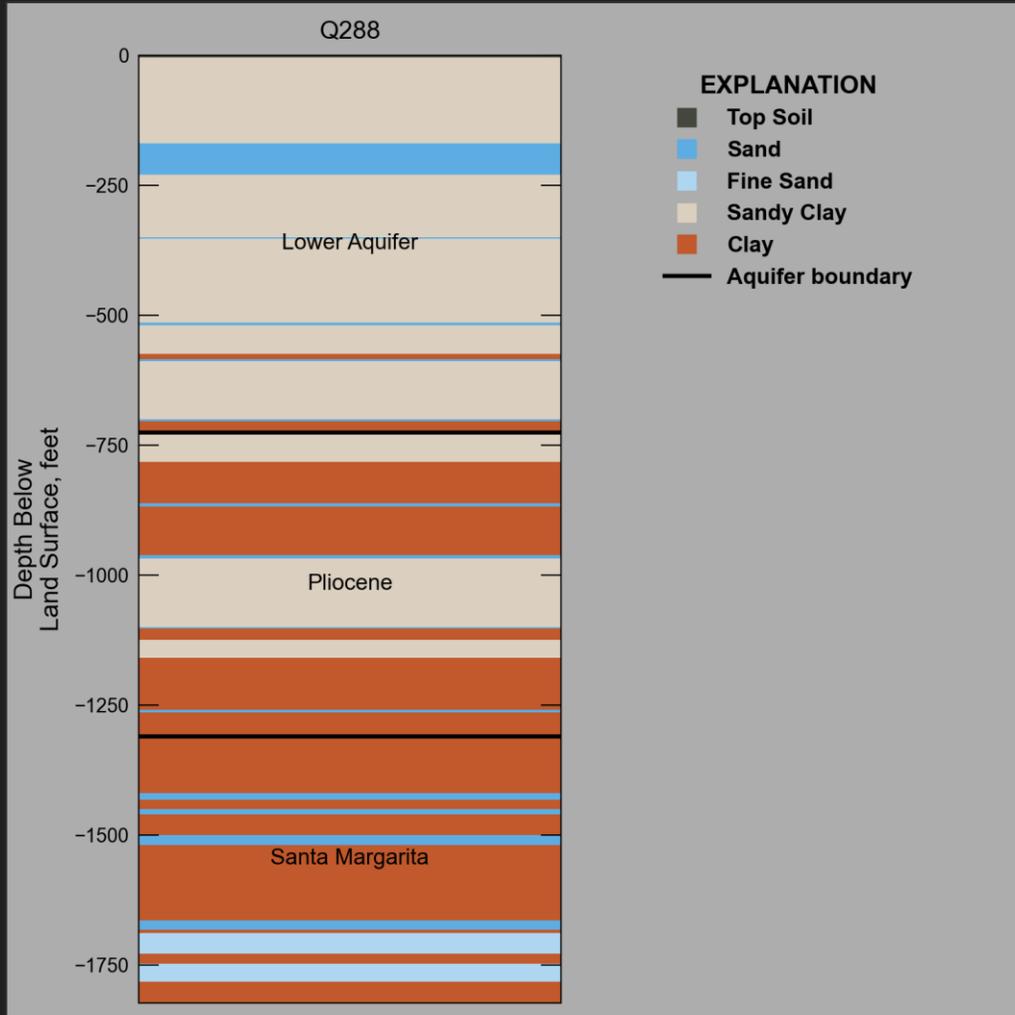
Was this helpful?

