Fast Network Solutions using Precise Point Positioning with Ambiguity Resolution for all Geodetic GPS Stations in the World

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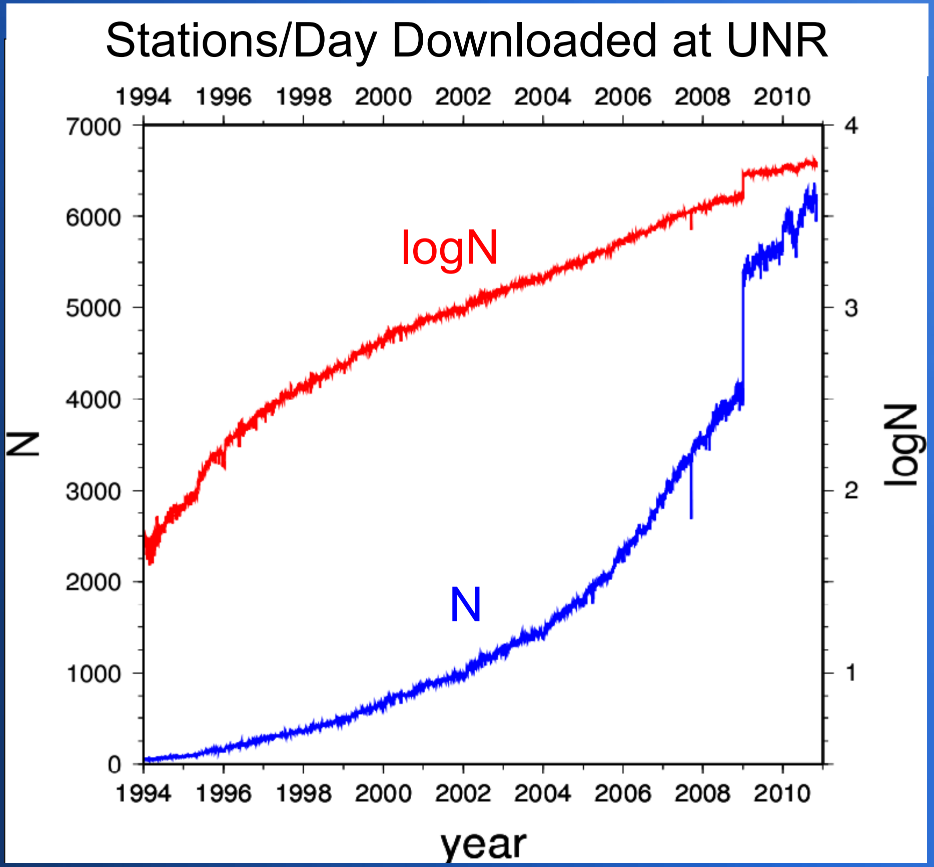
Overview

- The GPS Data Explosion
  - Opportunities and Challenges
  - Meeting the Challenge: A Geodetic “Moore’s Law”
- Methodology
  - General System Design
  - Analysis Engine
  - Design Details
- Current Developments
- Examples of Results
- Summary of Performance
  - 8,000 Stations/Day (operational)

The GPS Data Explosion:
Opportunities and Challenges

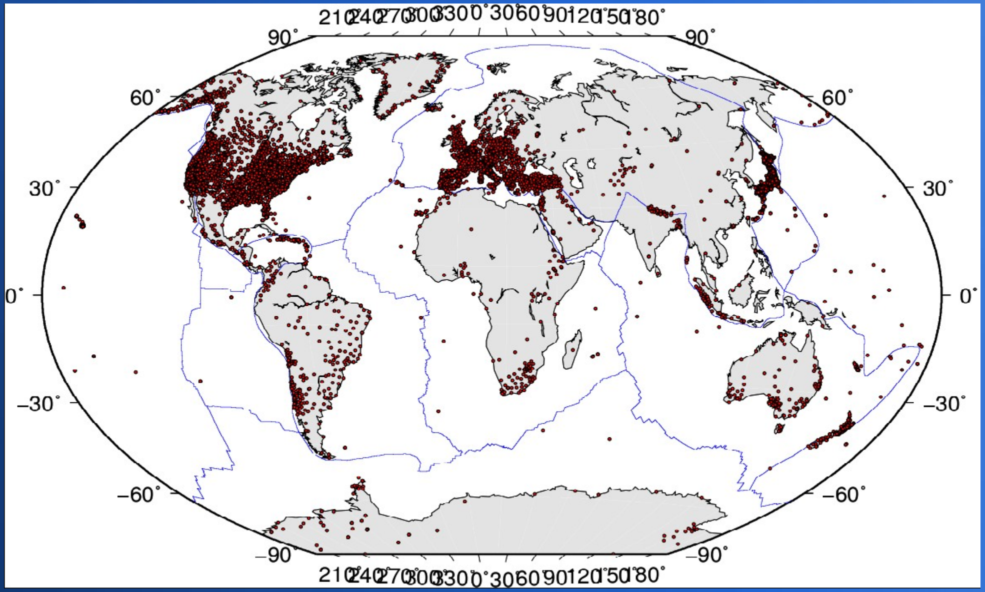
- Rinex Downloads @ UNR
  - From ~100 archives!
    - UNAVCO, CDDIS, SIO...
  - Now at *N*~8000 per day
- Exponential Growth
  - x 2 every 3 years
  - x10 every 10 years
- Problem Statement
  - Data processing systems must be exponentially scalable
  - The solution must be a kind of “Geodetic Moore’s Law”



