KAshima RAy-Tracing Service (KARATS)

Fast ray-tracing through numerical weather models for real-time positioning applications

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Overview

1. **Numerical weather models (NWM) from the Japanese Meteorologic Agency (JMA) – advantages and drawbacks for ray-tracing applications**
2. **Fast ray-tracing through numerical weather models (NMW)**
   - Re-sampling of NMW, usage of a fine mesh topography
   - Analytic ray-tracing
   - Speed and data throughput
3. **Examples**
4. **Outlook**
   - Planned improvements
   - KAshima RAytracing Service (KARATS)

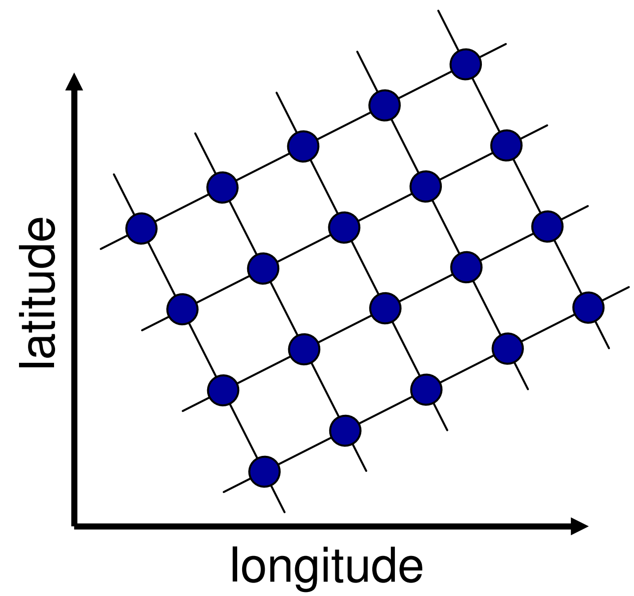
NWM from JMA

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

$$N = (n-1) \times 10^6 = 77.6 \times (\frac{P}{T}) + 3.82 \times 10^5 (\frac{P_v}{T^2})$$

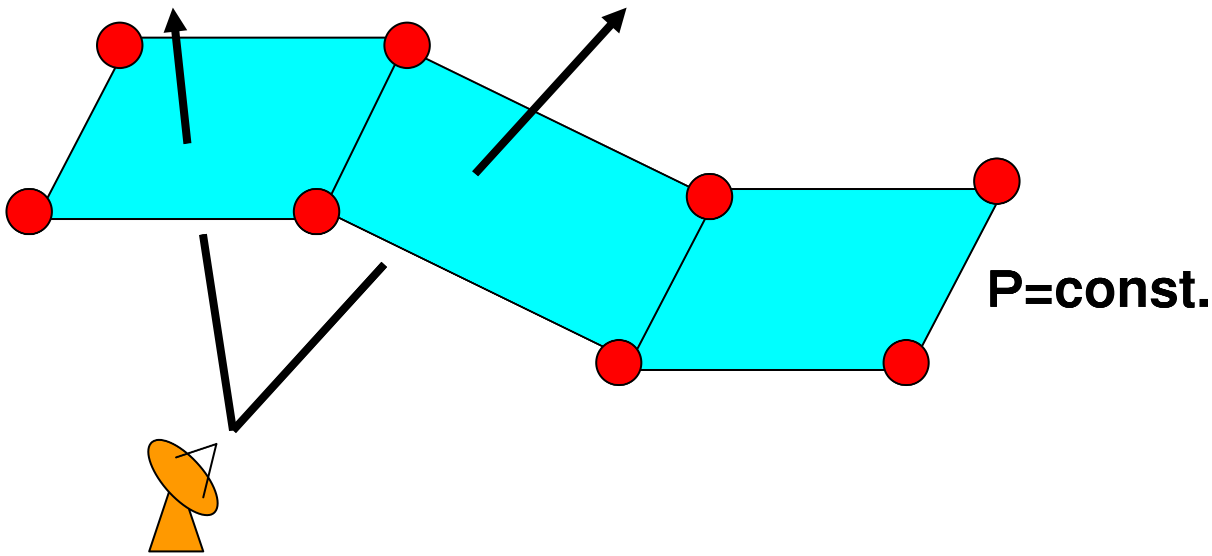
  - Refractivity **N** can be used to compute troposphere delay

  - Raster width 10km (≈ 0.1 deg)
  - 21 pressure levels up to 10mb
  - BUT: grid-spacing is not constant in geographical system



NWM contd.

