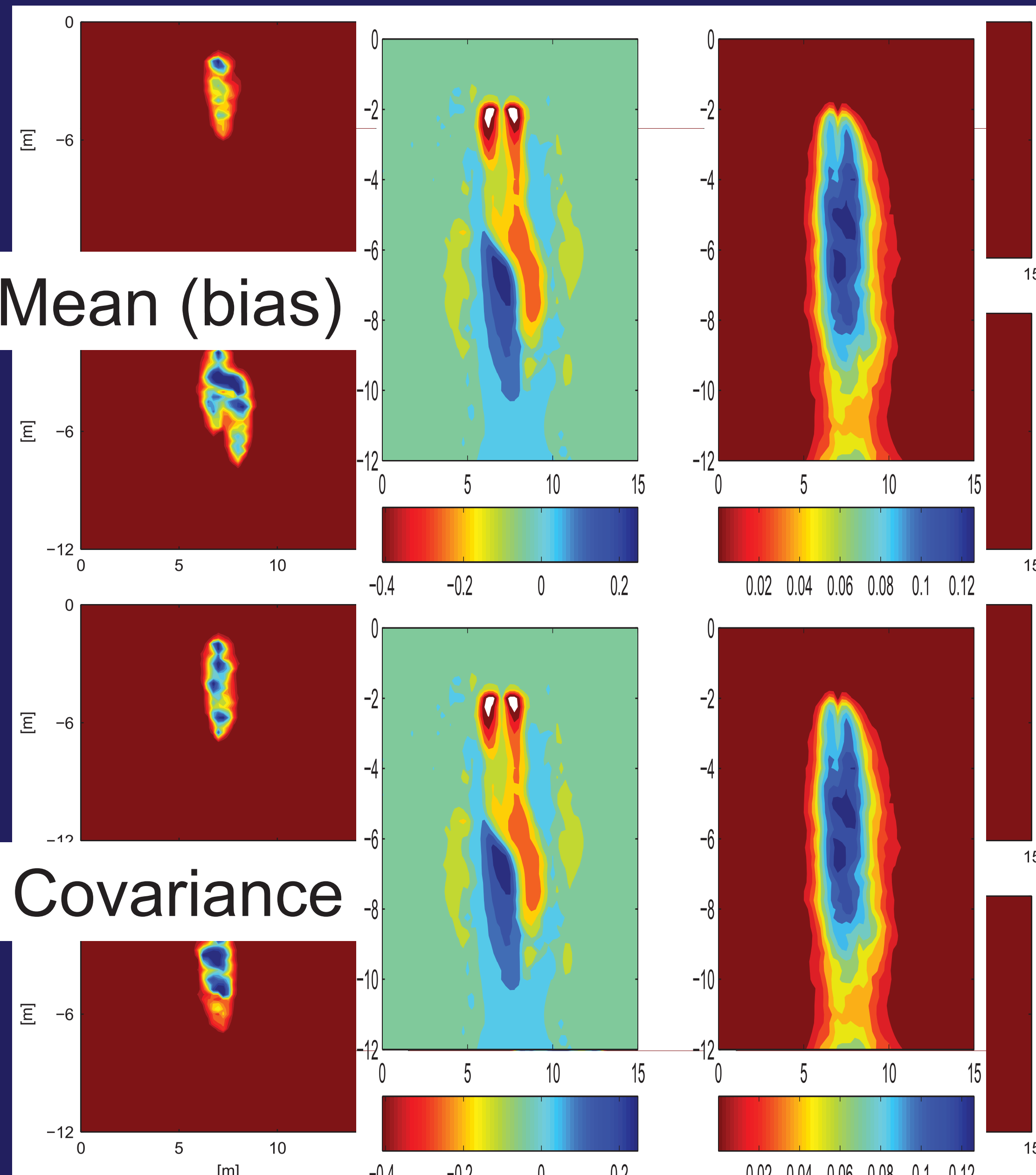
# Hydrogeophysical Imaging with Approximation Error Theory

