# KAshima RAy-Tracing Service (KARATS)

## Fast ray-tracing algorithms through numerical weather models for real-time positioning applications in East Asia

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# Overview

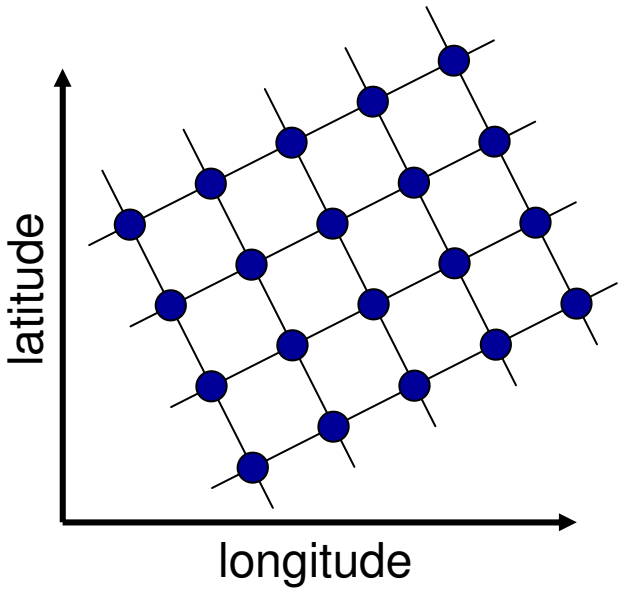
1. Numerical weather models (NWM) from JMA
2. Fast ray-tracing through numerical weather models (NMW)
3. Examples
4. KARATS
5. Outlook

# NWM from JMA

- **JMA provides information about**
  - Pressure (**P**), temperature (**T**), rel. humidity (which allows to calculate partial pressure of water vapour – $\mathbf{P_v}$)
  - Refractivity **N** can be used to compute troposphere delay

  - Raster width 10km (≈ 0.1 deg)
  - 21 pressure levels up to 10mb
  - Time resolution: 3 hrs

  - BUT:
  - ∗ grid-spacing is not constant in geographical system
  - ∗ Data given at isobaric levels