- **Data is sliced at isobaric levels (constant pressure), thus the height of grid-points is varying →ray tracing is time consuming**

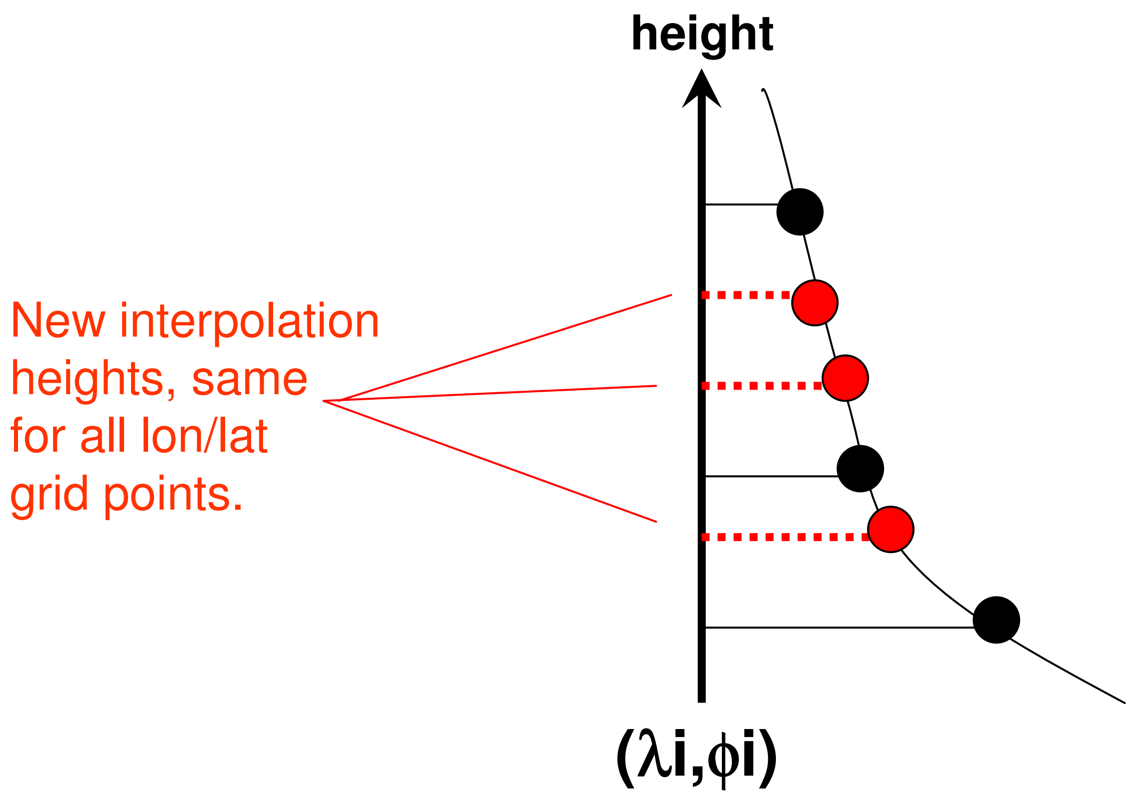


- **Data grid of NWM does not permit analytical ray-tracing**

→ re-gridding data

2.5D interpolation algorithm

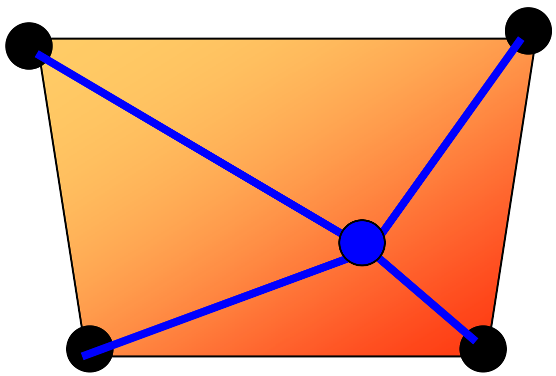
- **First step: Linear interpolation in height profile at each lon/lat grid node**



- **Advantage: curvature of the Earth has no influence, since profiles are assigned to geographic coordinates**

2.5D interpolation algorithm (contd.)

