In-situ observation of thermospheric gravity waves by GOCE

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0. Science Questions

- **What is the characteristics and distribution of gravity waves (GWs) in quiet-time (low Kp) thermosphere?**

1. Goals & Motivation

- Determine the time, location and intrinsic parameters of thermospheric GWs observed by GOCE satellites.
- Determine the uncertainties (errors) of derived intrinsic GW parameters.
- Investigate the thermospheric GWs during geomagnetic quiet times.
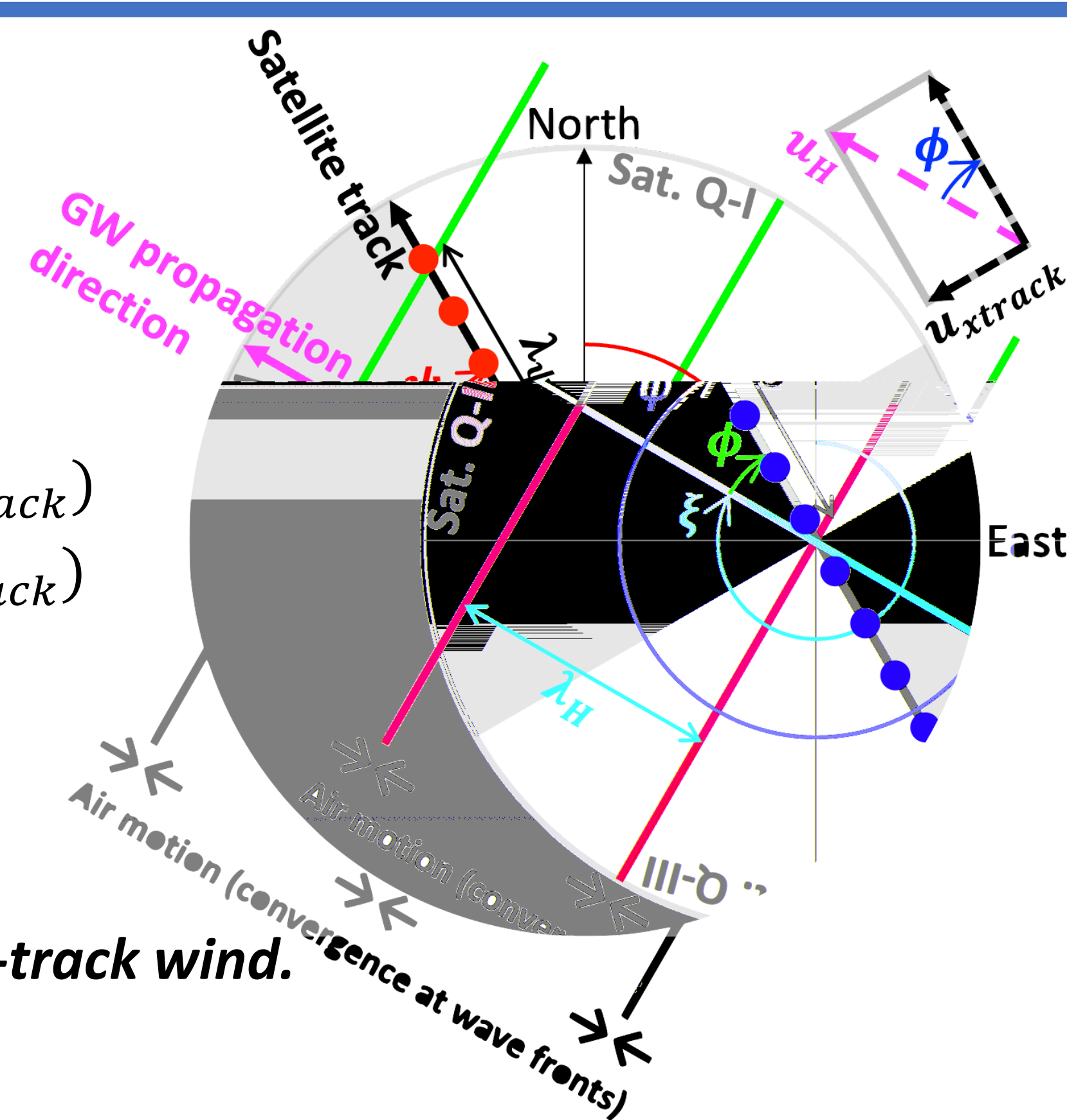
2. GOCE *in-situ* measurements