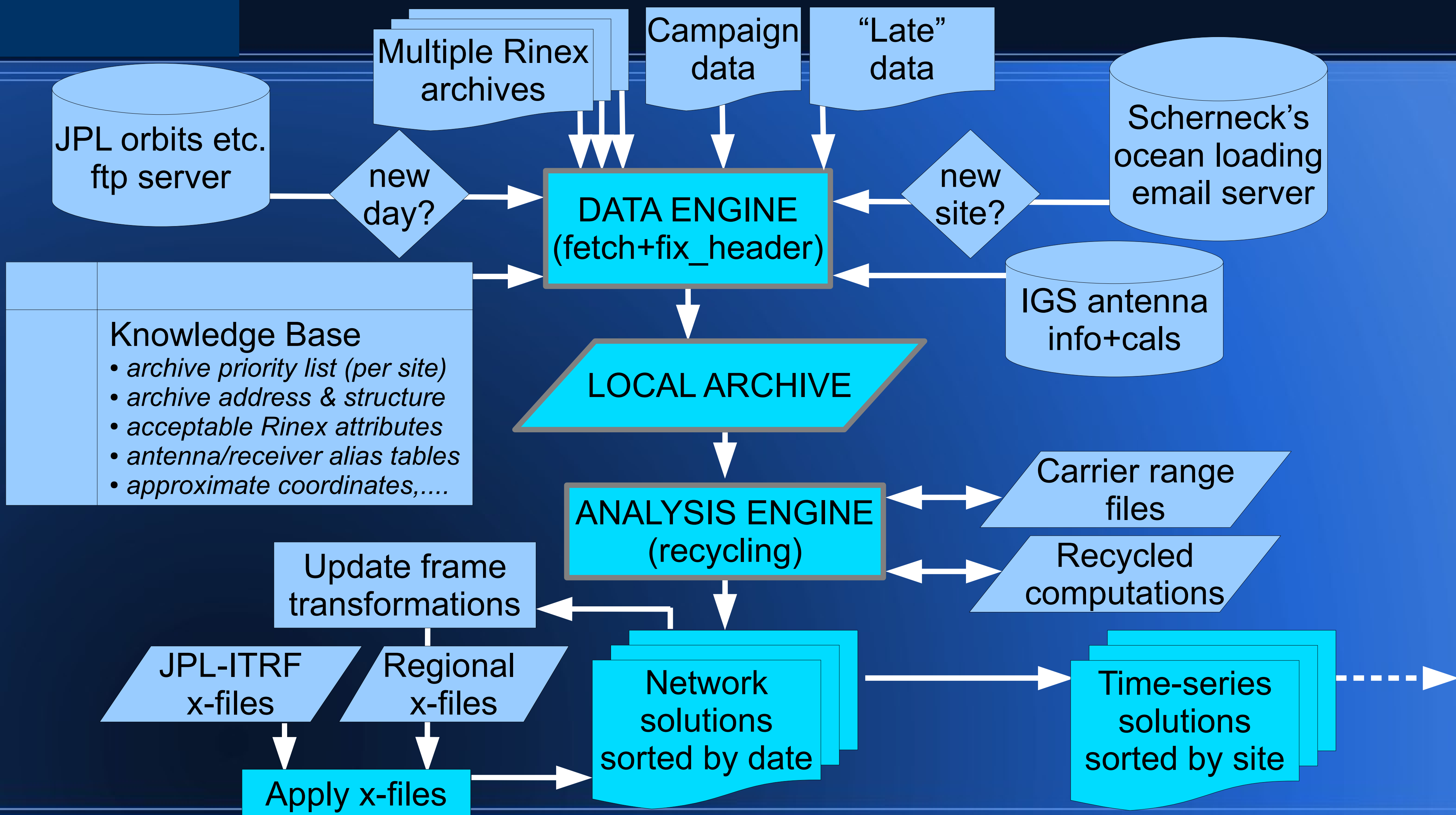
The GPS Data Explosion:
Meeting the Challenge

- Manage exponential growth in required computing time
  - The *real* Moore's law
  - But requires $O(N)$ algorithms!
- Manage exponential growth in datasets
  - No human decisions
  - No arbitrary sub-networks
  - Process all data seamlessly
  - Ability to add "late" data
- Maximize potential accuracy
  - Use algorithms that closely approximate full-network $O(N^3)$ algorithms
  - Ability to quickly reprocess all data with new models / quality control