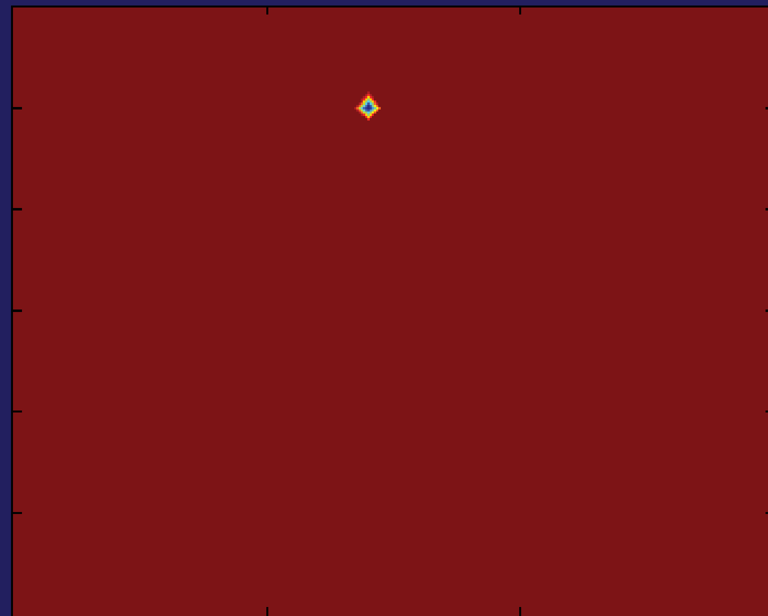
- Physical regularization for geophysical inversions
- Accounts for uncertainty in heterogeneity
- Approach:
  - Generate *k* fields
  - Simulate *S*(*k*,*t*)
  - Calculate state noise
  - Use error model in inversion



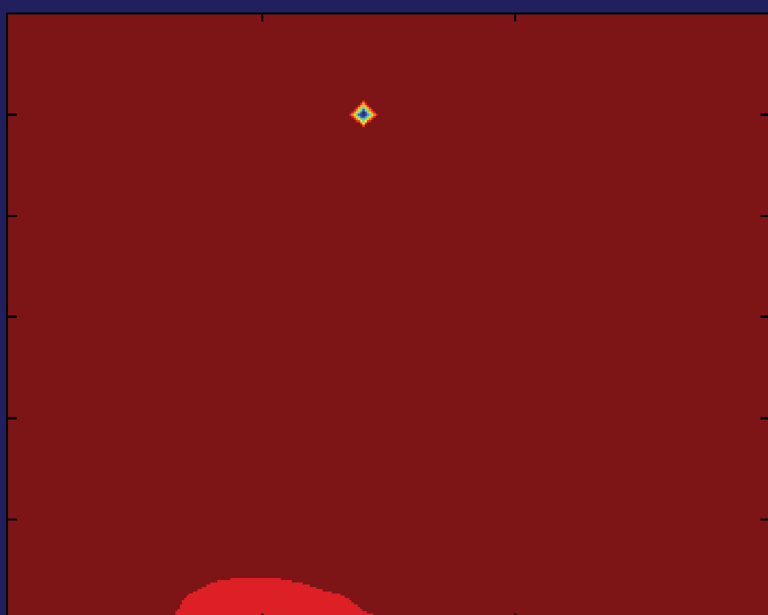

$$S_{t+1} = f_t(k) + \omega^1{}_t$$
$$= f_t(k^*) + \left[f_t(k) - f_t(k^*)\right] + \omega^1{}_t$$
$$= f_t(k^*) + \omega^1{}_t + \omega^2{}_t$$


Lehikoinen et al., *IPI*, *1*(2), 371–389, 2007.
Lehikoinen et al., *IPSE*, *17*(6), 715–736, 2009.
Lehikoinen et al., *WRR*, 46, W04513, 2010.