- **Second step: 2D Shepard interpolation in lon/lat domain**



$$\hat{d}(\mathbf{x}) = \frac{\sum w_k(\mathbf{x}) d_k}{\sum w_k(\mathbf{x})}$$

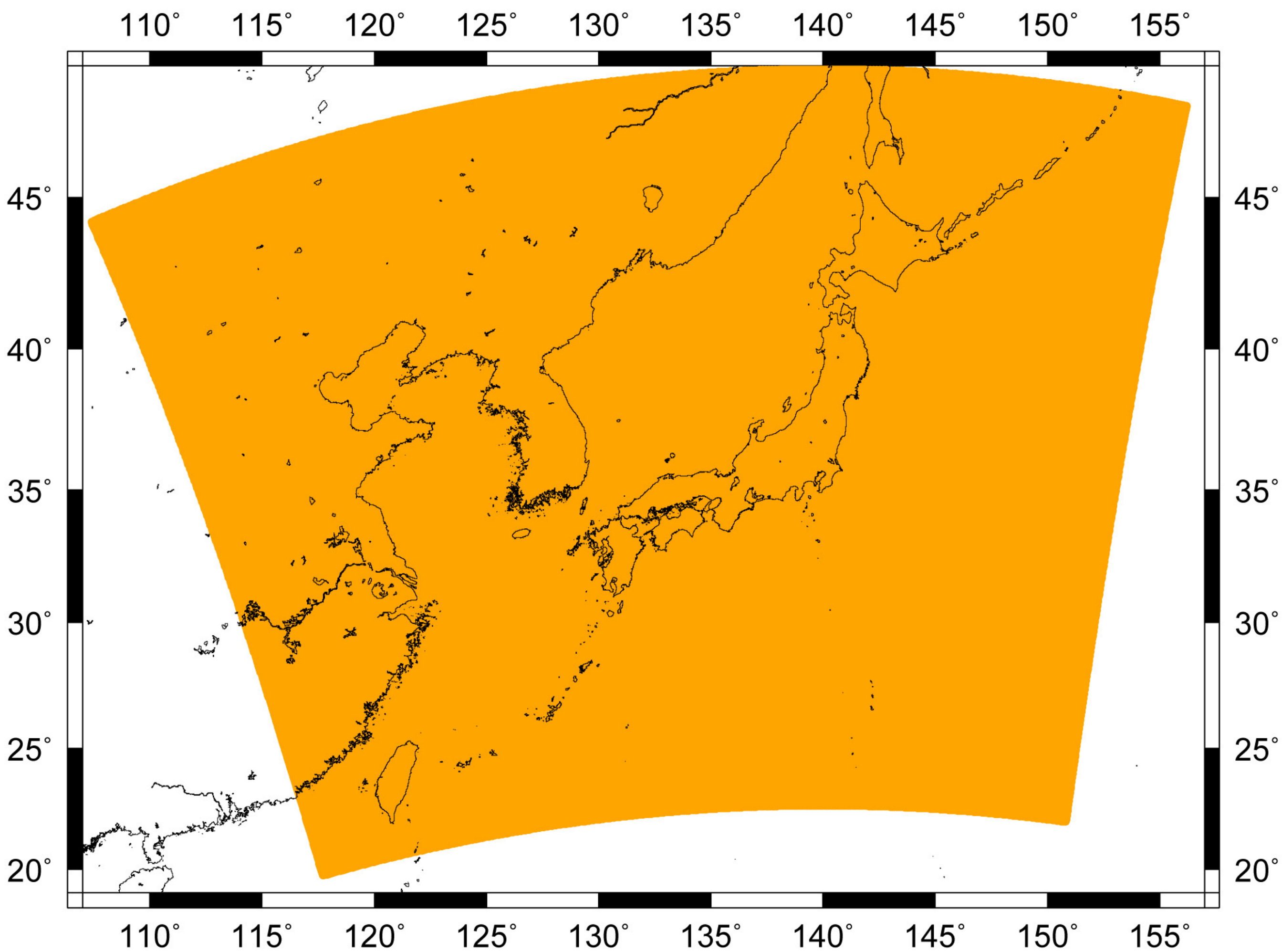
$$w_k(\mathbf{x}) = \|\mathbf{x} - \mathbf{x}_k\|^{-p}.$$

2.5D interpolation algorithm (contd.)