# Reduced-order Subsidence modeling

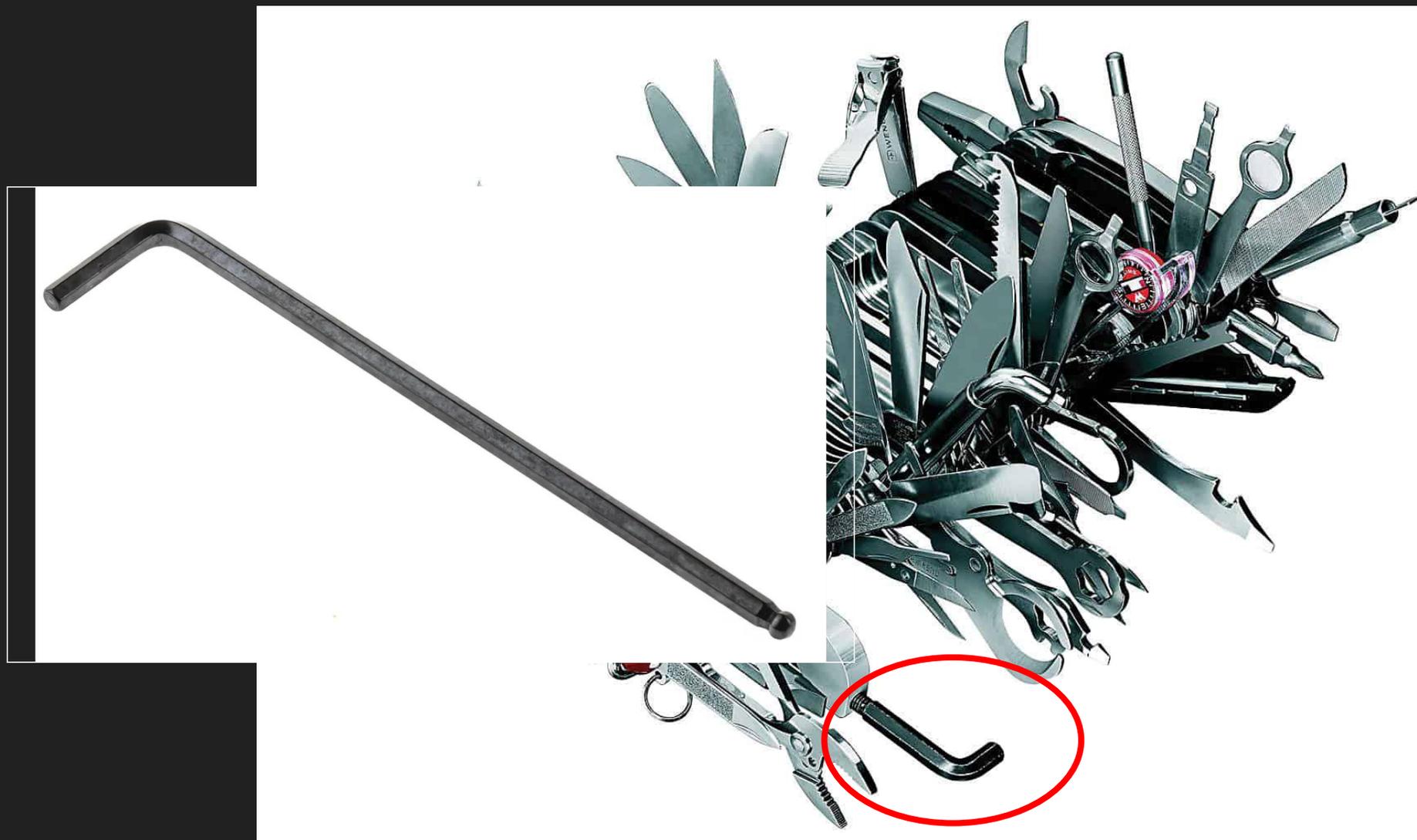
- Key: use observed GW levels as inputs



# Pepsi challenge site #5

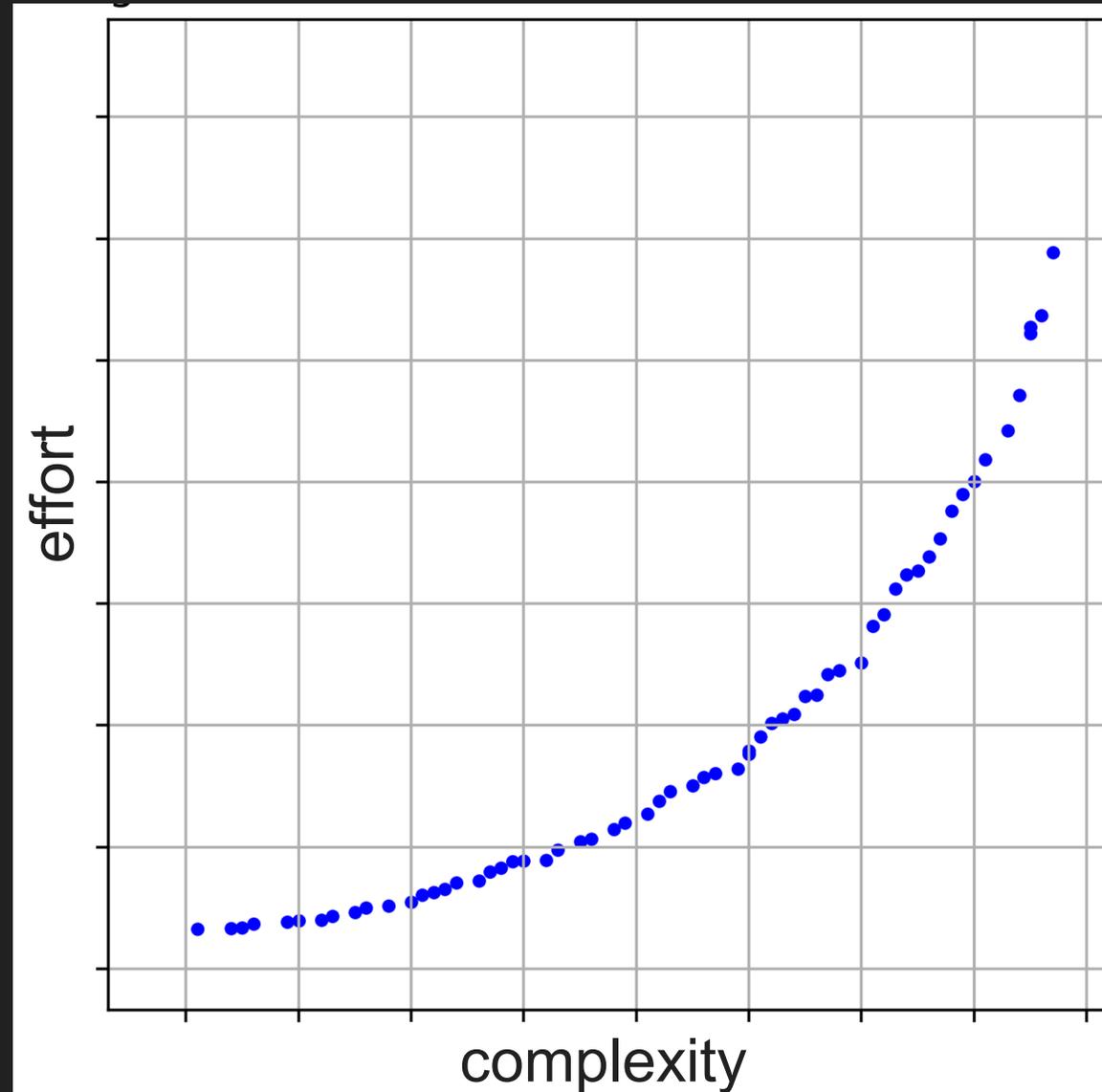


What do you really need?!



# Trade-offs in GW modeling

- Tradeoff shape depends on:
  - Hydrogeo Setting
  - Predictions of interest
  - Available data
  - etc...



“You’re cheating! The 3-D model wasn’t calibrated to all of those data!”

- First: Correct
- Second: Can regional-scale models effectively assimilate local-scale data?
- ...to the level that is needed for certain types of predictions?



# IMO...central valley 3-D models...

Represent major processes at a large spatial scale

- Groundwater flow
- Groundwater use
- Recharge and ET
- Surface-water flow and routing
- Surface-water/groundwater interaction
- Demand driven/Conjunctive use
- Agricultural practices/processes
- ...
- ...
- ...



