Development of the microBayesloc Method

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Mastering the Sub-surface

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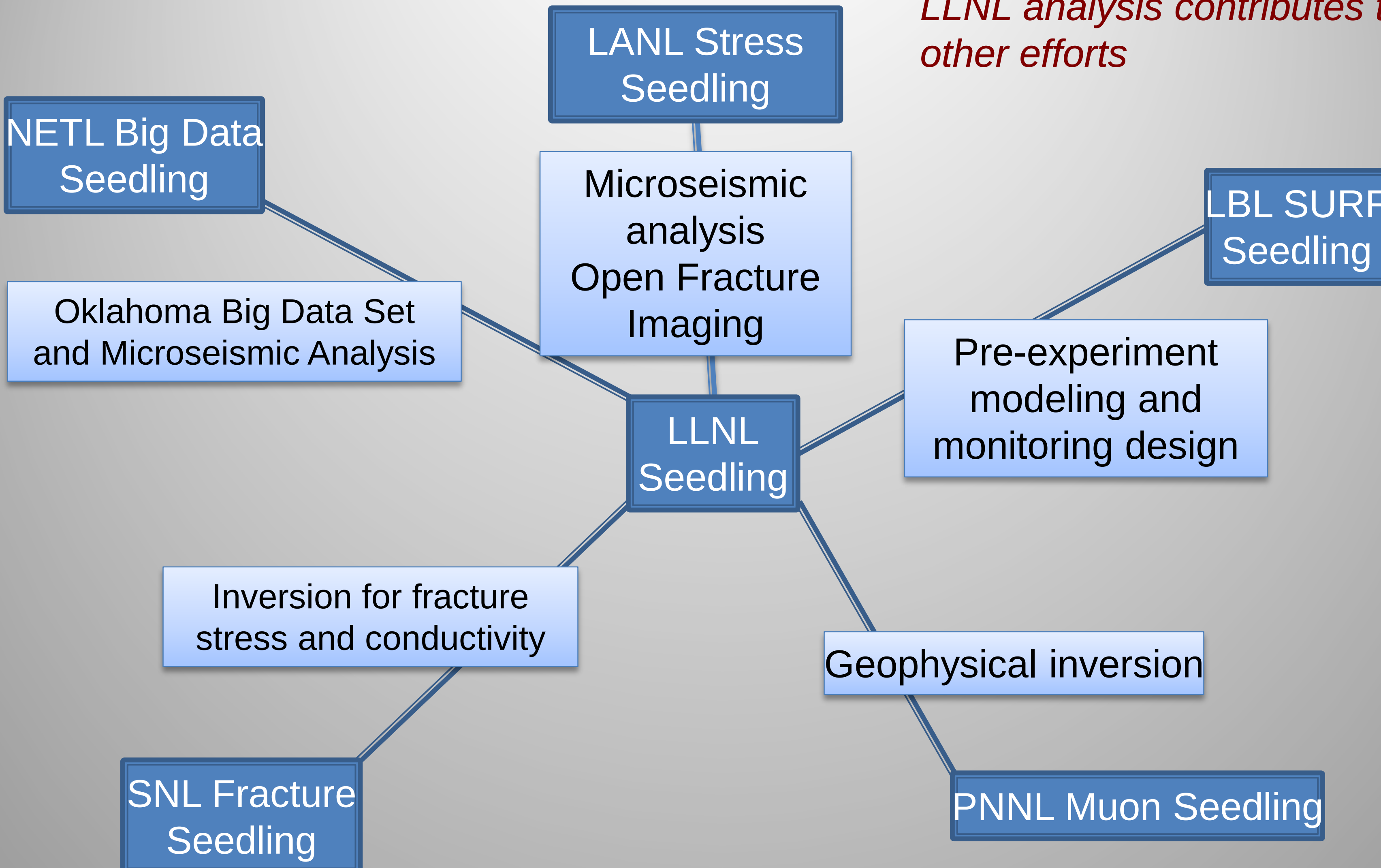
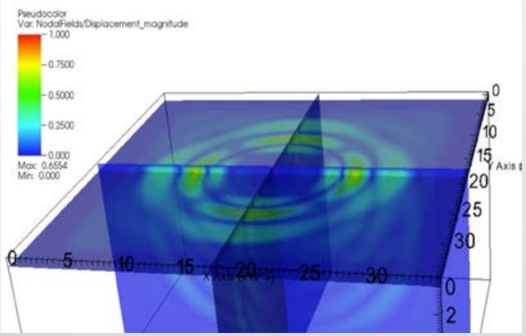
MicroBayesloc is a cornerstone of LLNL's SubTER effort

LLNL analysis contributes to other efforts

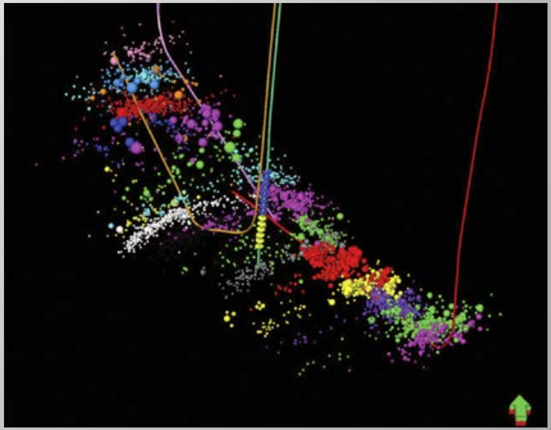


MicroSeismic locations are used to assess the evolving state of stress

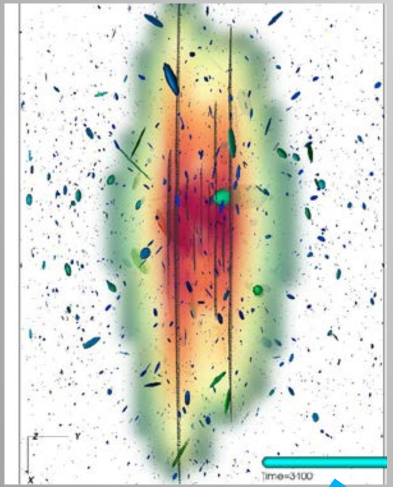
Predict observables



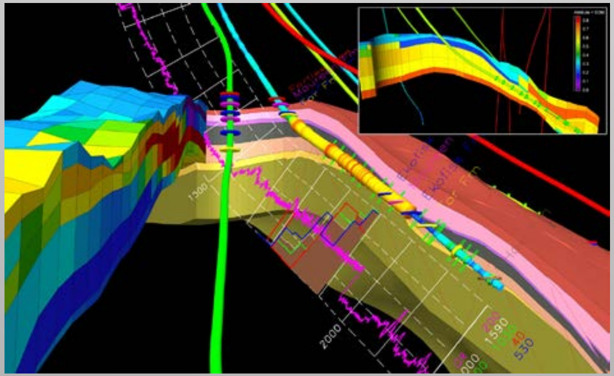
Field observation (microseismic)