True (synthetic) saturation evolution



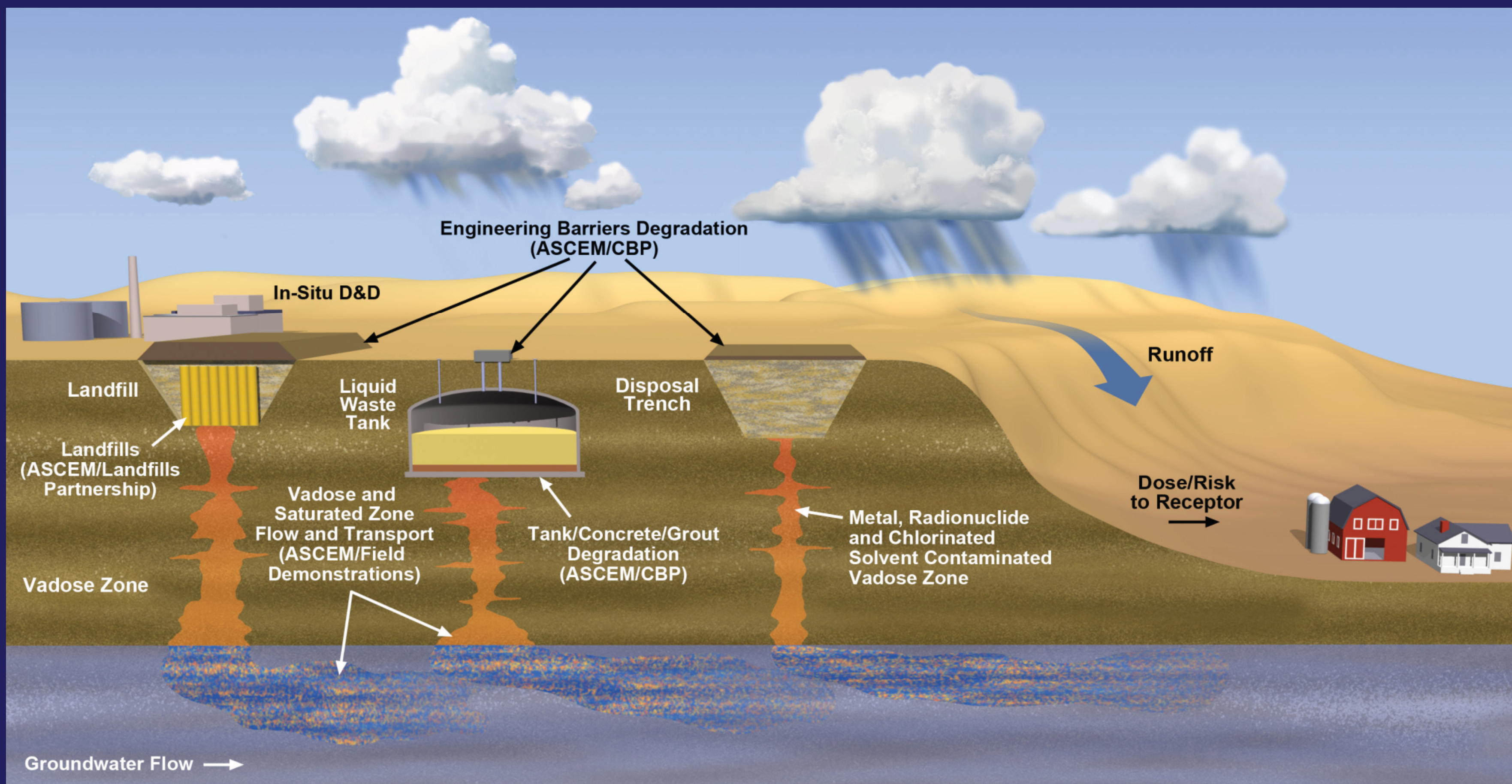
ERT tomogram



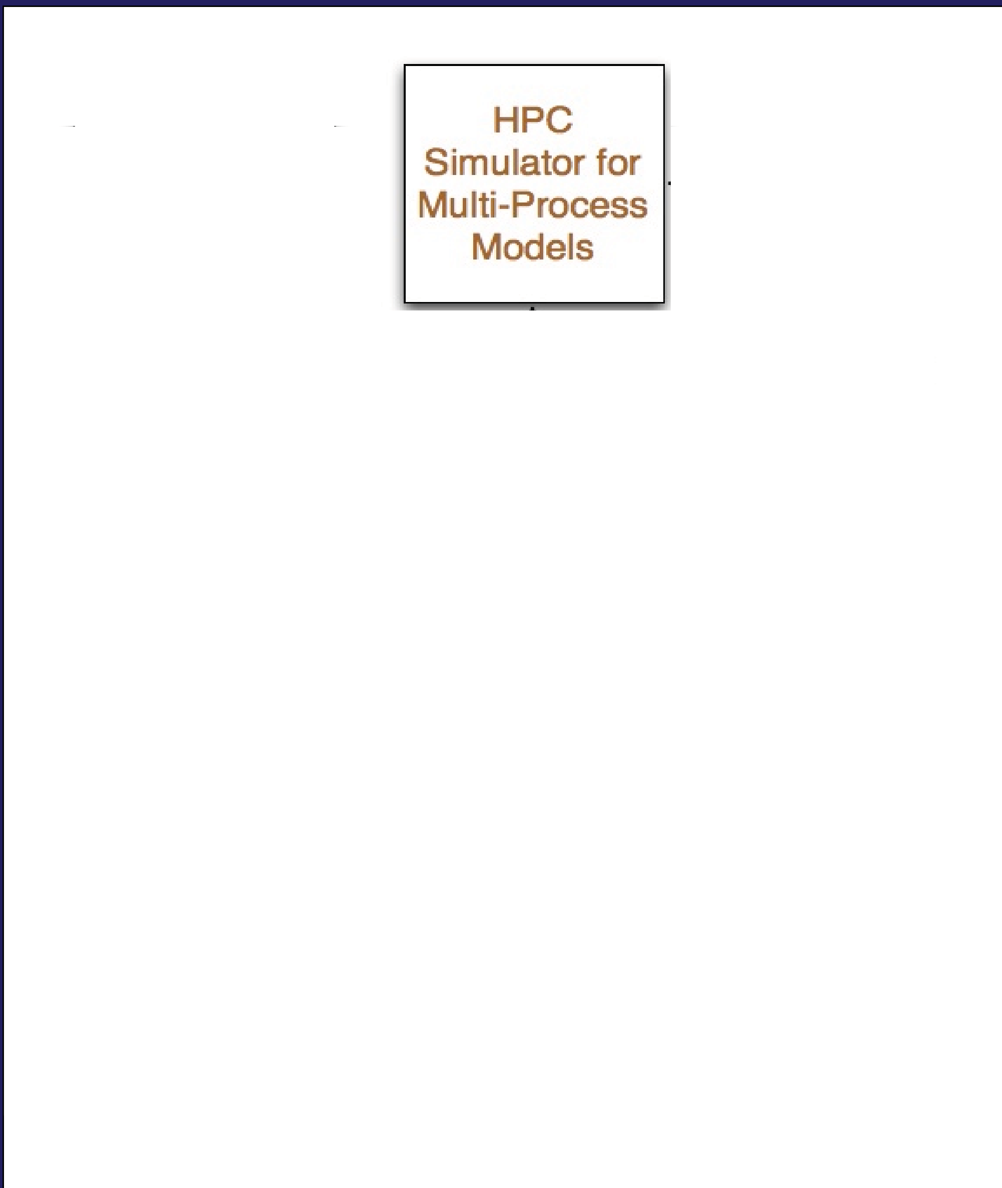
Extended Kalman Filter with dynamic evolution model and approximation error model

ASCEM

*"ASCEM is a state-of-the-art scientific tool and approach for understanding and predicting contaminant fate and transport in natural and engineered systems.  The modular and open source high performance computing tool will facilitate integrated approaches to modeling and site characterization that enable robust and standardized assessments of performance and risk for EM cleanup and closure activities."*