# IMO...central valley 3-D models...

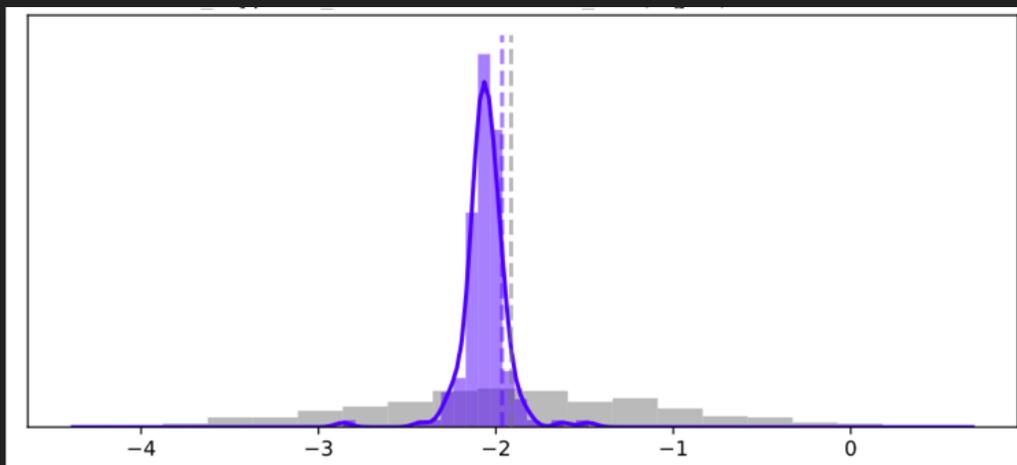
Represent major processes at a large spatial scale

- Groundwater flow
- Groundwater use
- Recharge and ET
- Surface-water flow and routing
- Surface-water/groundwater interaction
- Demand driven/Conjunctive use
- Agricultural practices/processes
- ...
- ...
- ...
- **Subsidence**