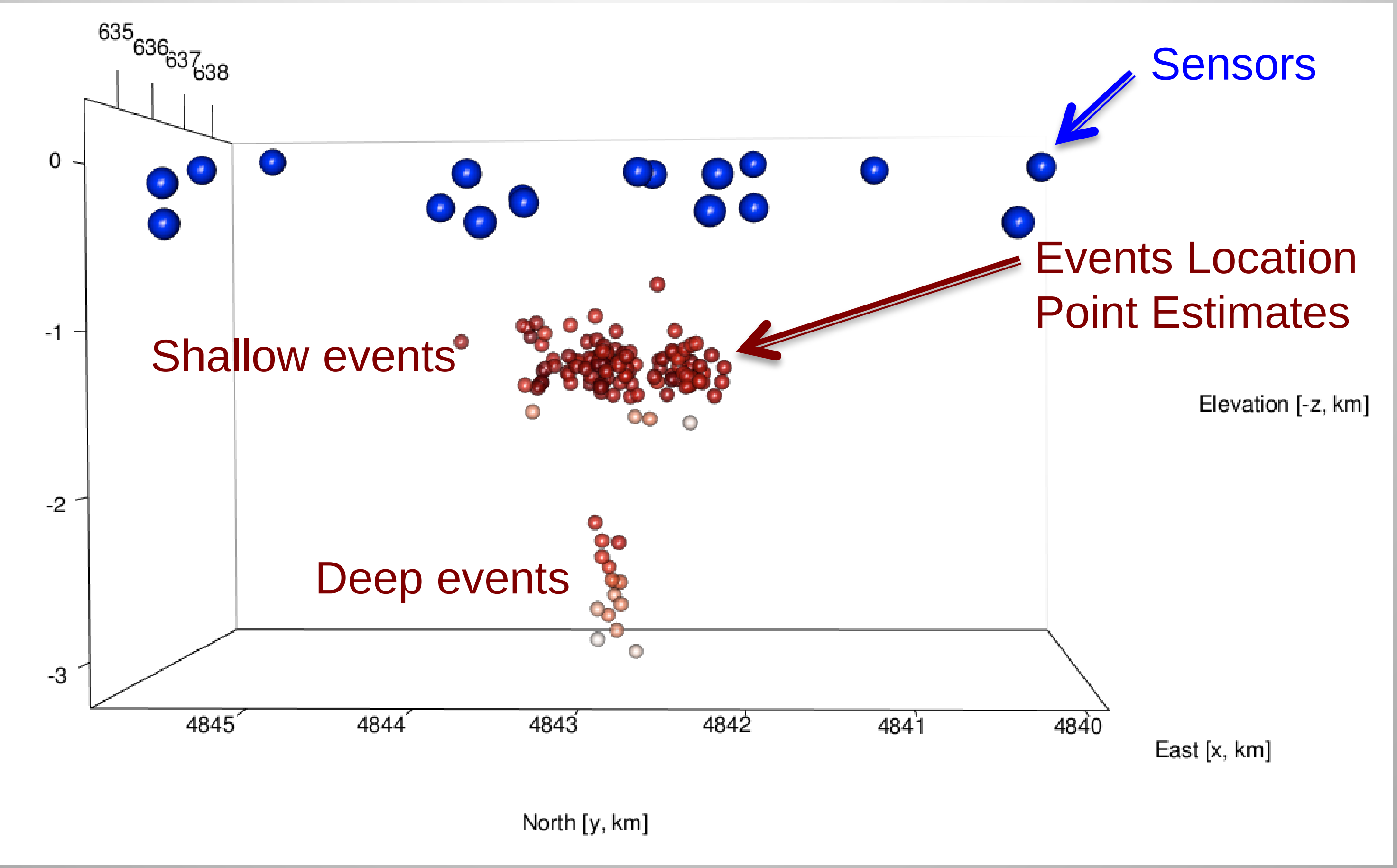
Physics-based simulation (GEOS)