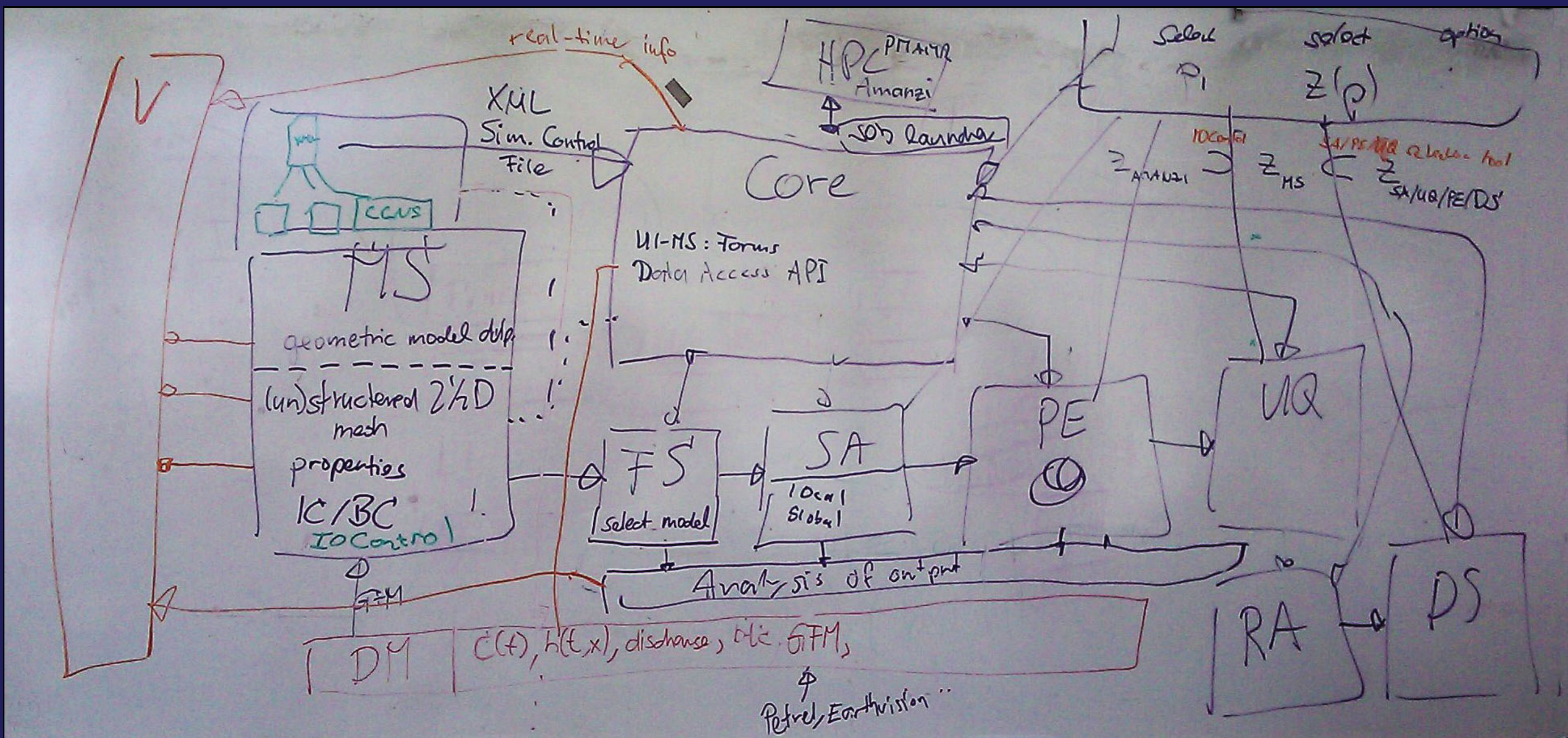


# ASCEM




- Multi-Process High Performance Computing Simulator
  - Modular simulation capability for barrier and waste form degradation, multiphase flow and reactive transport
- Platform and Integrated Toolsets
  - Toolset to facilitate model development and execution, parameter estimation, uncertainty quantification, risk assessment, and decision support
- Site Applications
  - Actively engage site user community to develop and test ASCEM tools

# ASCEM Approach…



# Path Forward


- Couple models
  - Noise becomes signal
- Joint inversion
  - Improve leak detection by analyzing complementary data
- Early warning
  - Combine monitoring with predictive modeling
- Error / uncertainty analysis
  - Reduce inversion artifacts
  - Provide decision support