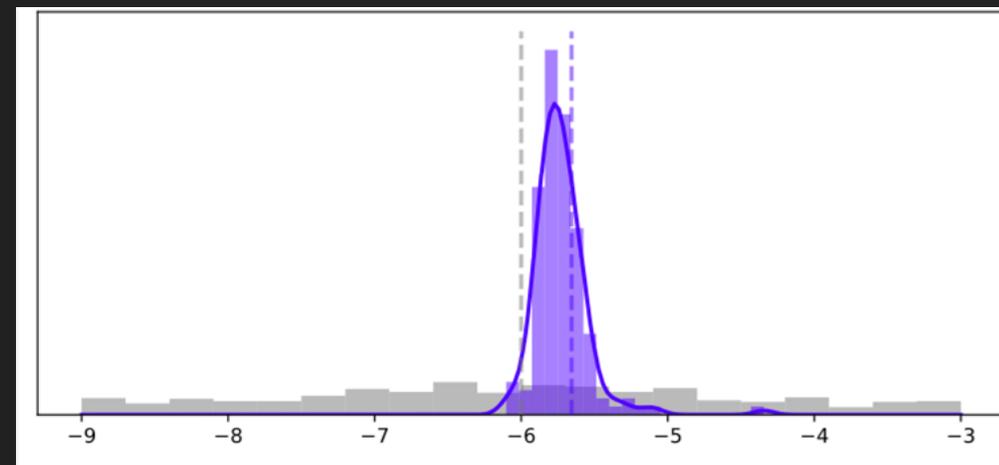


# A deeper dive: OCTOL

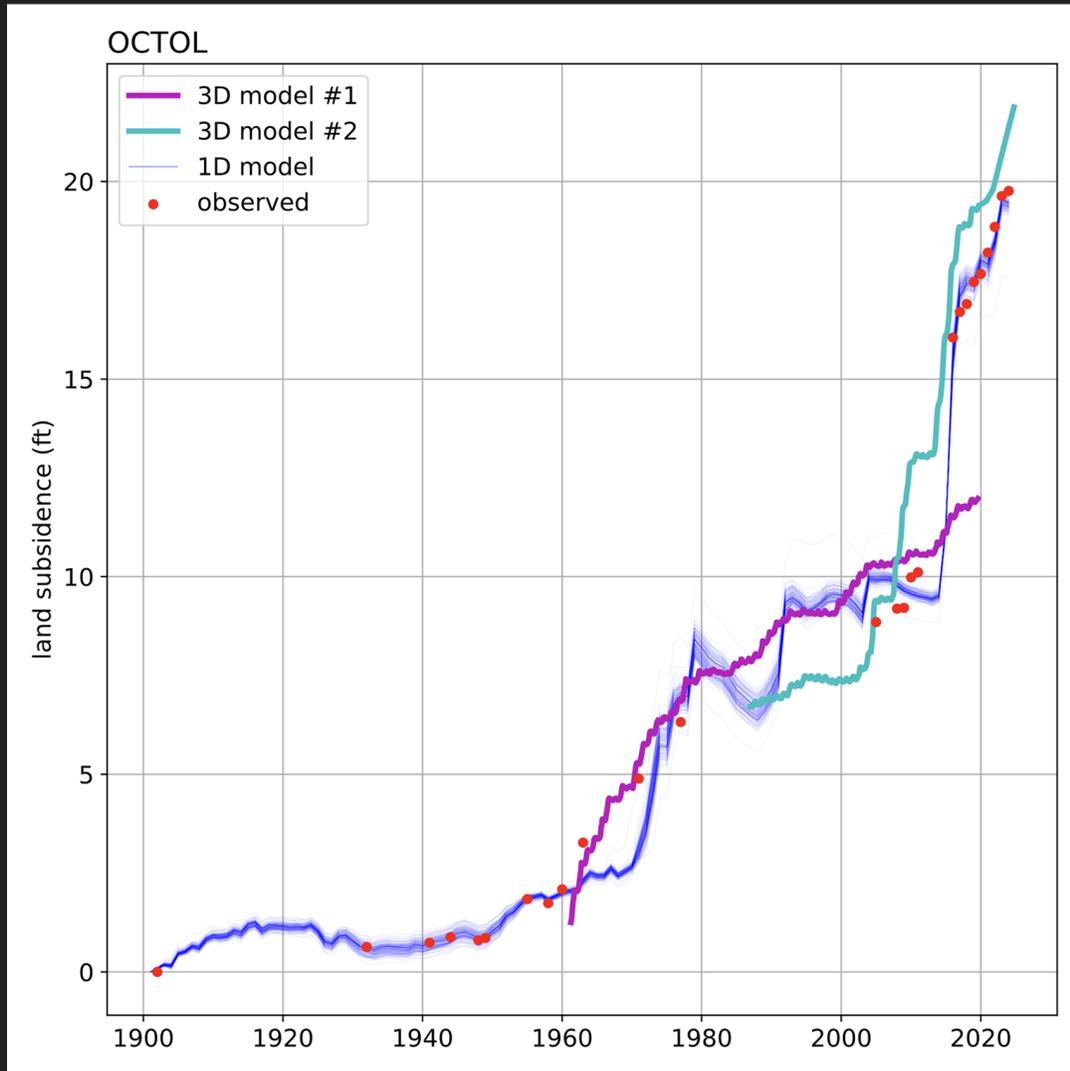
$\text{Log}_{10}$  interbed SSE/SSV



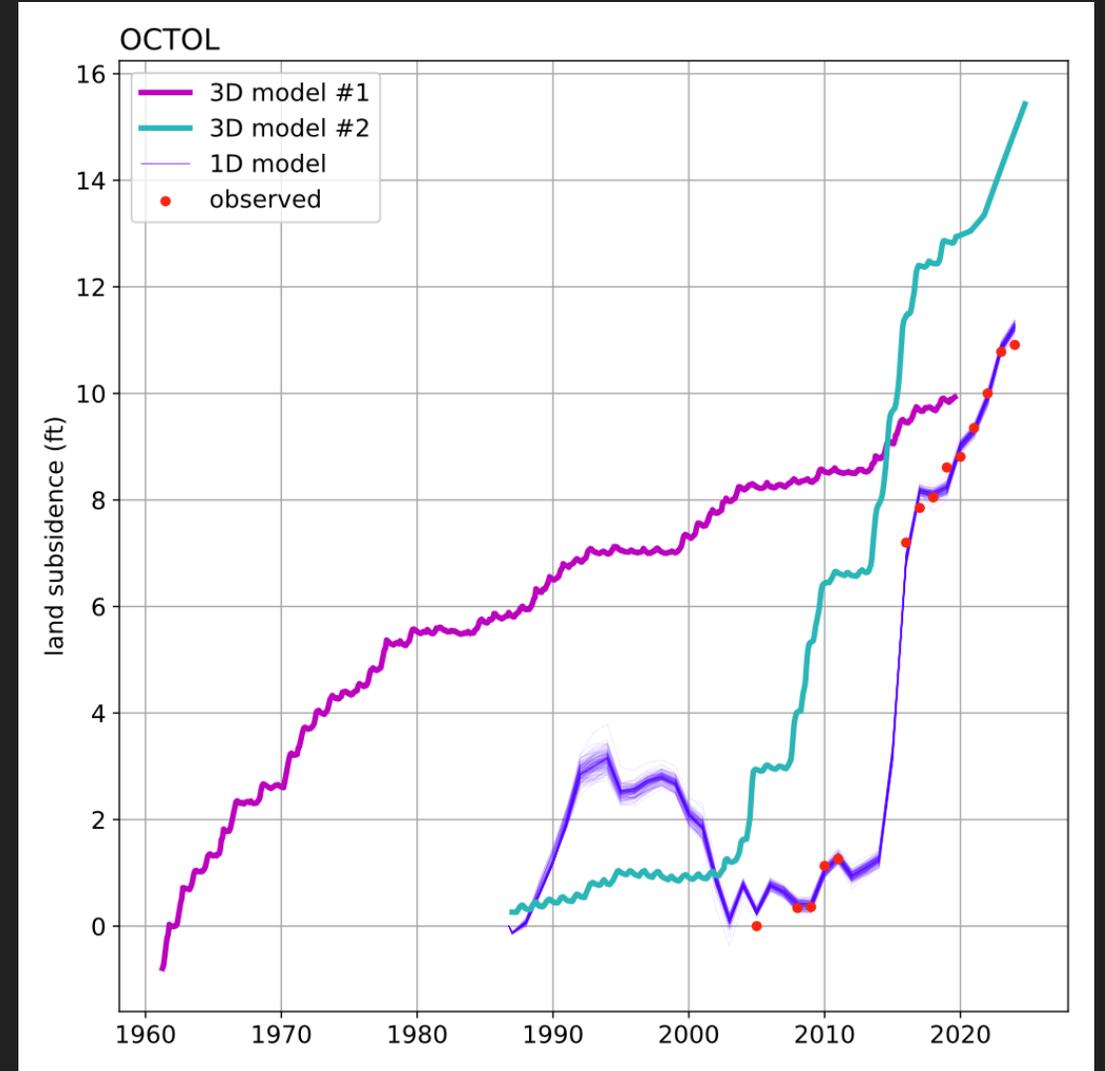