Site model

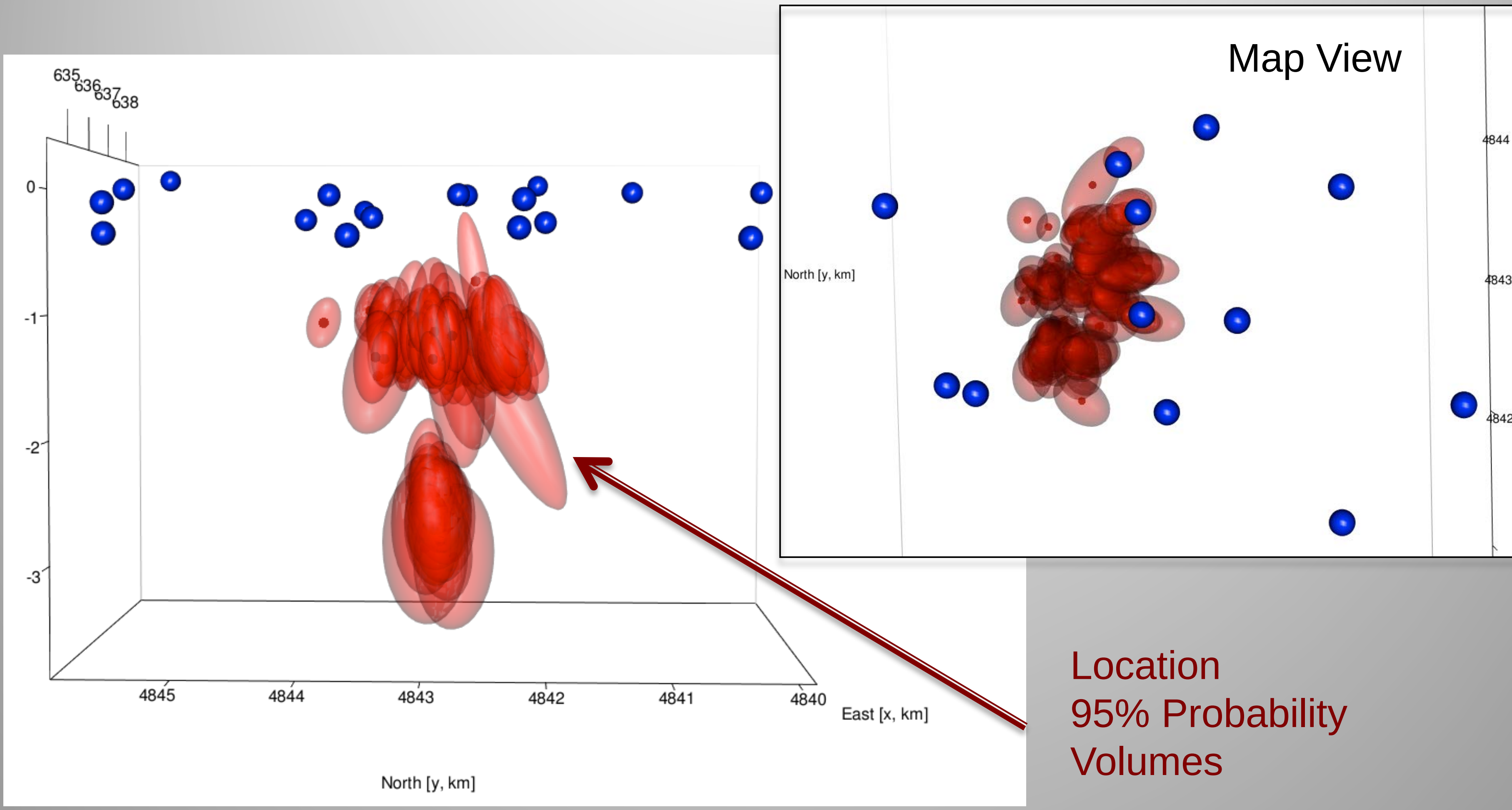


Seismic locations are are typically represented as point patterns



MicroBasesloc produces validated uncertainty estimates

Point patterns work if seismicity trends are large compared to location uncertainty



Location
95% Probability
Volumes

Bayesloc: Joint Probability Over Multiple-Event Parameters

- Event locations
- Travel times
- Measurement precision
- Phase labels

Statistical model

$$p(o, x, T, W, \sigma, V, \tau \mid a, d, w)$$

o = origin times
x = locations
T = phase travel times
W = phase labels
σ = measurement precisions (pick)
$\boldsymbol{V}$ = measurement precisions (diff)
τ = travel time corrections
a = arrival times (picks)
$\boldsymbol{d}$ = differential arrival times
w = input phase labels

Myers, Johannesson, and Hanley (2007, 2009)

Recast Probability of Inverse Problem Into a Set of Forward Problems, Bayes Theorem

Multiple-Event Conditional Probability

$$p(o, x, T, W, \sigma, V, \tau \mid a, d, w)$$

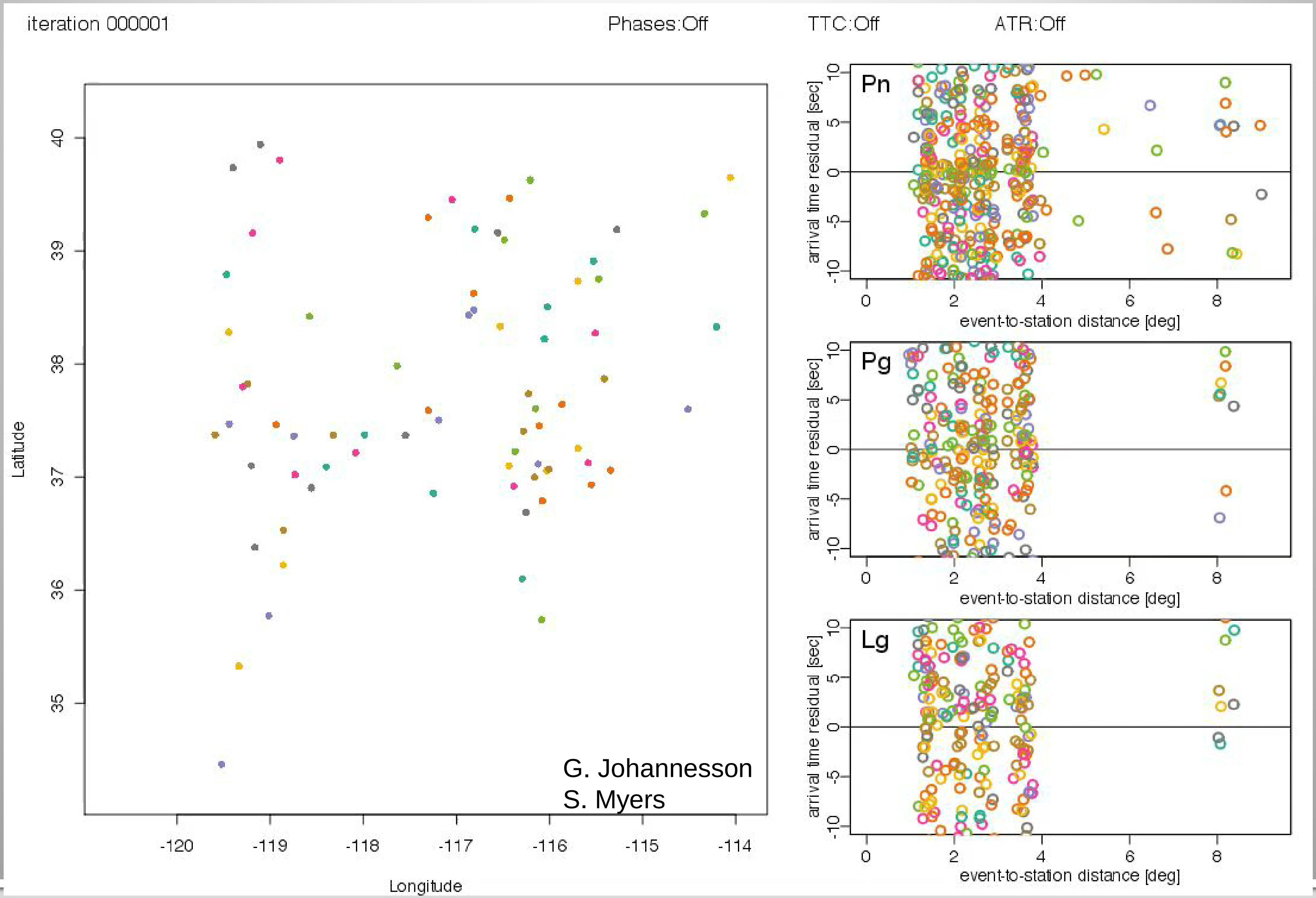
o = origin times
x = locations
T = phase travel times
W = phase labels
ʃ = measurement precisions (pick)
$\mathbf{V}$ = measurement precisions (diff)
τ = travel time corrections
a = arrival times (picks)
$\mathbf{d}$ = differential arrival times
w = input phase labels

$$p(o, x, T, W, \sigma, V, \tau \mid a, d, w) =$$

$p(a \mid o, T, W, \sigma)$	*Arrivals times given a set of locations and measurement uncertainties*
$p(d \mid o, T, W, V)$	*Differential times given a set of locations and measurement uncertainties*
$p(T \mid o, F(x), W, \tau)$	*Travel times given a set of locations and travel time corrections*
$p(W \mid w)$	*Phase labels given input phase labels*
$p(x, o)p(\sigma)p(\tau)$	*Prior constraints*
$/\,p(a)p(d)$	*Probability over all arrivals*