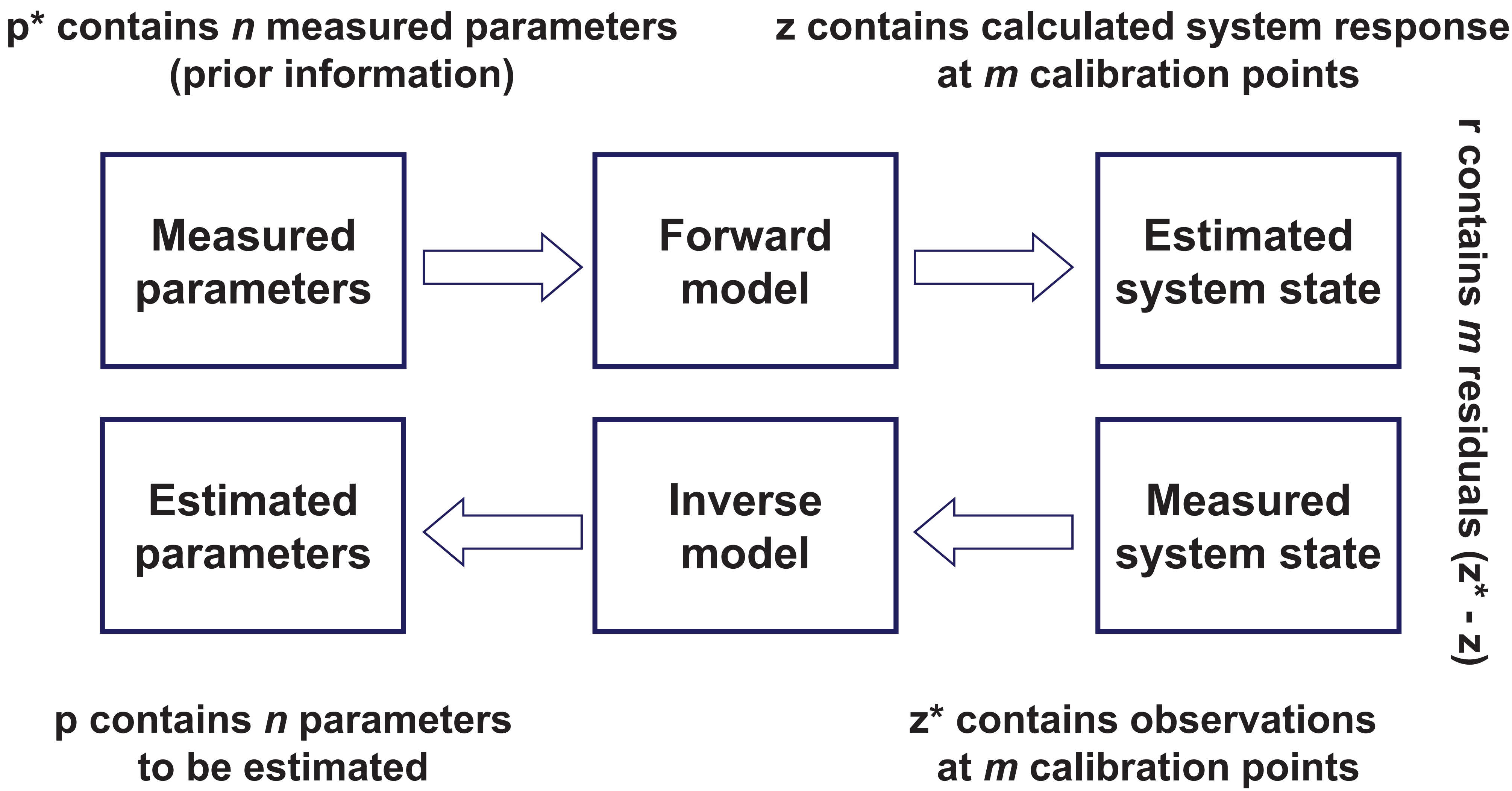
# Related Efforts and References

- Related efforts
  - ASCEM, ISCMEM, NEAMS, NRAP, SciDAC
- Development of monitoring and early warning systems for leakage from $CO_2$ storage sites
- References
  - Kowalsky et al., 2007, 2009, 2010, 2012
  - Lehikoinen et al., 2007, 2009, 2010
  - Finsterle and Kowalsky, 2008
  - Finsterle et al., 2008


http://www.funz.eu/2010/04/29/greatest-alcatraz-escape/

# Backup Slides

# Forward vs. Inverse Modeling



# Regularization

- Determine $n$ parameters based on $m$ observations → $m$ equations with $n$ unknowns
- $m > n$: overdetermined system
- $m < n$: underdetermined system → regularization
- Regularization (add “observations”):
  - Prior information about parameters
  - Smoothness criterion (minimize differences between “neighboring” parameter values)
- Advantage:
  - Stabilizes inversion (→ $m > n$)
- Disadvantage:
  - Prior model / smoothness unknown / uncertain / Inconsistent with data → bias / unphysical
  - Arbitrary weighting between regularization and data fit