- Shepard interpolation is implemented by grid partitioning (new approach) which speeds up computations by a factor of 100, compared to usual way
- Additional: 1km x 1km ground topography from Shuttle Radar Topography Mission, full 3D Shepard interpolation for this grid
- Standard Atmosphere 1976 is used to extend region above 30 km

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

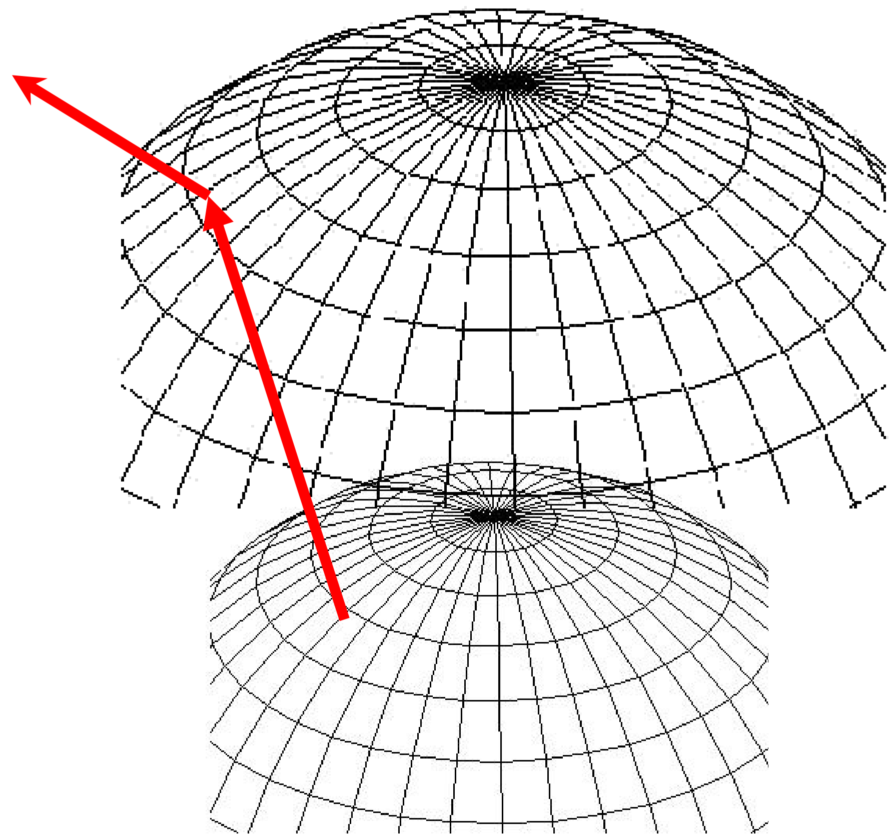


$\lambda=[107^{\circ},157^{\circ}]$
$\phi=[19^{\circ},49^{\circ}]$

Countries covered:
- Japan (100%)
- Korea (100%)
- Taiwan (100%)
- China (partly)

Ray-tracing

- **Once the data slices have been prepared ray-tracing can be carried 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**