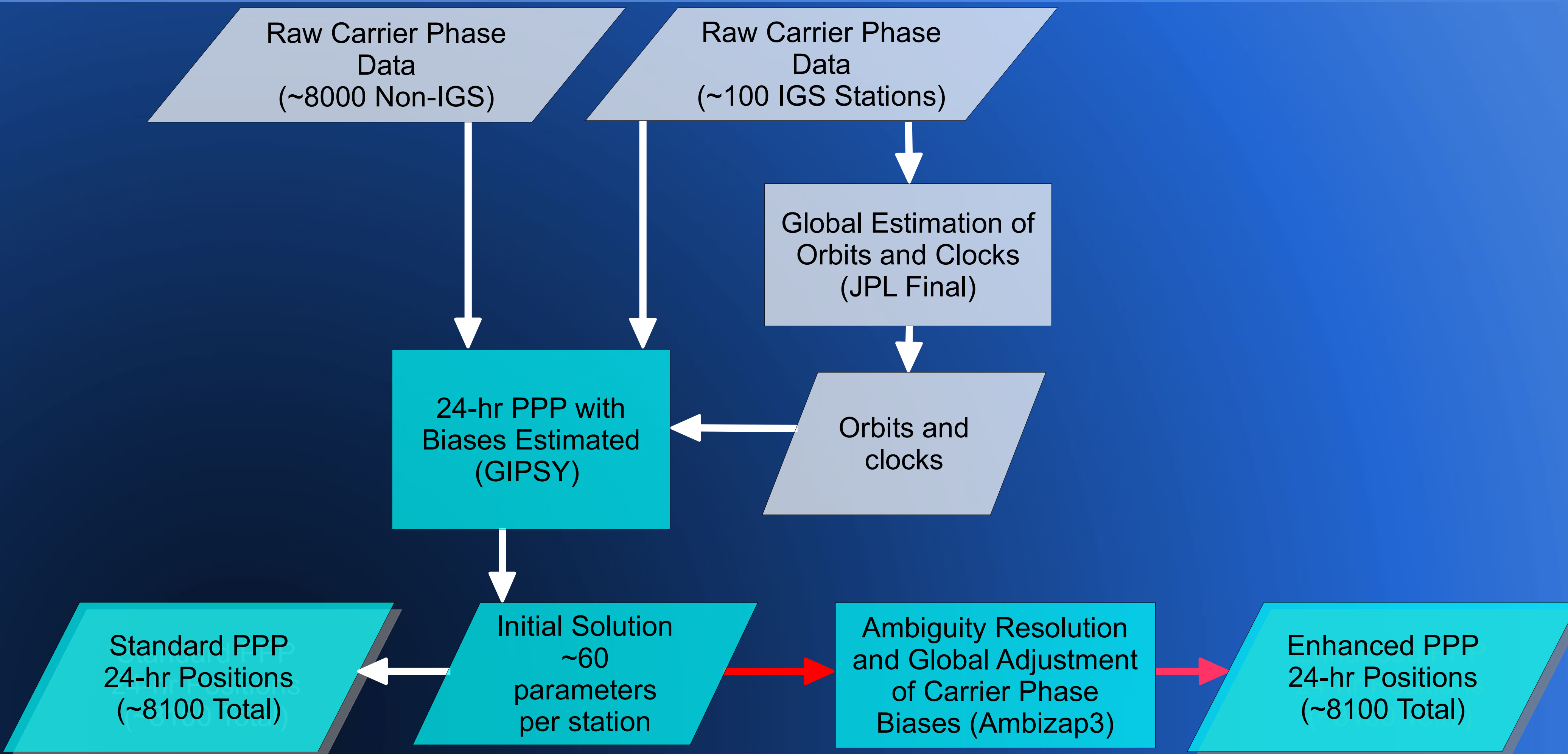
>8,000 Stations Processed at UNR



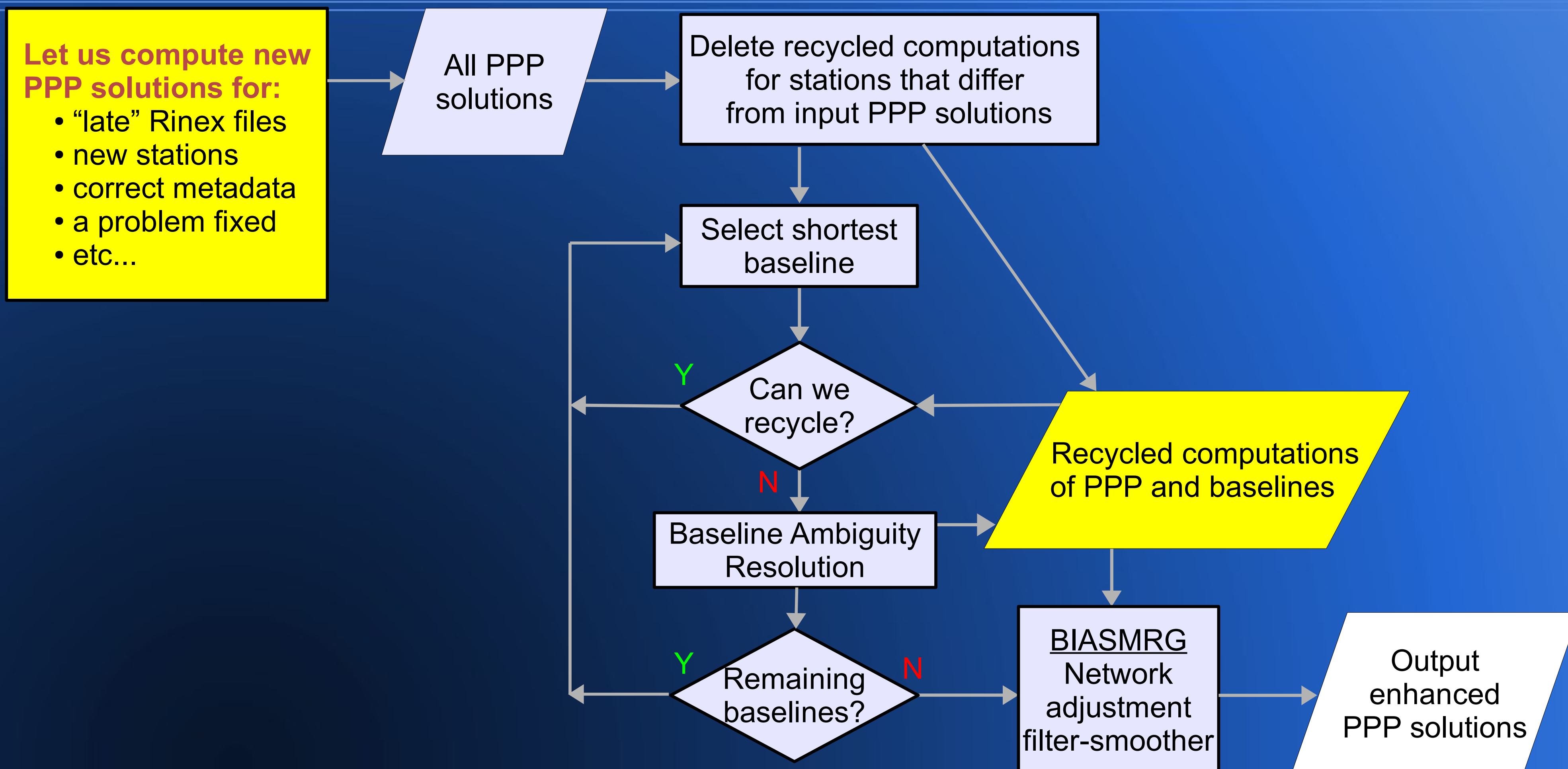
General System Design



Methodology: Analysis Engine
O(*N*) Enhanced Precise Point Positioning