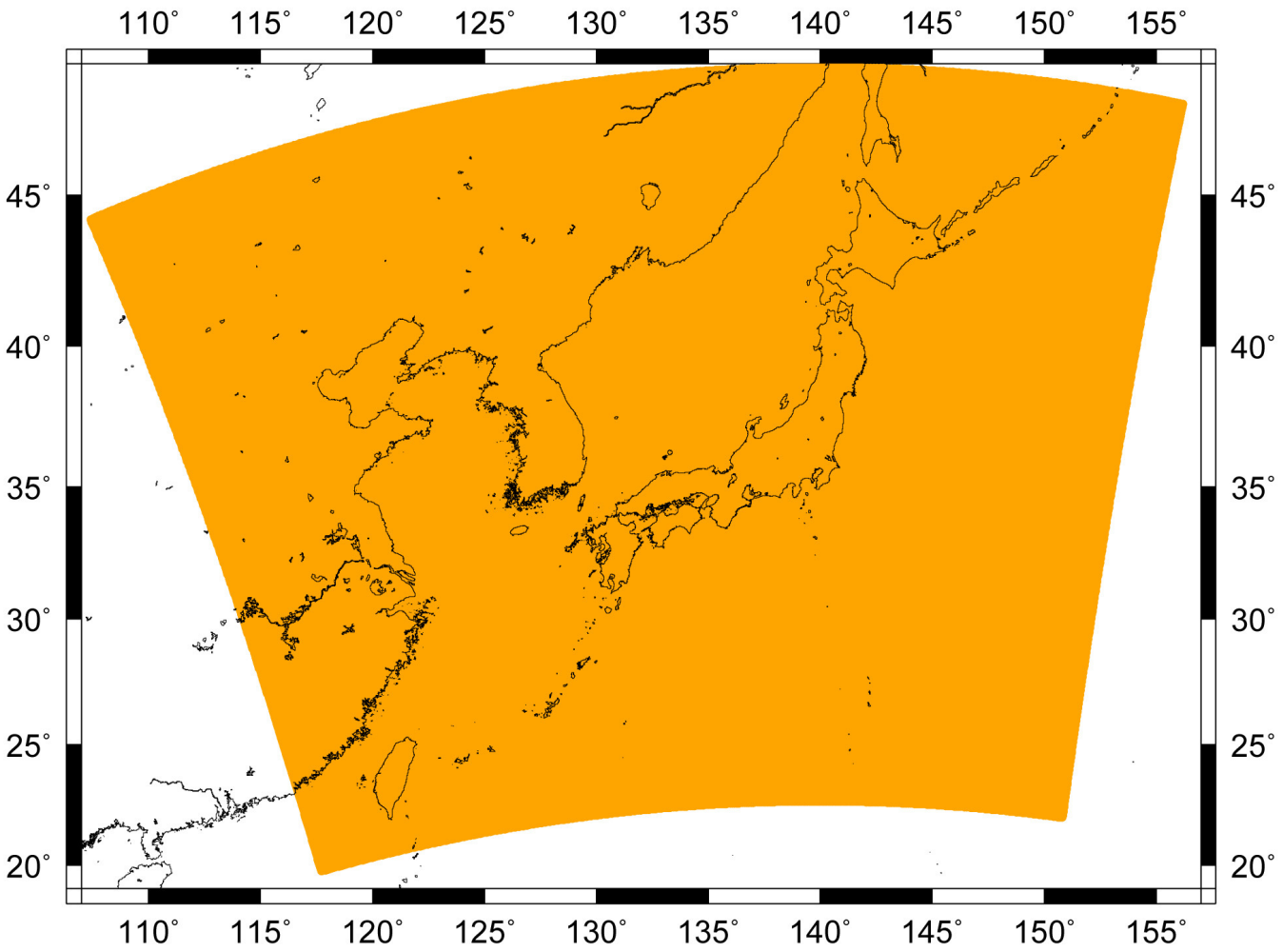

→ **Re-gridding to permit efficient ray-tracing computations**

# Height levels

- Standard Atmosphere 1976 is used to extend the region above 30 km
- Usage of 1x1 km ground topography, derived from SRTM
- Additionally, refractivity is provided at zero height level ("virtual layer" – since it has no physical meaning under land masses)

| from | to | height steps | Lat/Lon res. |
|---|---|---|---|
| topography | ---- | ---- | 1 km x 1km |
| ---- | 3 km | 30 m | 0.1 deg x 0.1 deg |
| 3 km | 10 km | 100 m | 0.1 deg x 0.1 deg |
| 10 km | 30 km | 500 m | 0.1 deg x 0.1 deg |
| 30 km | 86 km | 2000 m | 0.1 deg x 0.1 deg |