$\text{Log}_{10}$  interbed KV



# Full historic period



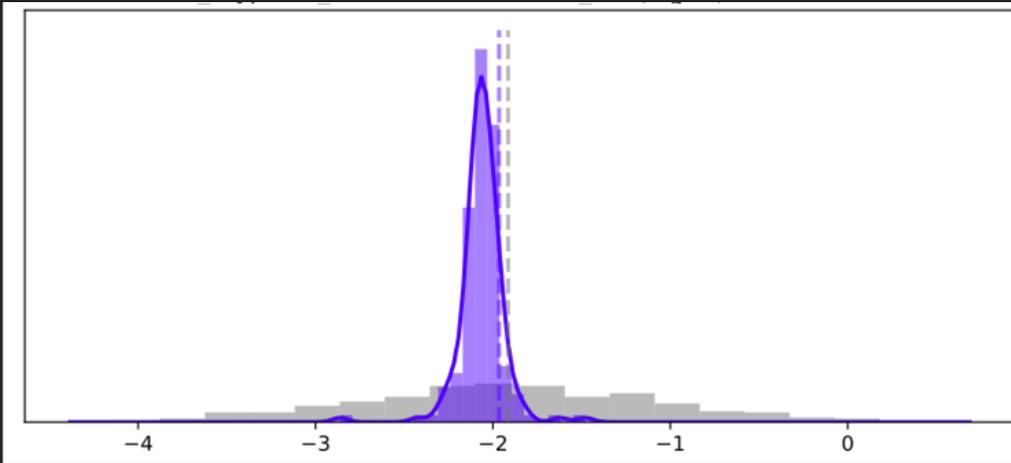
# 1986 to present



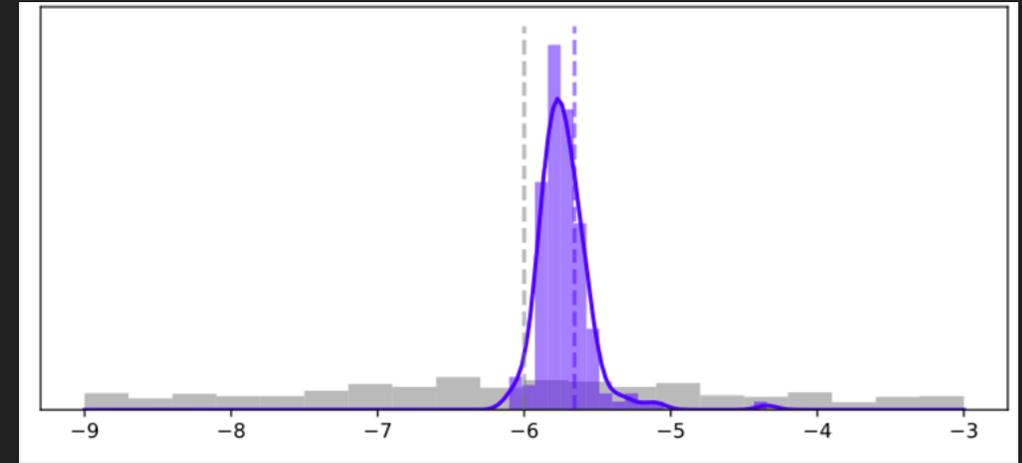