- **Density and x-track wind** derived from 6 accelerometers
- Altitude: ~270 km
- Velocity: ~7.8 km/sec
- Life span: 2009-11 ~ 2013-10
- Time resolution: 10 sec
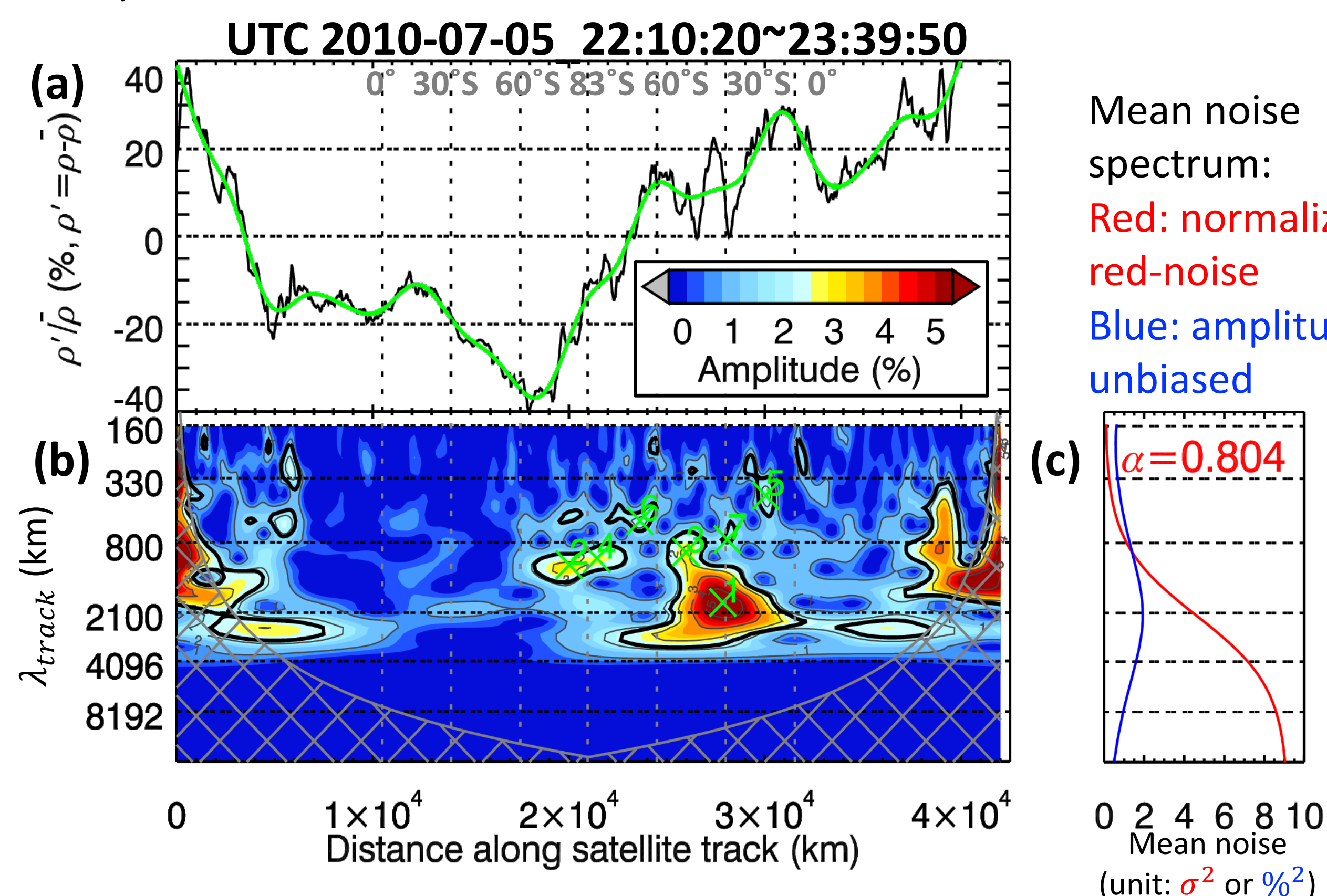
3. Methodology

- **Dispersion & polarization relation** of thermospheric GW (Vadas & Nicolls, 2012)
  $\Rightarrow$ **Complex function G:**

$$\begin{cases} -G_{arg}(\phi, \lambda_z) = PS(\tilde\rho, \tilde u_{xtrack}) \\ G_{mod}(\phi, \lambda_z) = AR(\tilde\rho, \tilde u_{xtrack}) \end{cases}$$