# Covered region




**Boundaries**

$\lambda=[107^{\circ},157^{\circ}]$

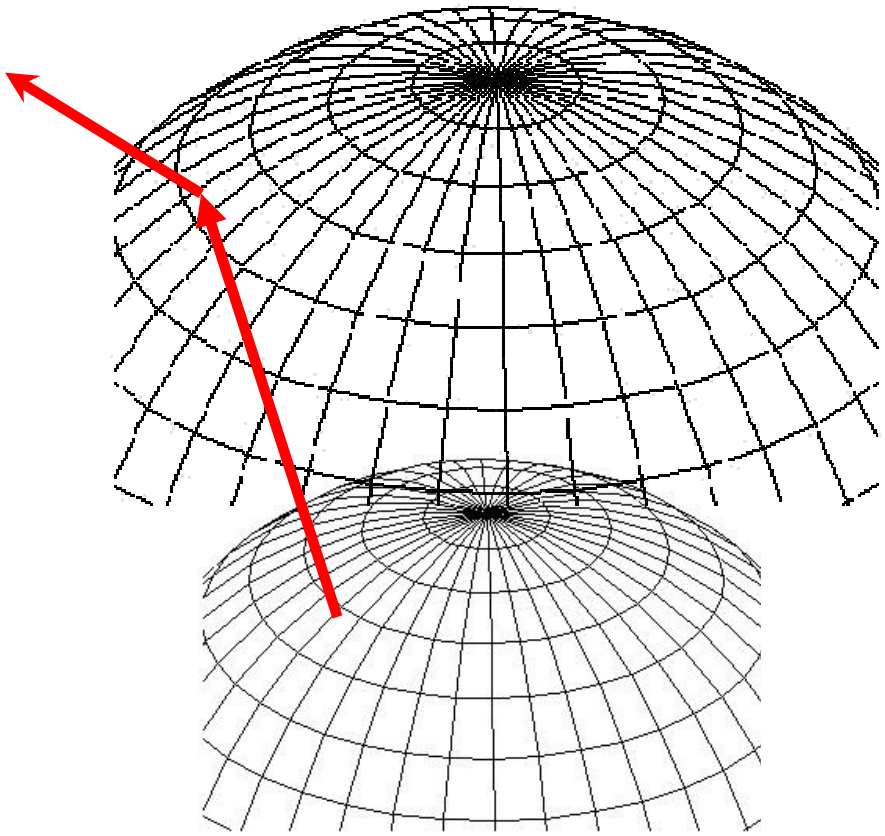
$\phi=[19^{\circ},49^{\circ}]$

Countries covered:

- Japan (100%)
- Korea (100%)
- Taiwan (100%)
- China (partly)

# Ray-tracing

- **Once the data slices have been prepared ray-tracing can be carried out very efficiently using analytical expressions for the calculation of**
  - 3D – intersection points with the slices
  - Delay inside the segments
  - Bending angle due to refractivity gradients



- **Output of total delay, bending angle and ground refractivity**

# Performance and Results

# Speed and data through-put

- **Preparing the data-set (computation of the slices)**

  **– computation takes about 30 sec./data-set, has do be done only once, thereafter the slices are stored in binary format for ray-tracing**

  **– 1 day (i.e. 8 epochs) ≈ 800 MB**

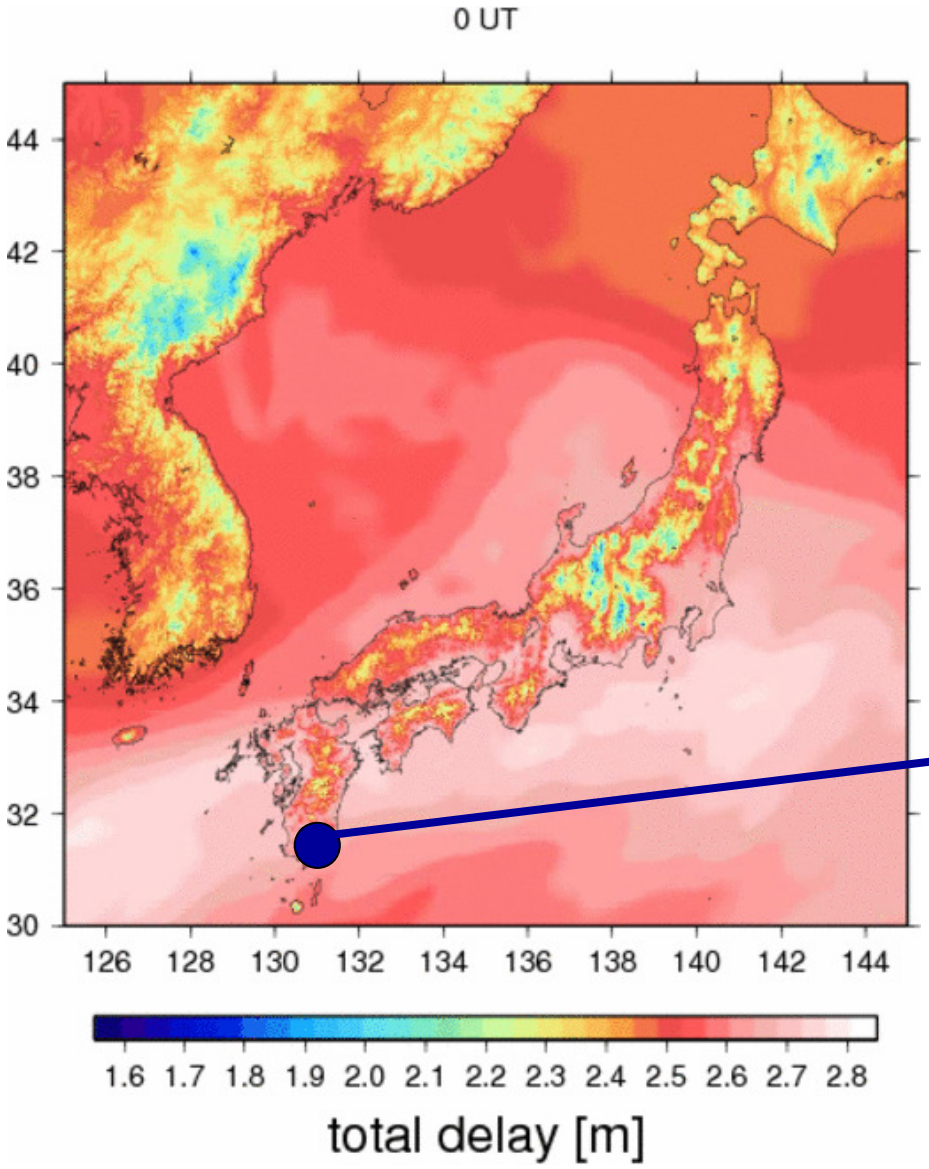
  **– values are represented by integer integer numbers (2 bytes)**