Design Feature: Ambizap3
Recycled Computations



Design Feature: Ambizap3
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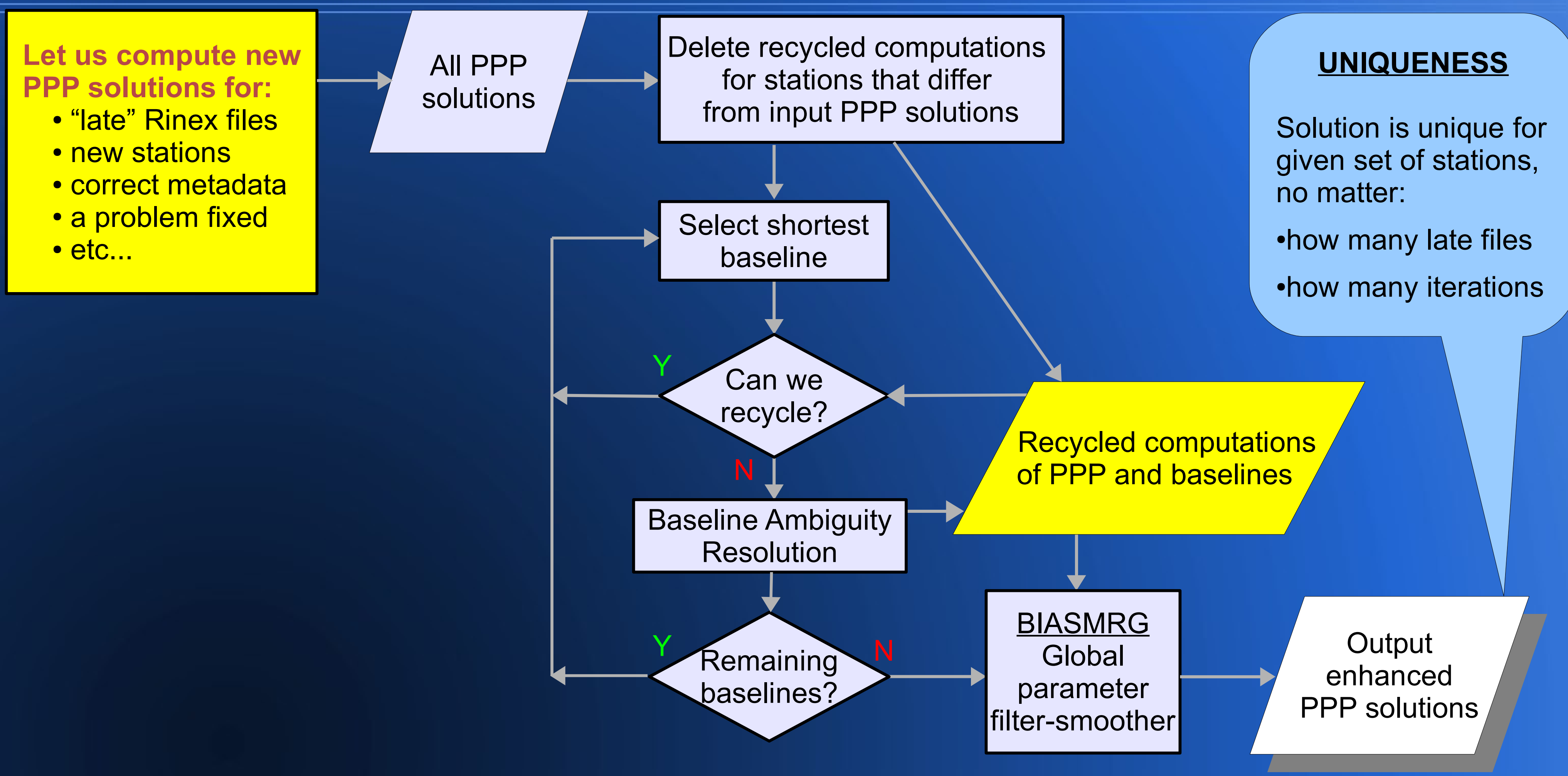
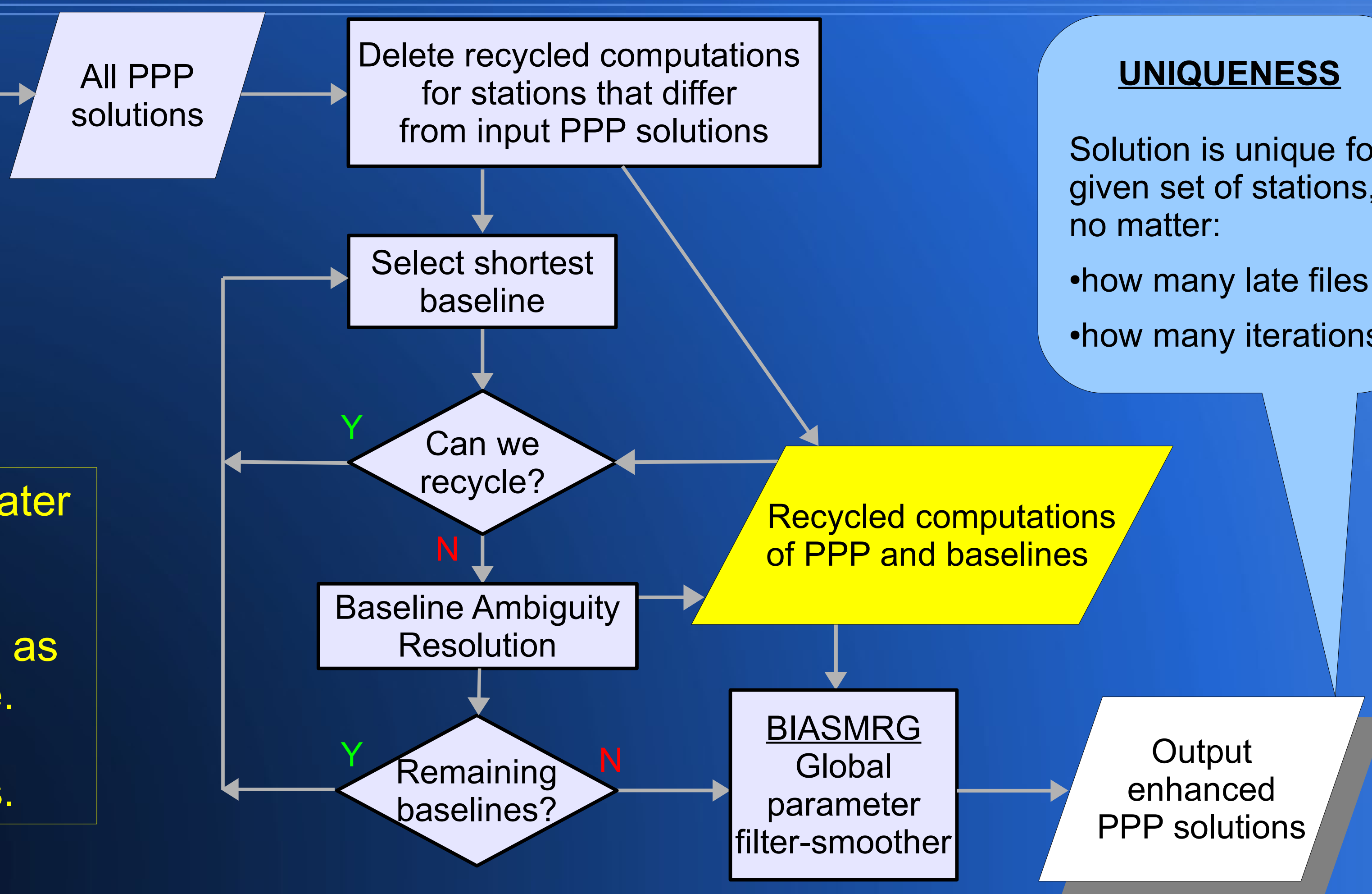