Simultaneous location and data analysis

Bayesian analysis : event location example (Bayesloc)



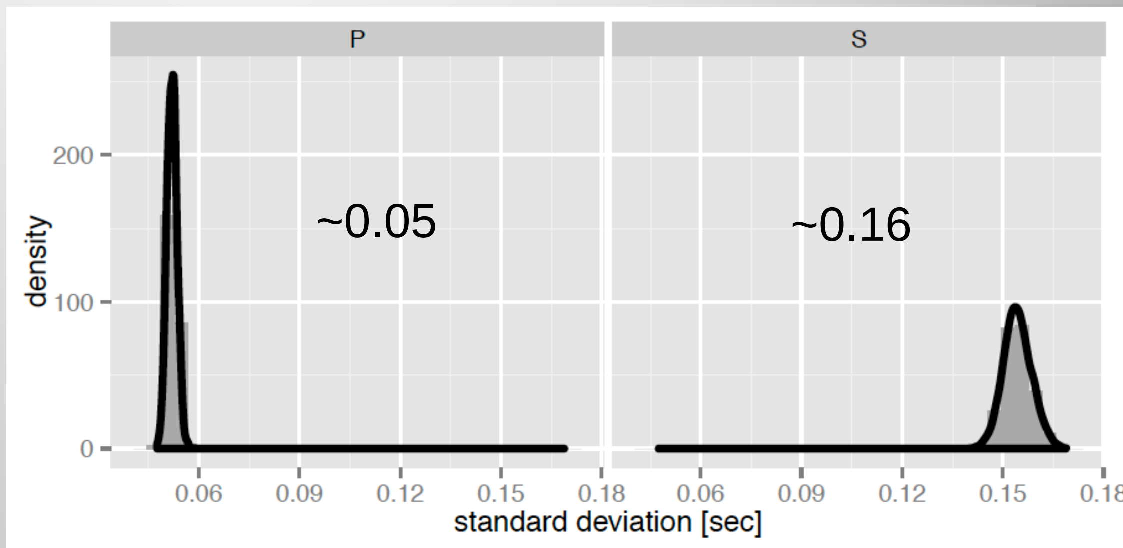
MicroBayesloc assesses components of error budget at Newberry

- S-wave uncertainty 3-times P-wave uncertainty and 40 times the sample rate

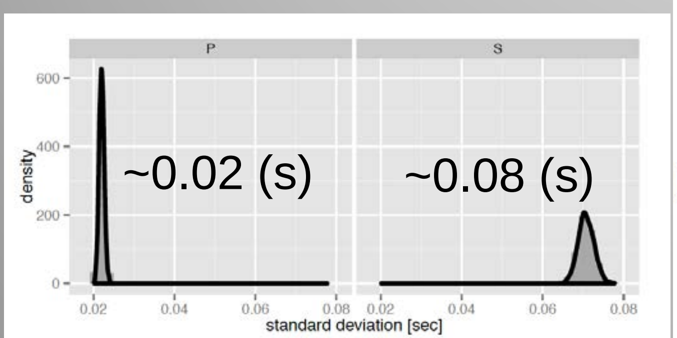
- Estimated time uncertainty (measurement + model+ station corrections)

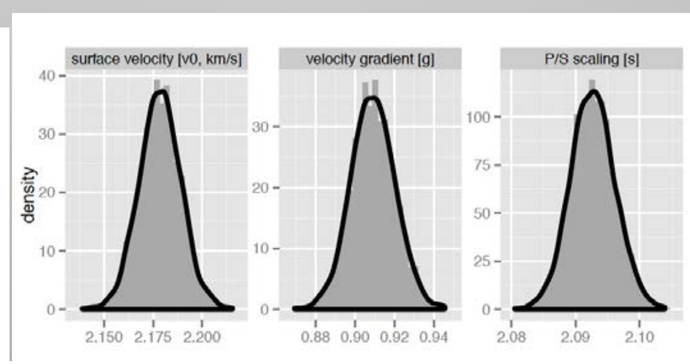
- P waves: 0.05 sec
- S waves: 0.16 sec

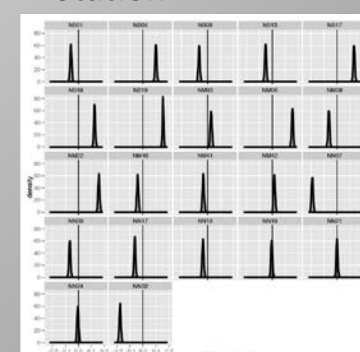
Estimate of summed error



Pick **+** **Model** **+** **Station**







Adaptation of PageRank to assess microSeismic data

$$\vec{x} = \mathbf{A}\vec{x}$$

PageRank, as developed by Page *et al*. (1999) for webpages, is the probability that a “random surfer” will visit a particular web page.

We use PageRank to find the connectivity of seismic signals based on a correlation value.