"PS" = phase shift.
"AR" = amplitude ratio.
$\tilde\rho = \rho'/\bar\rho$.
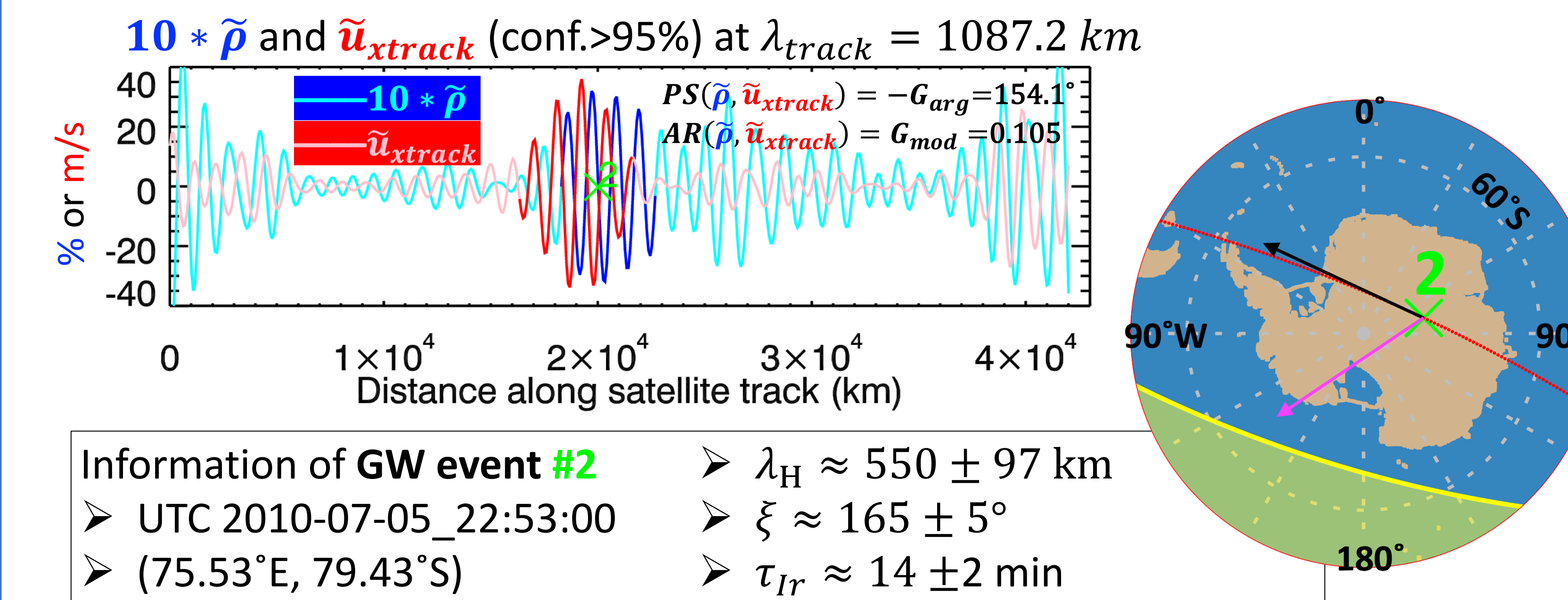$\tilde u_{xtrack}$ = perturbation of x-track wind.