Design Feature: Ambizap3
Recycled Computations

Let us compute new PPP solutions for:
- “late” Rinex files
- new stations
- correct metadata
- a problem fixed
- etc...



UNIQUENESS

Solution is unique for given set of stations, no matter:

- how many late files
- how many iterations

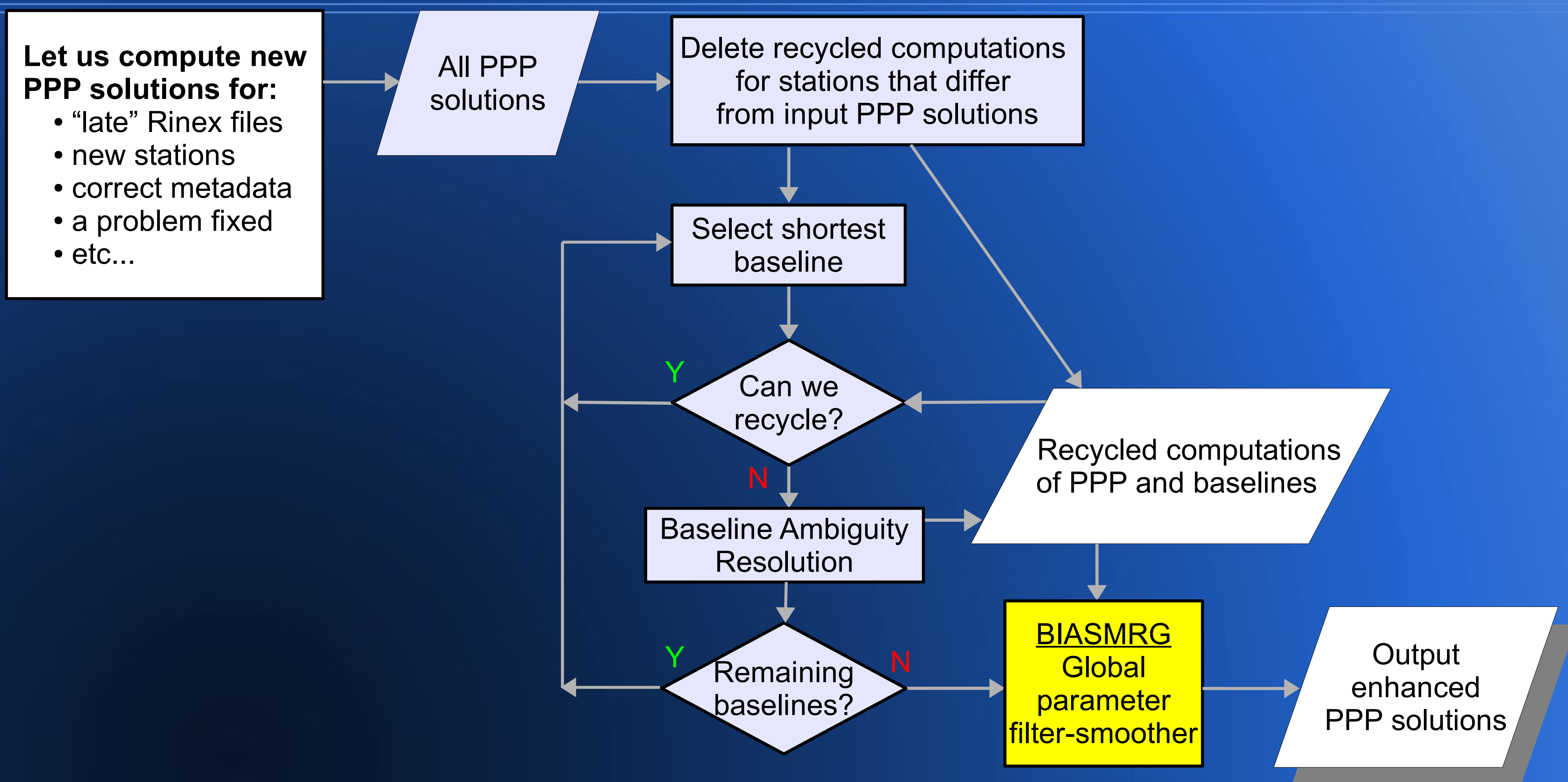
No need to wait for later data.

Simply process data as it becomes available.

No human decisions.