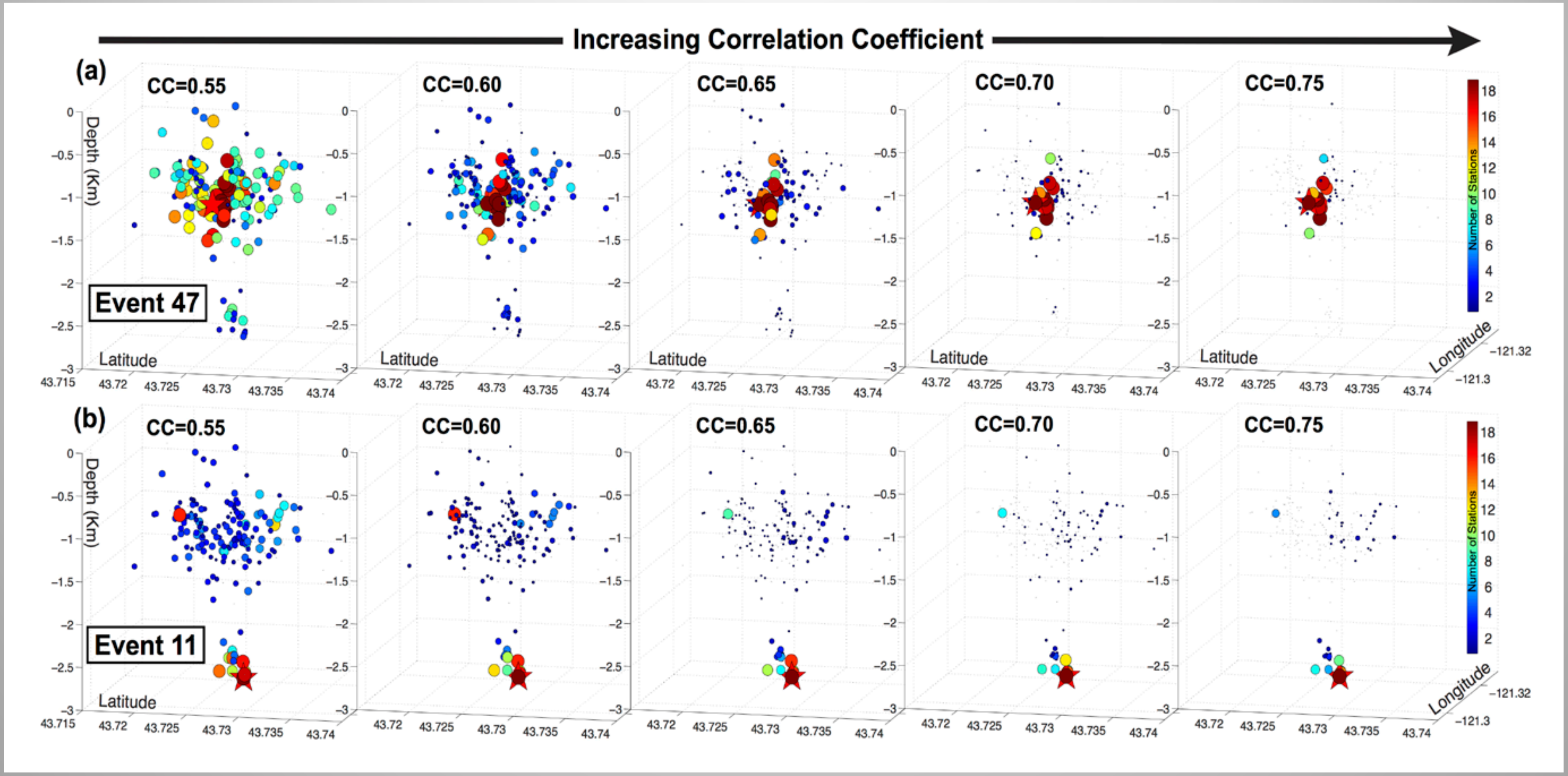
x = PageRank
A = transition probability matrix

$$a_{ij} = \begin{cases} pg_{ij}/c_j + \delta & \Rightarrow \quad c_j \neq 0 \\ 1/n & \Rightarrow \quad c_j = 0 \end{cases}$$

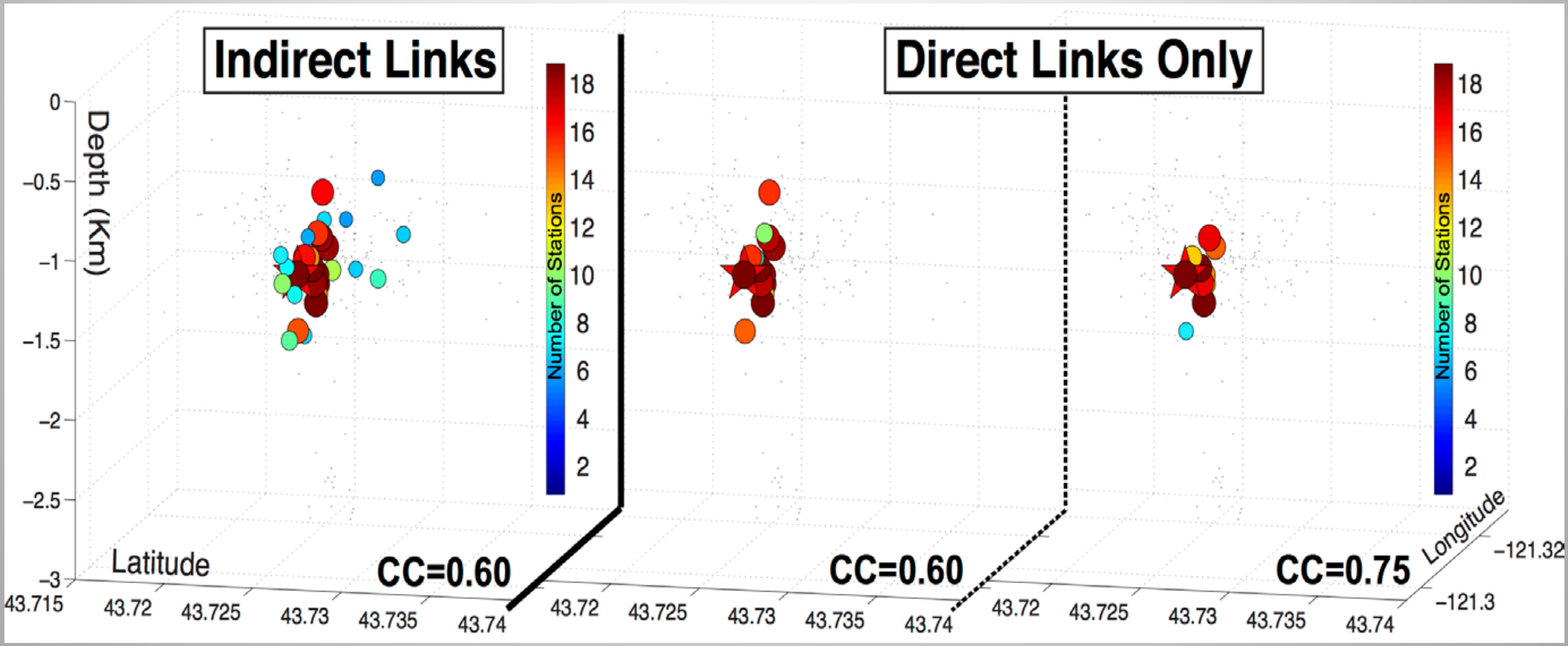
g = 1 if cc exceeds a threshold
p = probability that signals are linked
δ = probability of a random link