- Use **red-noise** model and **Wavelet analysis** (Torrence & Compo, 1998) to determine the **power, location and uncertainty** of each **traveling atmospheric disturbance (TAD)** event.
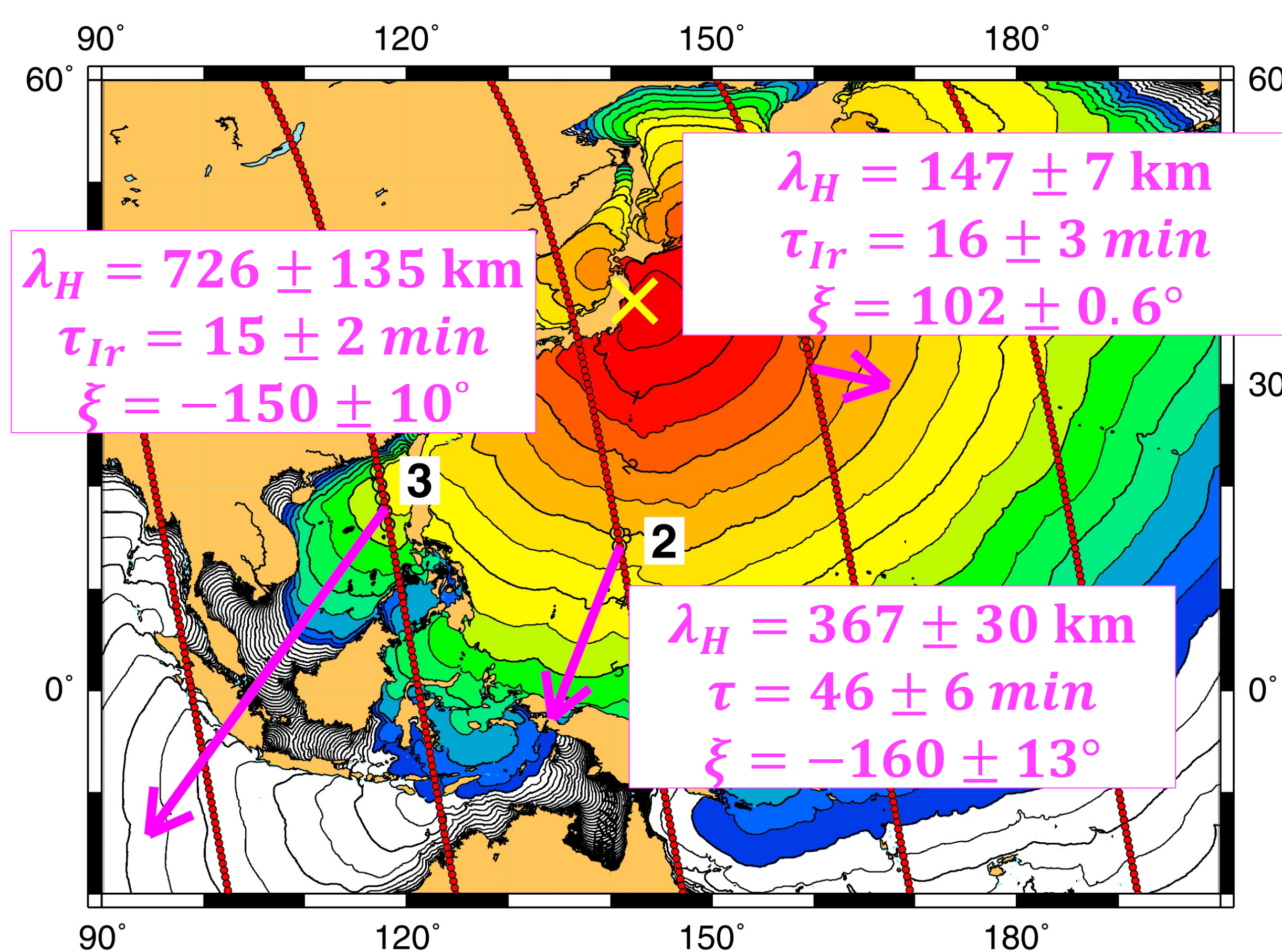- **Power spectrum** $\Rightarrow$ **rectified amplitude spectrum** (Chen et al., 2016)

UTC 2010-07-05 22:10:20~23:39:50

Mean noise spectrum:
Red: normalized red-noise
Blue: amplitude unbiased
$\alpha = 0.804$

4. Results

Case example: Deriving intrinsic parameters of a GW event.

$10 * \tilde\rho$ and $\tilde u_{xtrack}$ (conf.>95%) at $\lambda_{track} = 1087.2\ km$

$PS(\tilde\rho, \tilde u_{xtrack}) = -G_{arg} = 154.1°$
$AR(\tilde\rho, \tilde u_{xtrack}) = G_{mod} = 0.105$