# A deeper dive: OCTOL

Full historic period

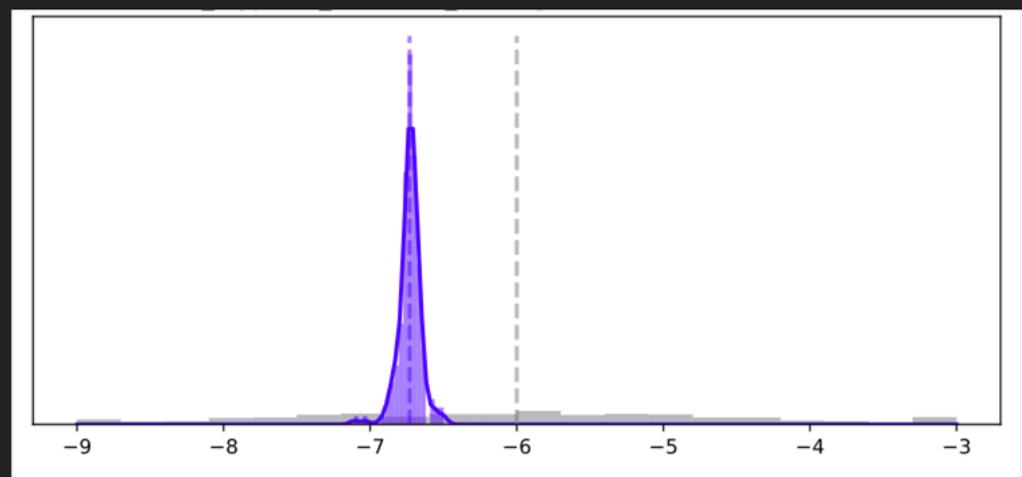
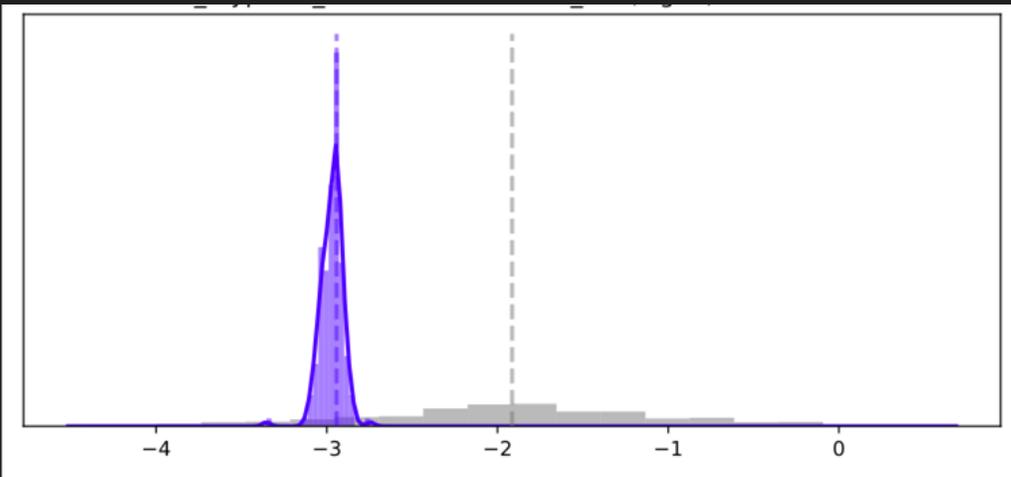
$\text{Log}_{10}$  interbed SSE/SSV