Speed and data through-put

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

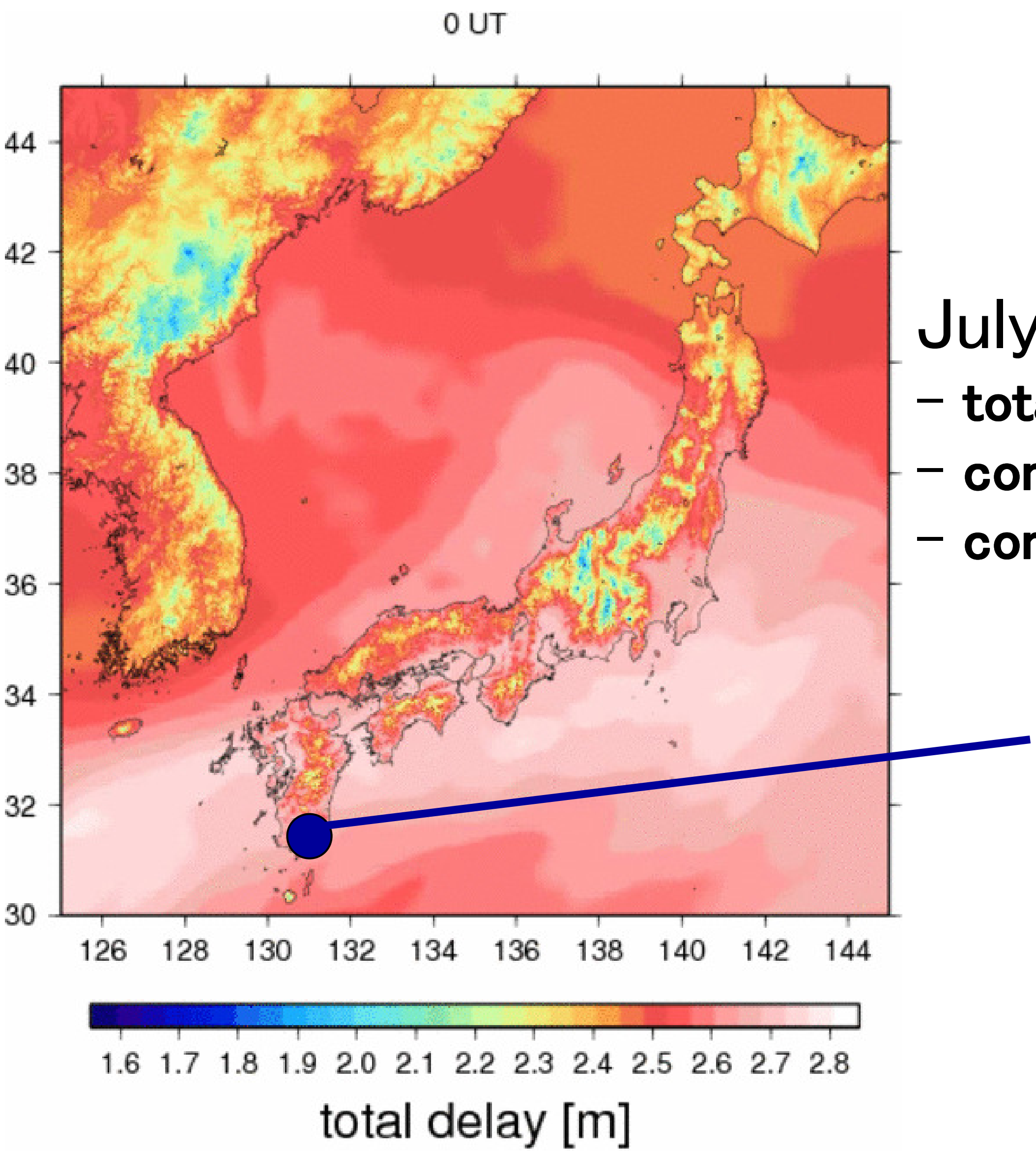
  – computation takes about 30 sec./data-set, has do be done only once, thereafter the slices are stored in binary format for ray-tracing

  – 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
  - **<u>1000 observations / sec. !!!</u>**