Information of **GW event #2**
- UTC 2010-07-05_22:53:00
- (75.53°E, 79.43°S)
- $\lambda_H \approx 550 \pm 97$ km
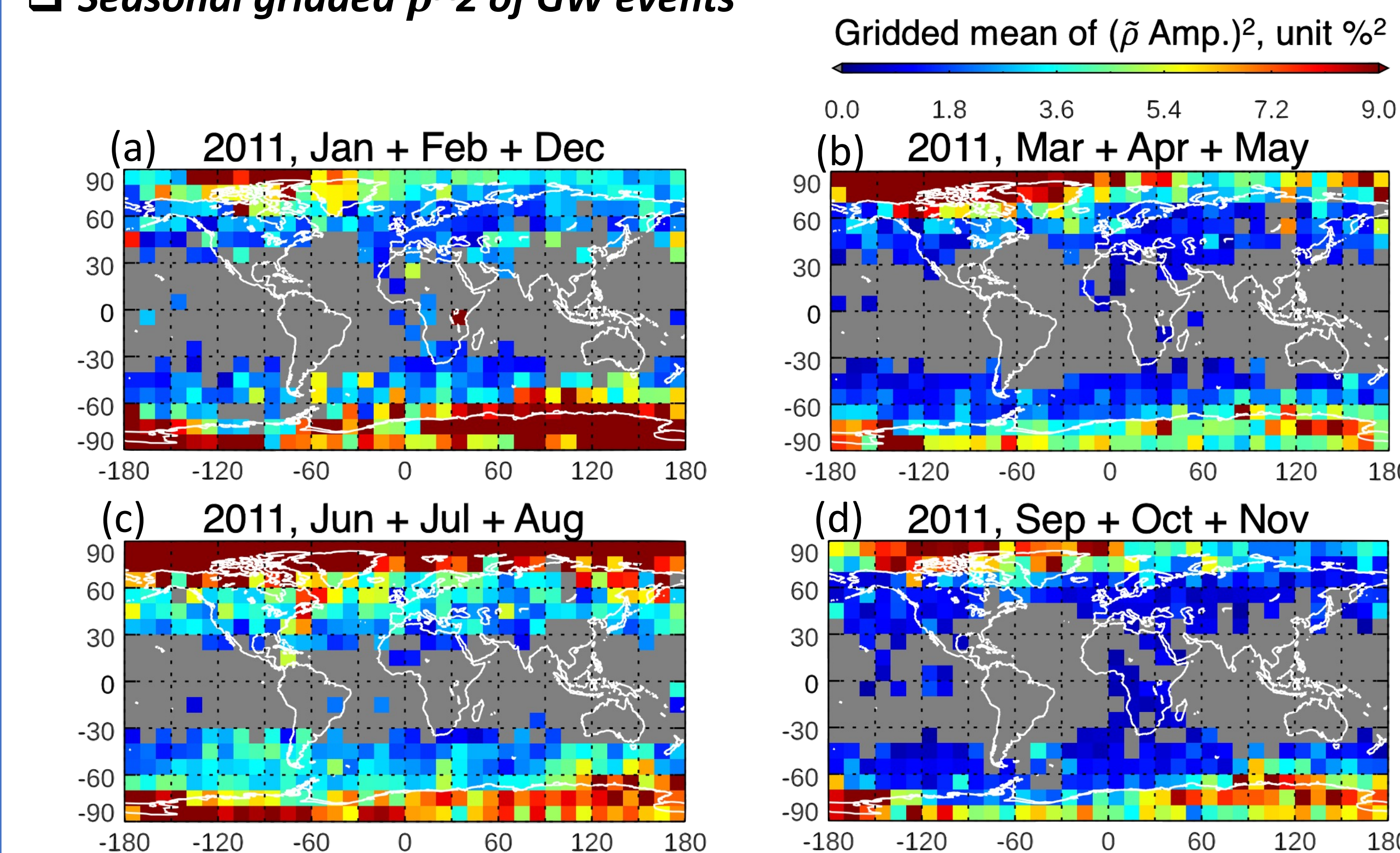- $\xi \approx 165 \pm 5°$
- $\tau_{Ir} \approx 14 \pm 2$ min