$$c_j = \sum_i g_{ij} \qquad \delta = (1-p)/n$$

Adaptation of PageRank to assess microSeismic data

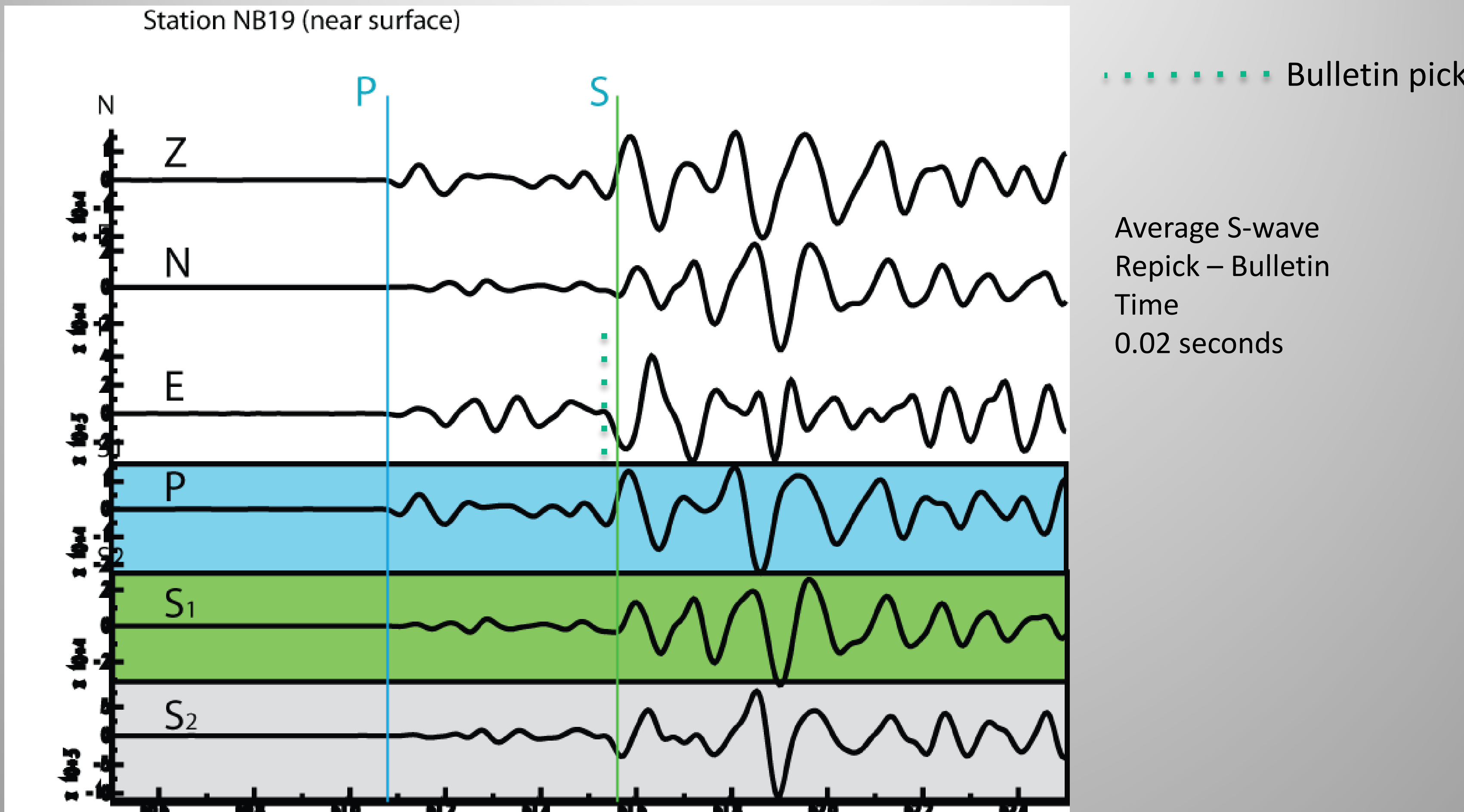


A closer look…



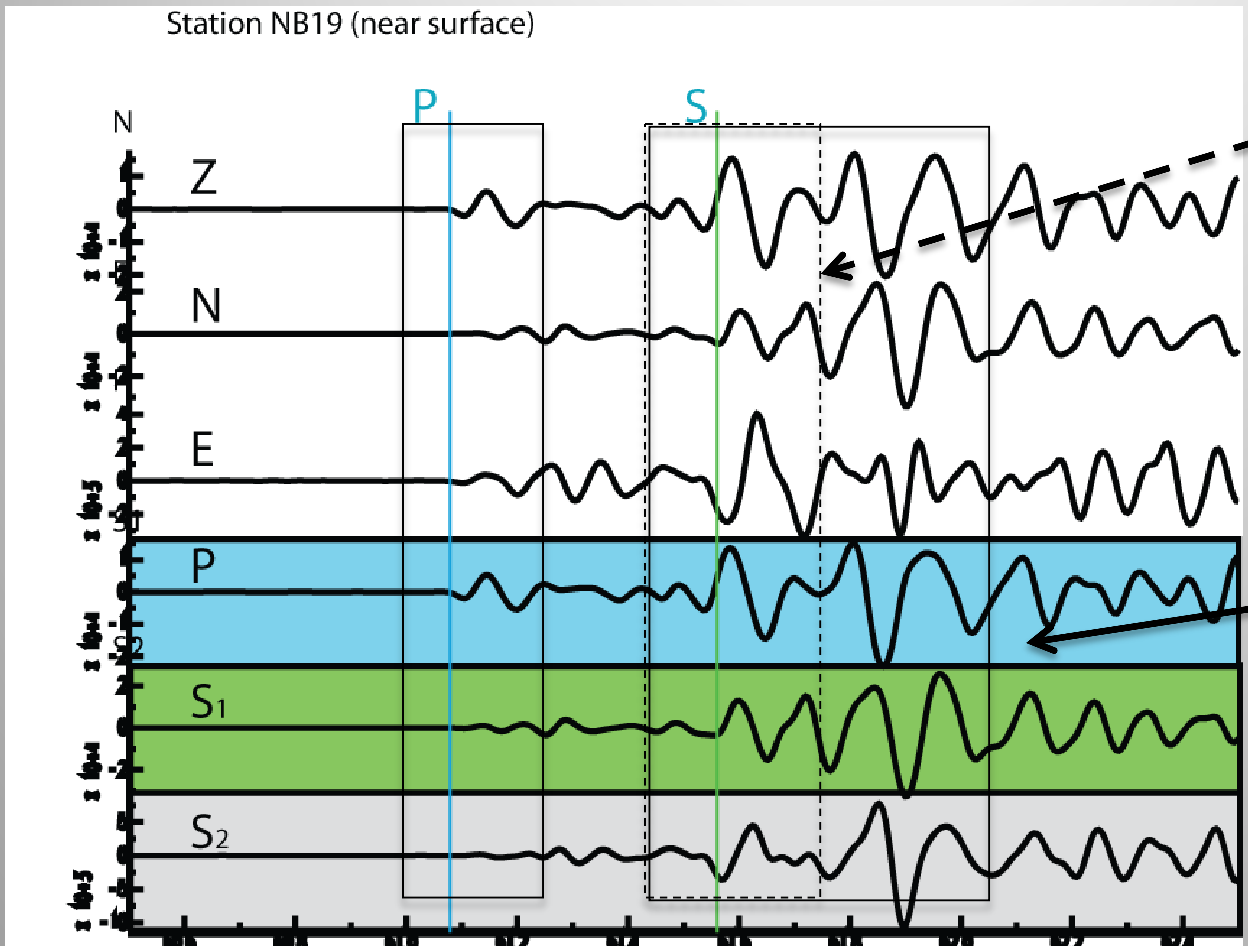
We reexamine waveforms that are determined to be linked