- **Ray-tracing through-put (on Pentium D, 3GHz)**

  – About 3 sec. for reading slices

  – **1200 observations / sec. !!!**

# Results




July 21, 2006:

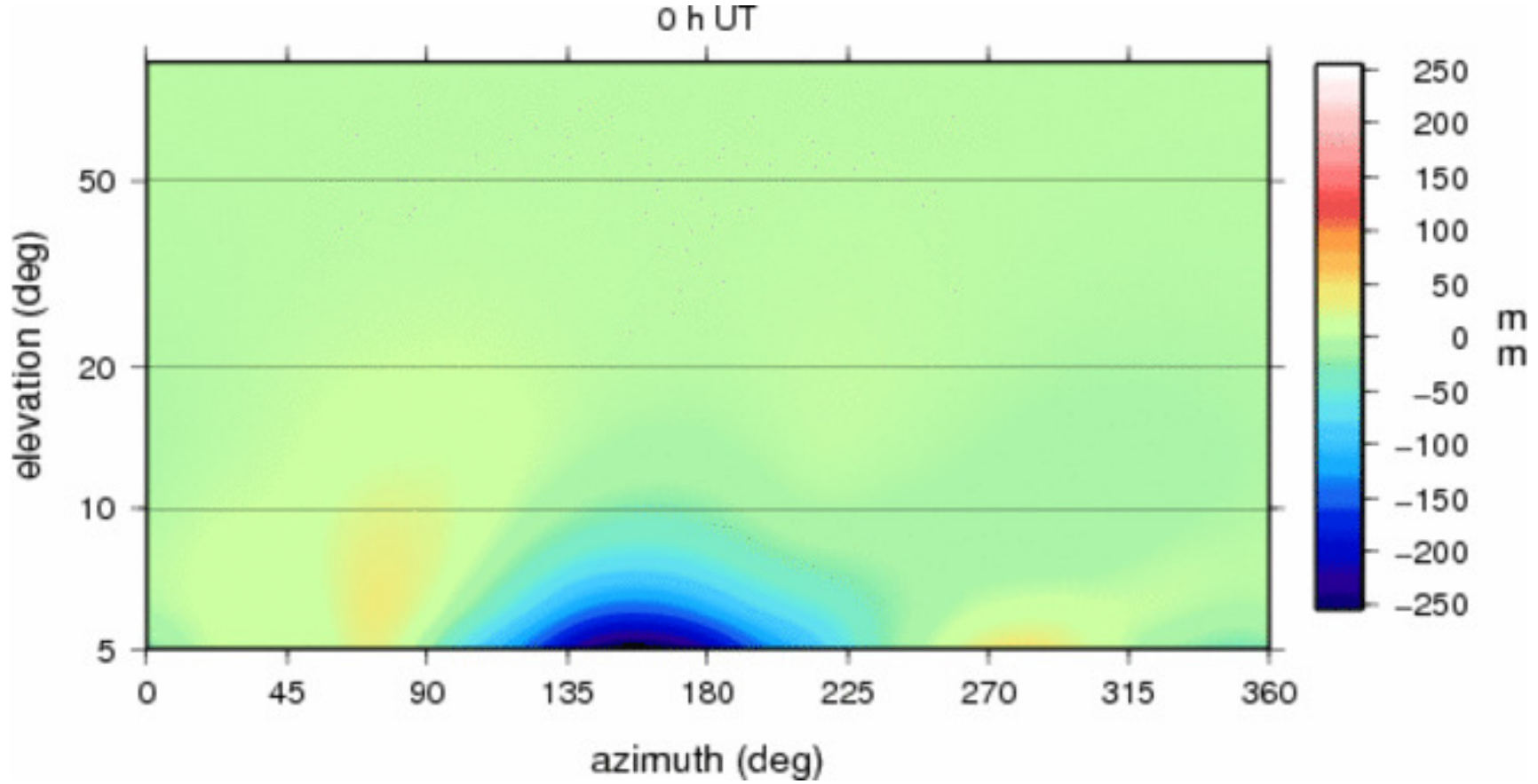
- **total troposphere zenith delay**
- **computed from ray-tracing**
- **complex weather situation**