$\text{Log}_{10}$  interbed KV



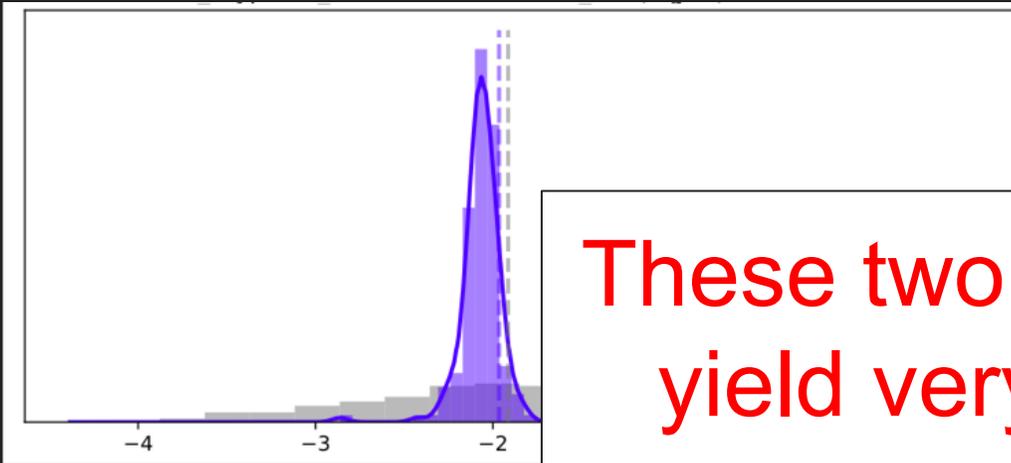
1986 to present



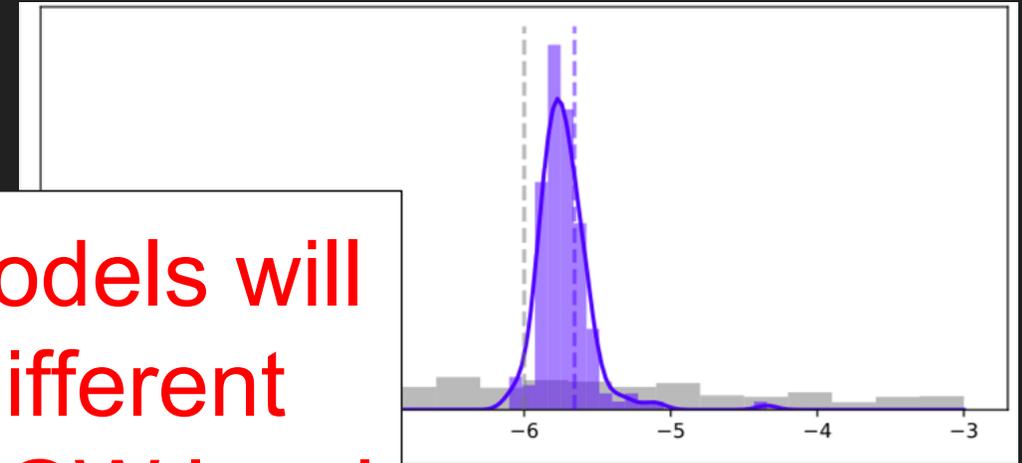
# A deeper dive: OCTOL

Full historic period

Log<sub>10</sub> interbed SSE/SSV



Log<sub>10</sub> interbed KV



These two models will yield very different responses to GW level changes

1986 to present