1) Rotate to principle components of particle motion



Average S-wave Repick – Bulletin Time 0.02 seconds

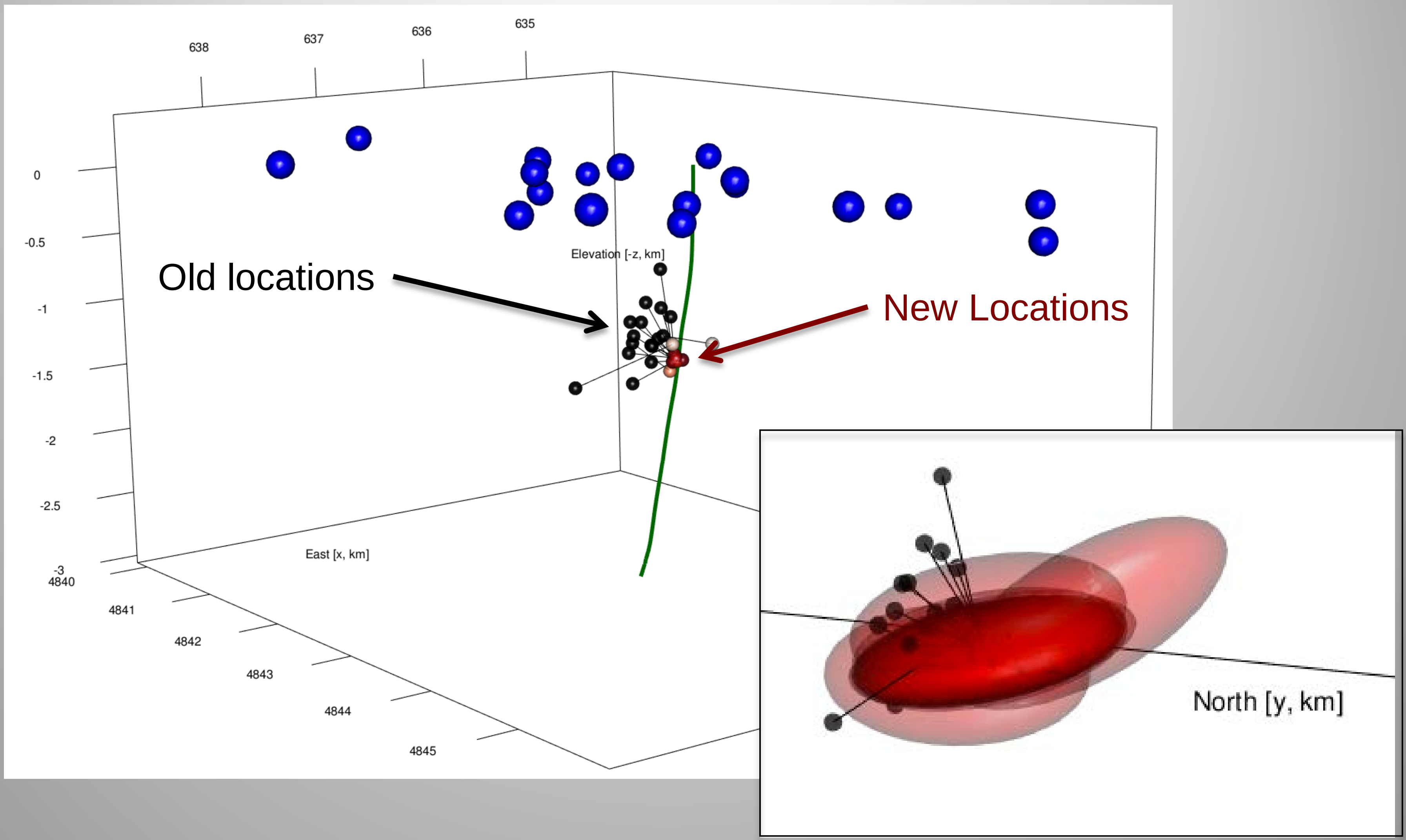
2) Re-assess windowing for phase-specific correlation analysis