Example:
AIRA (鹿児島)

# Results (contd.)

## July 21, 2006: Aira

Resid. delay (i.e. the delay excess due to the neglection of asymmetry)



# Improvement of (GPS) positions

- **Computed PPP solution using BERNESE 5.0 for station AIRA on July 21st, 2006**
- **First analysis run:**
  - RINEX obs, IGS final clocks + orbits
  - Estimated: station coordinates, clock, troposphere (Niell MF)
- **Second analysis run:**
  - Troposphere reduced RINEX file (RINEX handling by GPSTk)
  - IGS final clocks + orbits
  - Estimated: station coordinates, clock, troposphere (1/sin(e))

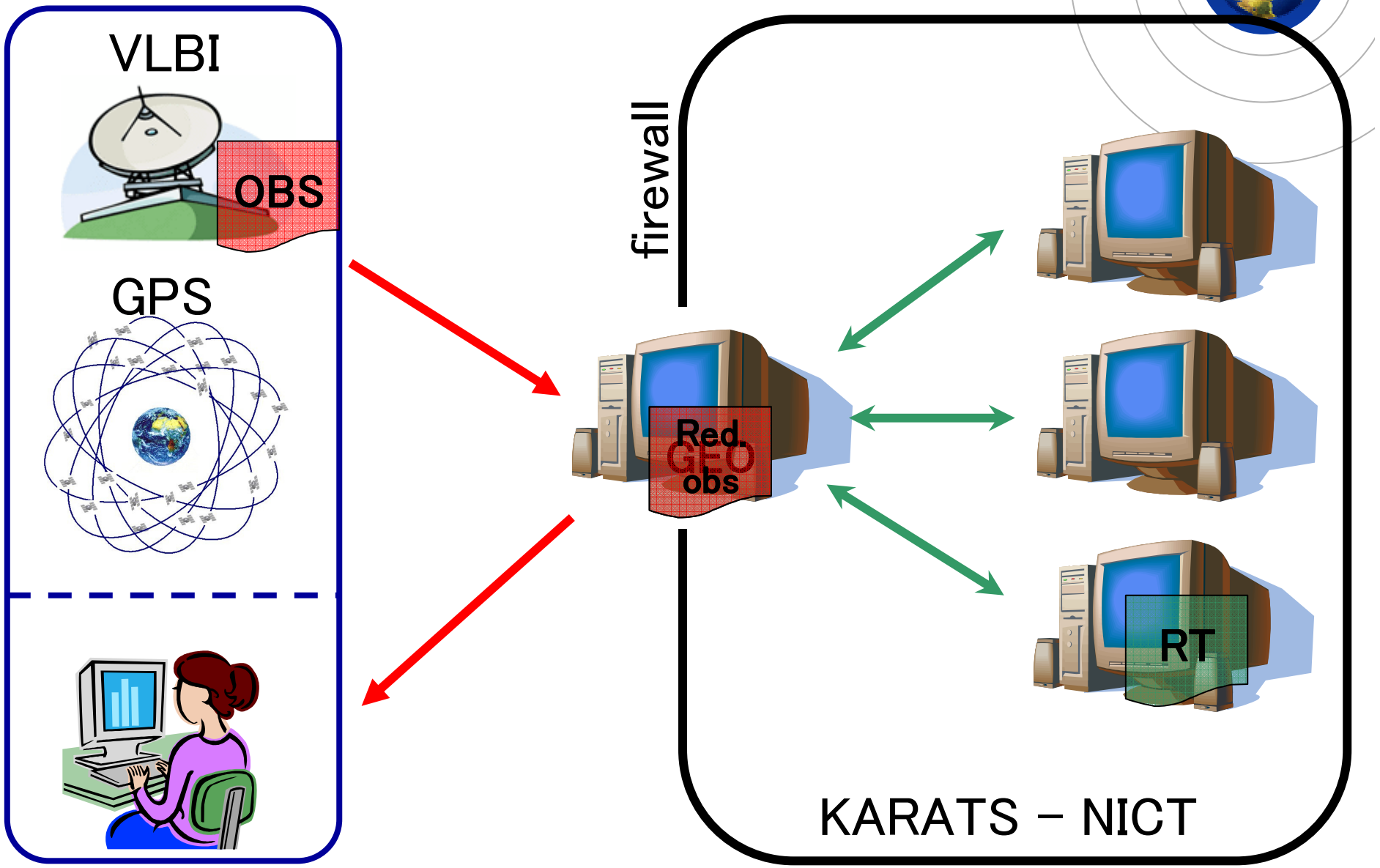
# Improvement of (GPS) positions ctd.