Design Feature: Biasmrg

Solving 500,000 Parameters by *O*(*N*)



Design Feature: Biasmrg

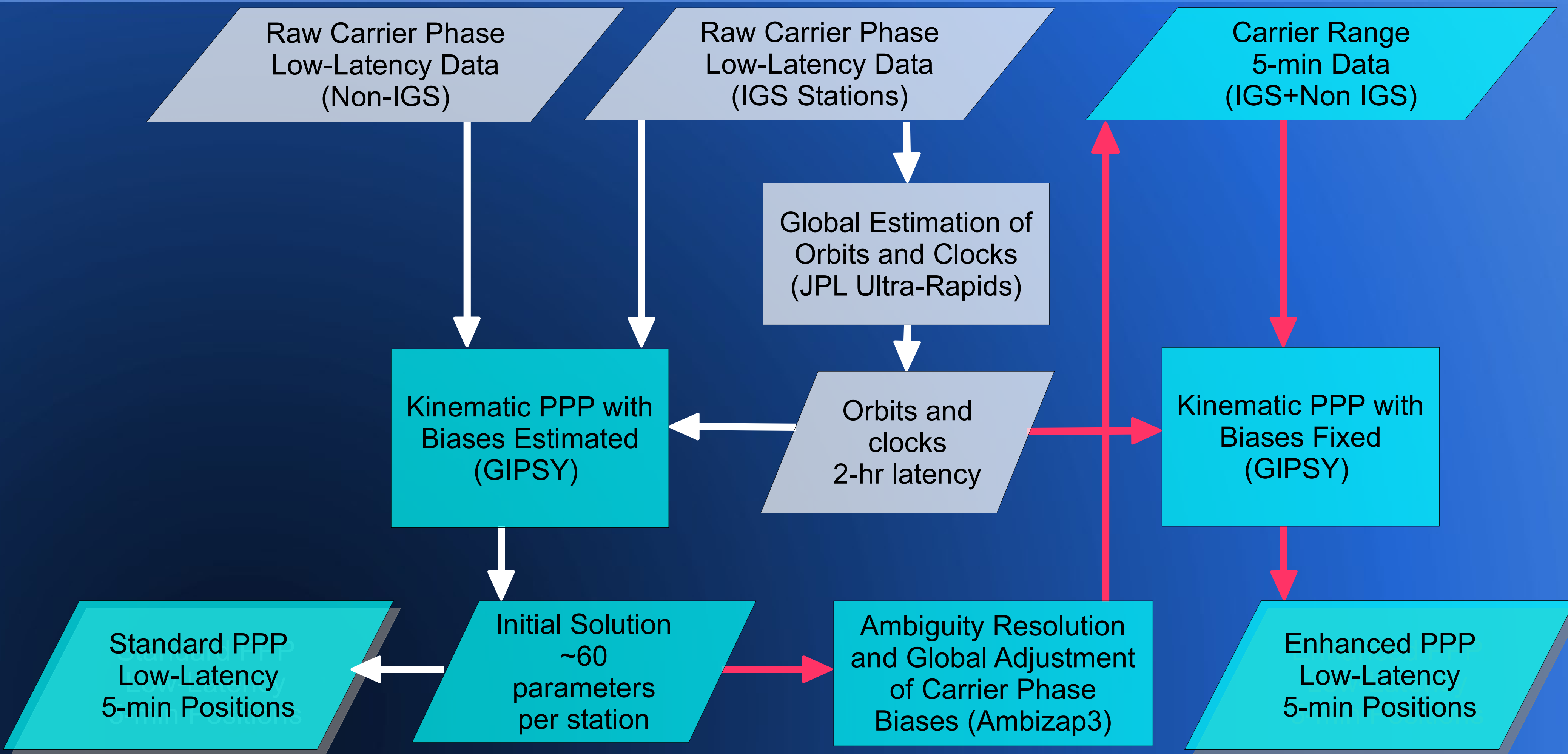
Solving 500,000 Parameters by *O*(*N*)

- Biasmrg (new in Ambizap3)
  - Merges ~60 parameters for (*N*-1) baselines
    - 60 = (x + y +z) + clock + (ztrop + etrop' + ntrop') + 53 biases
  - For N~8000, consistent global solution for ~500K parameters
- Extreme Form of Helmert Blocking
  - Filter-smoother, steps through "network space"
  - Recursive Fortran 90
  - Linear processing time, O(*N*)
  - Takes only a few minutes for *N*~8000
- Information Content
  - No "double counting" of stations in multiple baselines

Current Developments:
Carrier Range Data

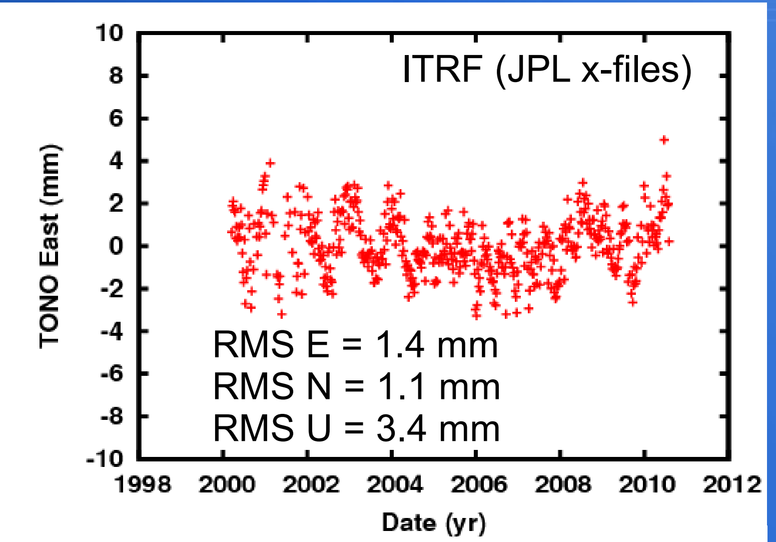
- "Carrier Range" = "Bias-Fixed Carrier Phase"
  - Calibrate Rinex carrier phase data for the carrier phase biases
  - Now we can apply PPP <u>but without bias estimation</u>
- Result
  - <u>Faster processing</u> with ambiguity-resolved precision
  - Can use carrier range for <u>kinematic PPP</u> (ambiguity-fixed)