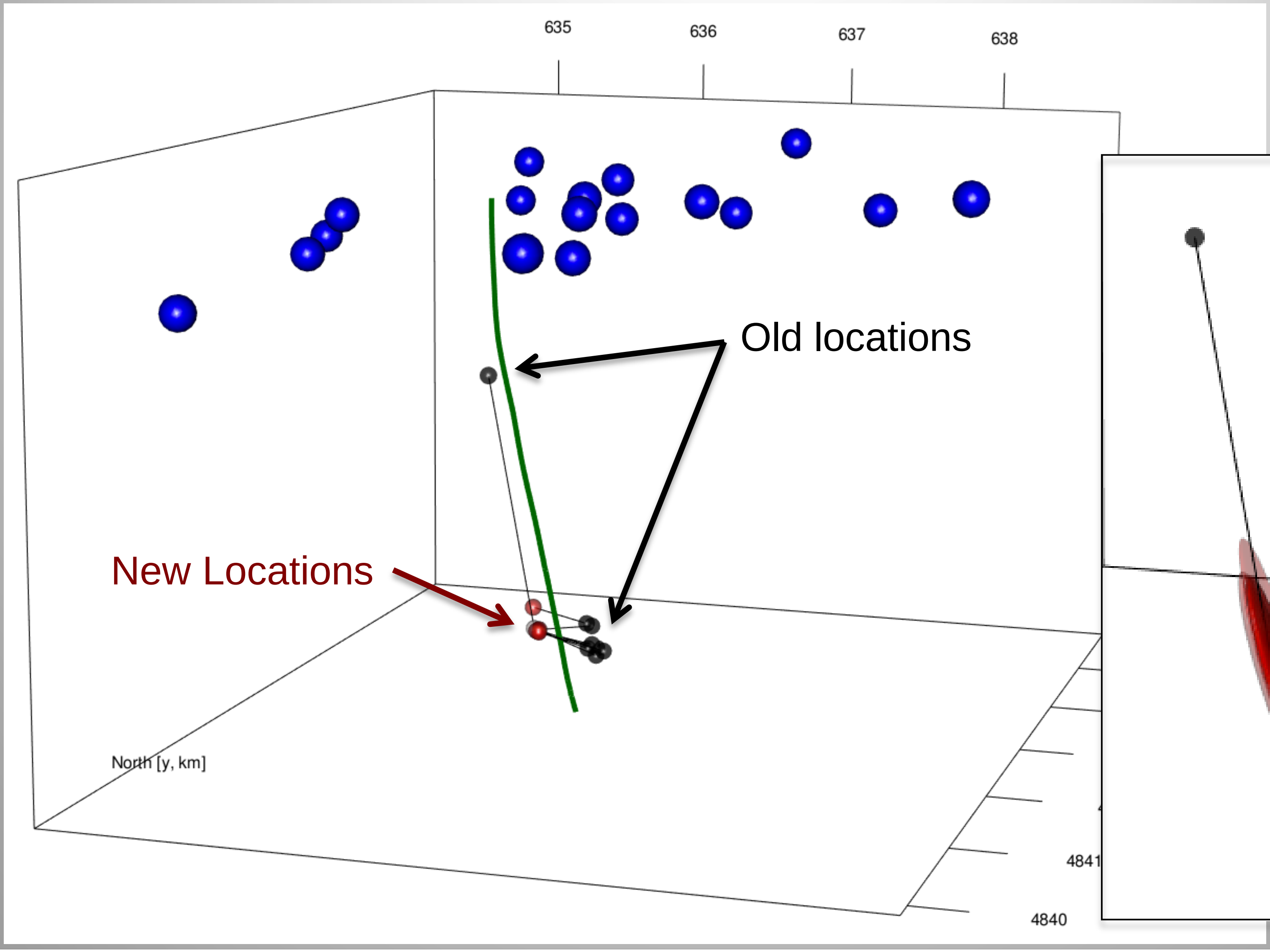
Updated S-wave window

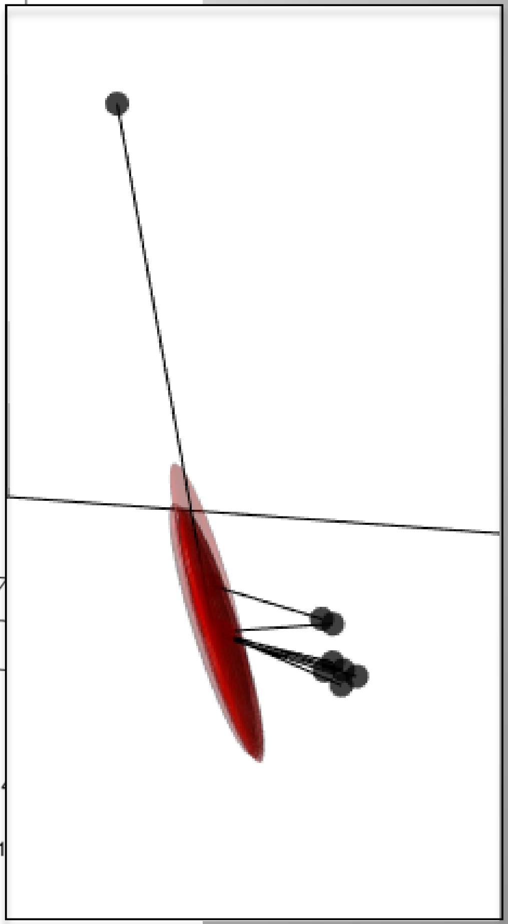
Initial windowing of S-waves for waveform correlation-based differential time measurement included probable surface wave

3) Relocate using microBayesloc



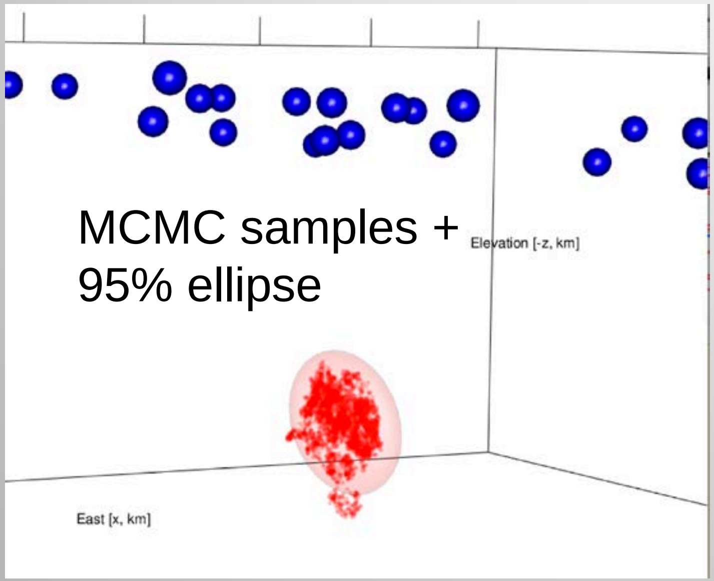
3) Relocate using microBayesloc





What's next: Langevin-Hastings for improved MCMC sampling

MCMC sampling is inefficient, potentially inaccurate, when differential times are used.



Correlated parameter samples

We are adapting the Langevin-Hastings approach to efficiently sample high-dimensional, correlated parameter spaces

$$\frac{d}{d\boldsymbol{x}_i} \log p(\boldsymbol{\theta}|\boldsymbol{a},\boldsymbol{d}) = \sum_{j,k} \left(A_{ijk} \cdot \mu'_{ijk} + \sum_{i_p \in Q^2_{ijk}} D_{i_p ijk} \cdot \mu'_{ijk} - \sum_{i_q \in Q^1_{ijk}} D_{i i_q jk} \cdot \mu'_{ijk} \right)$$

Summary

- ***LLNL supports the SubTER effort with microSeismic analysis, geomechanical modeling, and basic research.***

- ***The microBayesloc method is a cornerstone of LLNL's microSeismic analysis***
  - *Formulation of the joint probability function for multiple-event location*
  - *Event location probability volumes are representative of true error*
  - *Improvements to microBayesloc*
    - ***Use of 3D velocity models of seismic wave speed***
    - ***Joint use of differential and absolute arrival time measurements***
    - ***Improved analysis of differential arrival time data sets (PageRank)***
    - ***Improved efficiency of the microBayesloc MCMC algorithm***

Thank You!

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