- **Results:**
  - > 99% of total troposphere are removed due to ray-tracing (estimated troposphere from approach two shows values <1 cm)
  - Formal errors of station heights reduce by a factor of 3 compared to first approach
  - Formal errors of horizontal position reduce by a factor of 1.5
  - Error ellipsoid of PPP solution shrinks by a factor >2
  - Troposphere free solution agrees well (difference < 2mm) with daily GEONET solution, whereas the first solution has larger differences (>4 mm)
  - Clock estimates of both strategies are identical

# Improvement of (GPS) positions ctd.

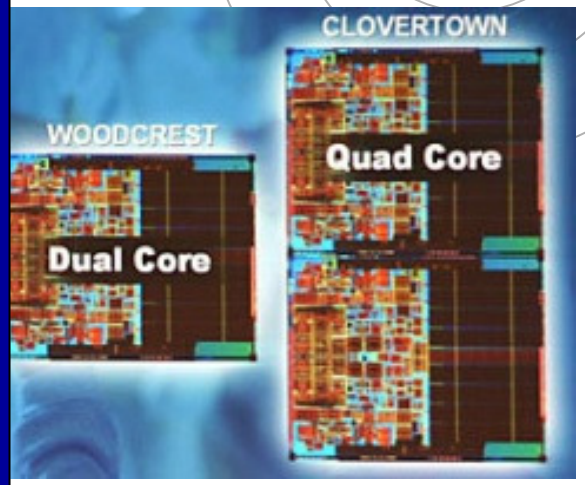
- **Thus:**
  - A simple mapping function (1/sin(e)) can be used to catch the remaining troposphere delay
  - Asymmetric contributions are completely removed (verified by estimation of gradients, too)
- **Currently:**
  - rigorous tests covering longer time-spans and including more stations to obtain significant values of improvements

# KARATS processing chain



# Planned improvements

- Optimizing code
  dual/multi-core
  architectures (p
  done), will be im
  OPENMP™
- Making usage of
  processing strat
- End of year goa
  process all 1300
  using 1 Hz samp
  machines


s allows to
rs in real-time
by 4 quad-core

# Planned improvements (ctd.)

- Direct interfaces to GPS & VLBI observation formats
- Use weather prediction data for real-time applications (contracting in progress)
- Replace the 10km x 10km by the 5km x 5km JMA model (contracting in progress)
- Improve time interpolation between two NWM epochs

# KAshima Ray-tracing Service (KARATS)

## Post-processing mode

- **Planned to be operational within the 2nd half of 2007**
- **Free of charge**
- **User uploads observation files (GPS, VLBI ...)**
- **Planned formats to be supported**
  - GPS: RINEX
  - VLBI: MK3, FITS (?)
  - Plain text: user provides only geometry
- **Expected turn-around time < 1 min / file**
- **Time coverage of data: TBD**

# Acknowledgements

***Thank you for your attention !***

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