Results



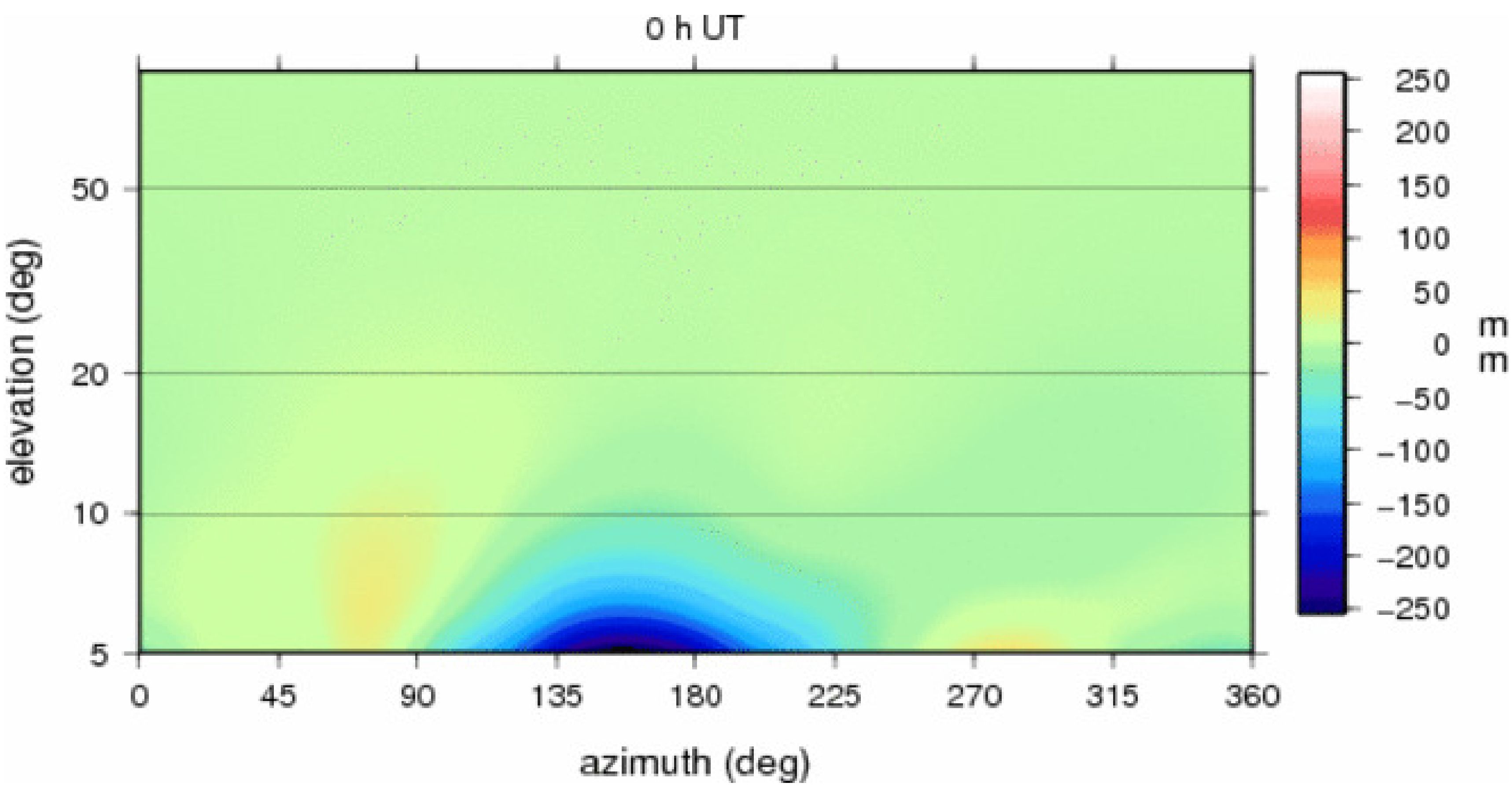
July 21, 2006:

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

Results (contd.)

July 21, 2006: Aira (鹿児島)

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



Improvement of (GPS) positions

- **First tests with GPS data have shown that**
  - At least 99% of total troposphere are removed due to ray-tracing
  - A simple mapping function (1/sin(e)) can be used to catch the remaining troposphere delay
  - Asymmetric contributions are completely removed
  - Formal errors of station heights reduce by a factor of 2-4, doing Precise Point Positioning (PPP), compared to traditional approach (Niell mapping function)
  - Error ellipsoid of PPP solution shrinks by a factor >2
- **Currently: rigorous tests covering longer time-spans and including more stations to obtain significant values of improvements**