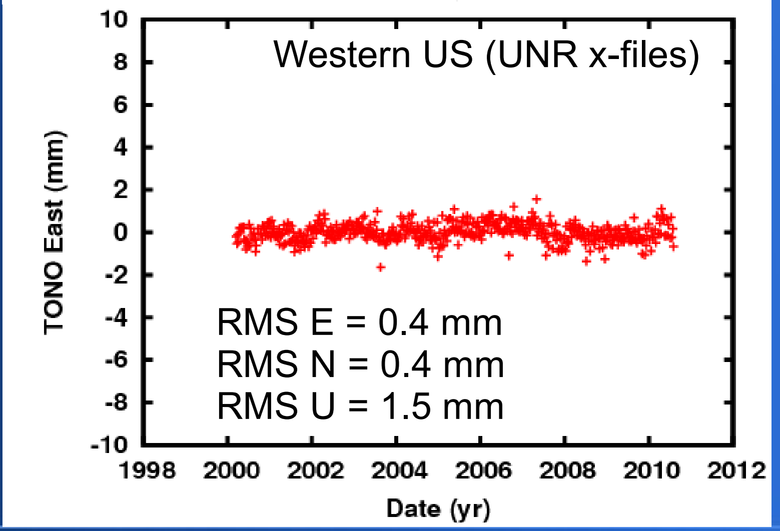
Current Developments:
5-min positions, low latency, all the world



Examples of Results:
"Best GPS Site in the World"

- TONO (Tonopah, Nevada)
  - Extremely dry, "no hydrology"
  - Bedrock, on top of hill
    - Deep-braced monument
    - Optimal horizon visibility
  - Instrumentally stable (>2000)
- Time series
  - (1) In ITRF (IGS05 from JPL)
  - (2) In western U.S. (UNR)
  - Weekly average position
  - Remove trend
  - Compute RMS

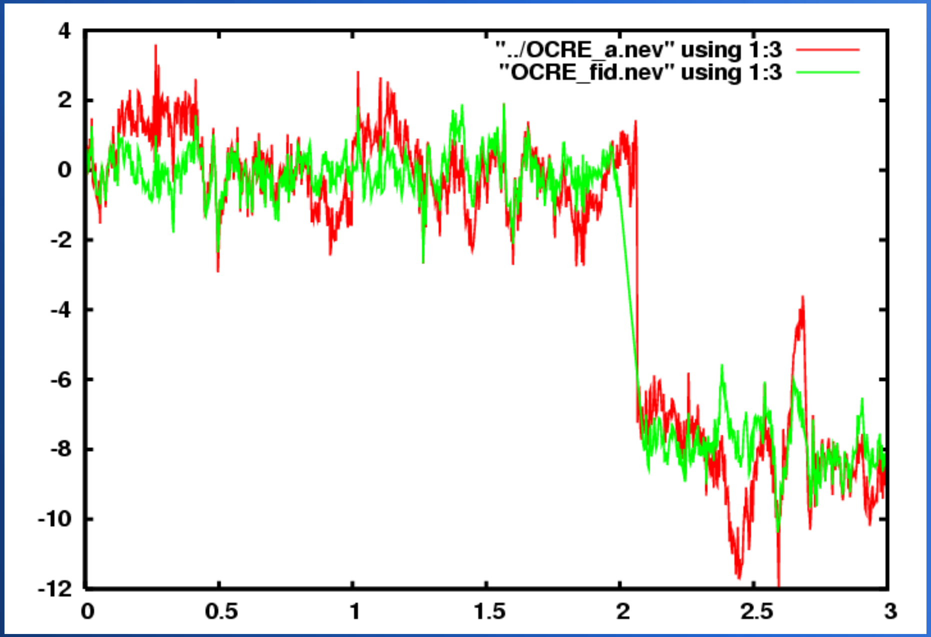




Examples of Results:
5-min Time Series

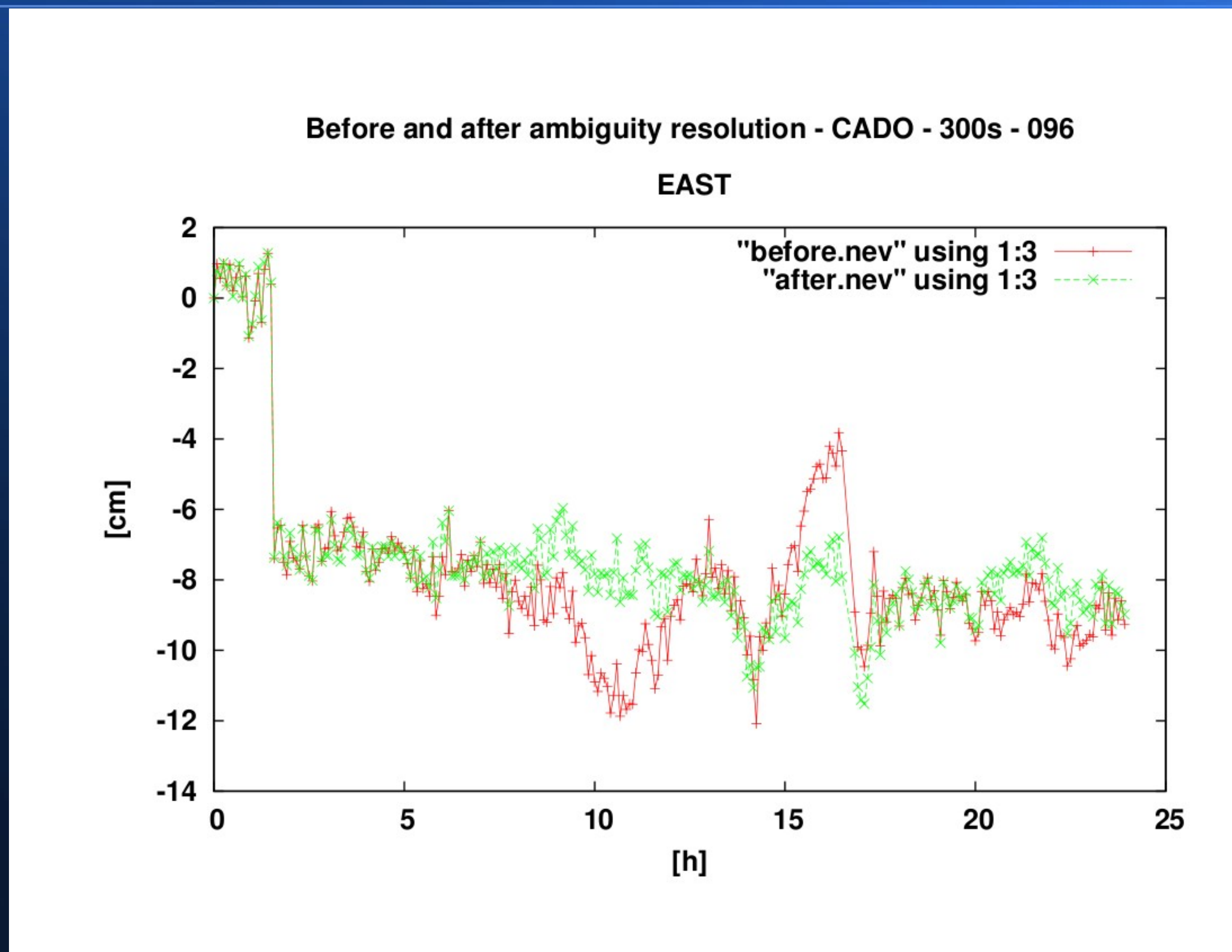
- L'Aquila Earthquake (INGV)
  - 6 April 2009, M_w 6.3
  - Example: station OCRE
  - Red = carrier phase **PPP**
  - Green = carrier range **EPPP**
  - **EPPP** = **PPP** + Ambizap3
  - Carrier range more accurately represents station motion

5-min time series over a 3 day period



RMS: PPP = 13 mm   EPPP = 7 mm

Carrier Range vs. Carrier Phase
L'Aquila 2009-04-06 M_w6.3, CADO
JPL Ultra-Rapid Orbits (2 hr latency)



Carrier Range vs. Carrier Phase
L'Aquila 2009-04-06 M_w6.3, ROIO
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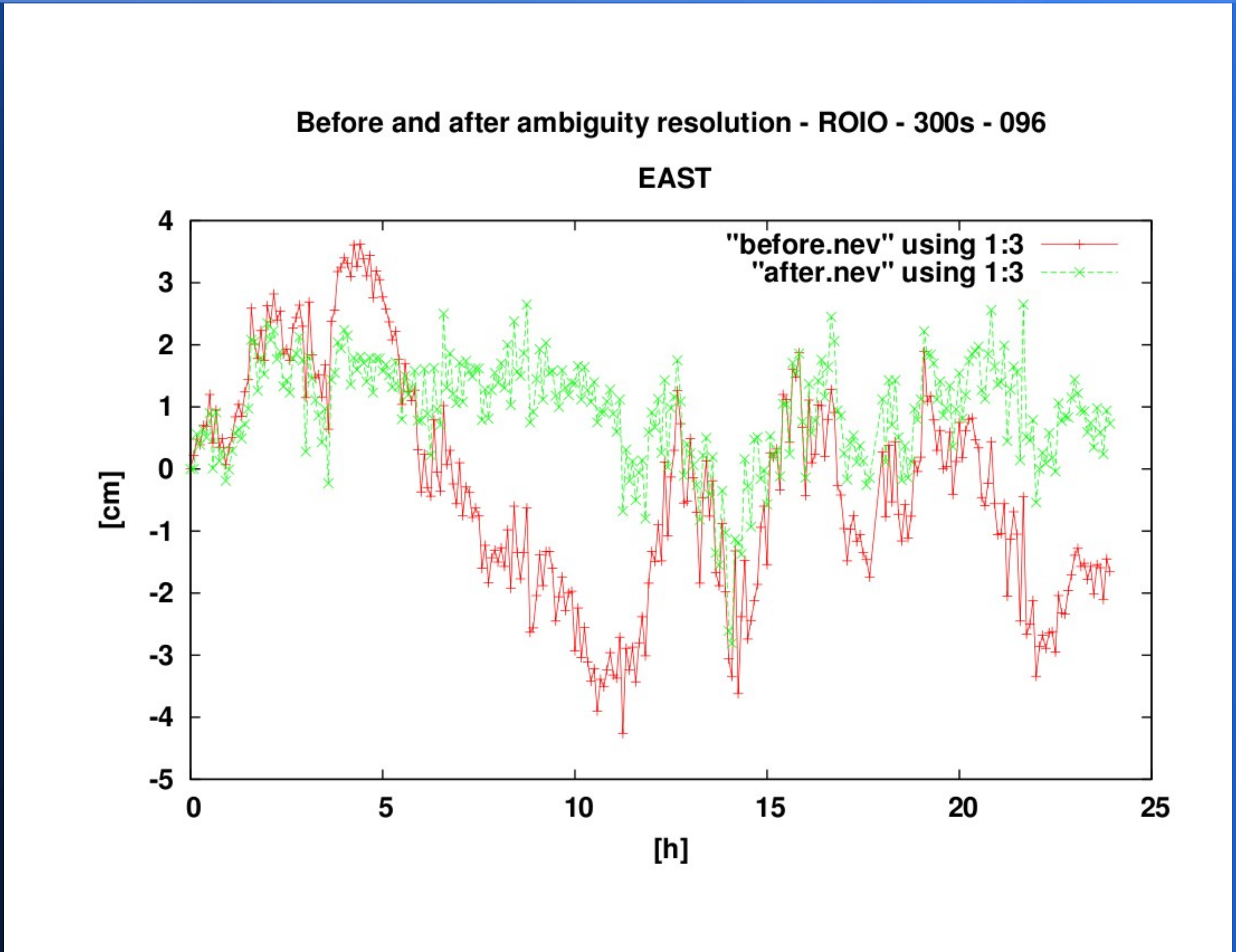

Conclusions

- Extreme Solutions for Extreme Problems...
  - "Geodetic Moore's Law" = *O*(*N*) PPP + "Real Moore's Law"
  - PPP with Ambiguity Resolution in O(*N*) using Ambizap
  - Kinematic PPP using Carrier Range in O(*N*) from Ambizap3
  - 5-min solutions with low latency for all the world in O(*N*)!
- Precision of Enhanced PPP (in ITRF)
  - RMS precision, 7 day: ~1 mm E,N 3 mm U
  - RMS precision, 24 hr: ~2 mm E,N 7 mm U
  - RMS precision, 5 min: ~7 mm E,N 20 mm U
- Processing time of Enhanced PPP
  - O(*N*)
  - 2 min / day / 100-cores / 1000-stations