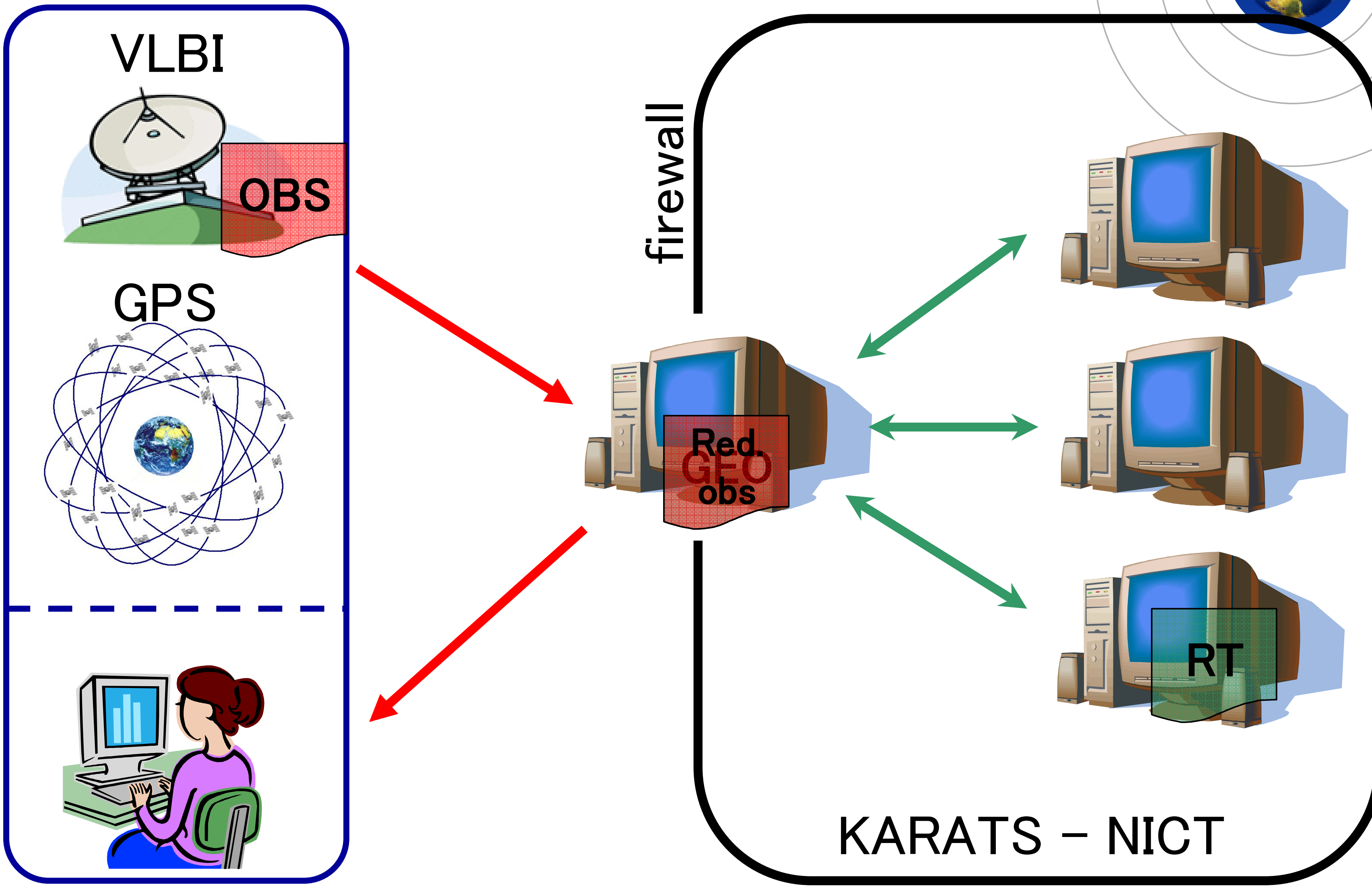
Planned improvements

- Optimizing code for dual/multi-core processor architectures
- Making usage of distributed processing strategies
- Interfaces to GPS & VLBI observation formats
- Replace the 10km x 10km by the 5km x 5km JMA model
- Use weather prediction data for real-time applications
- End of year goal: >15.000 obs./sec (this allows to process all 1200 GPS GEONET receivers in real-time using 1 Hz sampling, note: the 30s sampling mode can already be processed in real-time)

KAshima Ray-tracing Service (KARATS)

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

KARATS processing chain



Acknowledgements

Thank you for your attention !

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