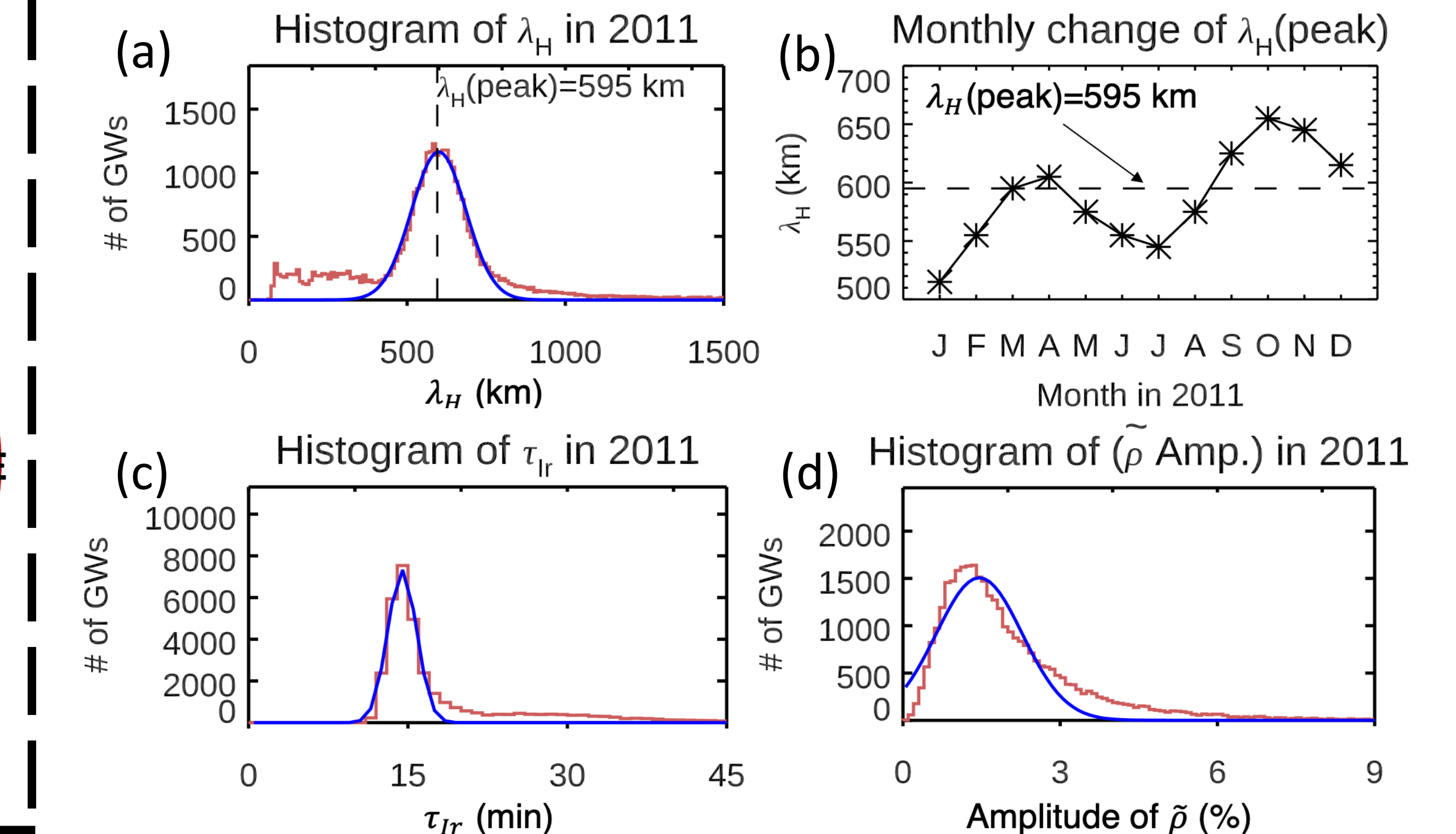### Methodology validation using the tsunami-generated GW cases.

Tsunami occurrence: 05:46 UTC on 11 March 2011 (⊠). GOCE observed tsunami-generated GWs in 3 orbits.

(Base map and Tsunami Travel Time are from Figure 1 of Garcia et al. (2014))

$\lambda_H = 726 \pm 135$ km
$\tau_{Ir} = 15 \pm 2\ min$
$\xi = -150 \pm 10°$

$\lambda_H = 147 \pm 7$ km
$\tau_{Ir} = 16 \pm 3\ min$
$\xi = 102 \pm 0.6°$

$\lambda_H = 367 \pm 30$ km
$\tau = 46 \pm 6\ min$
$\xi = -160 \pm 13°$

Seasonal gridded $\tilde\rho^2$ of GW events

Gridded mean of $(\tilde\rho\ Amp.)^2$, unit %²

(a) 2011, Jan + Feb + Dec
(b) 2011, Mar + Apr + May
(c) 2011, Jun + Jul + Aug
(d) 2011, Sep + Oct + Nov

Statistics of GW intrinsic parameters in 2011

(a) Histogram of λ_H in 2011, λ_H(peak)=595 km
(b) Monthly change of λ_H(peak), λ_H(peak)=595 km
(c) Histogram of τ_{Ir} in 2011
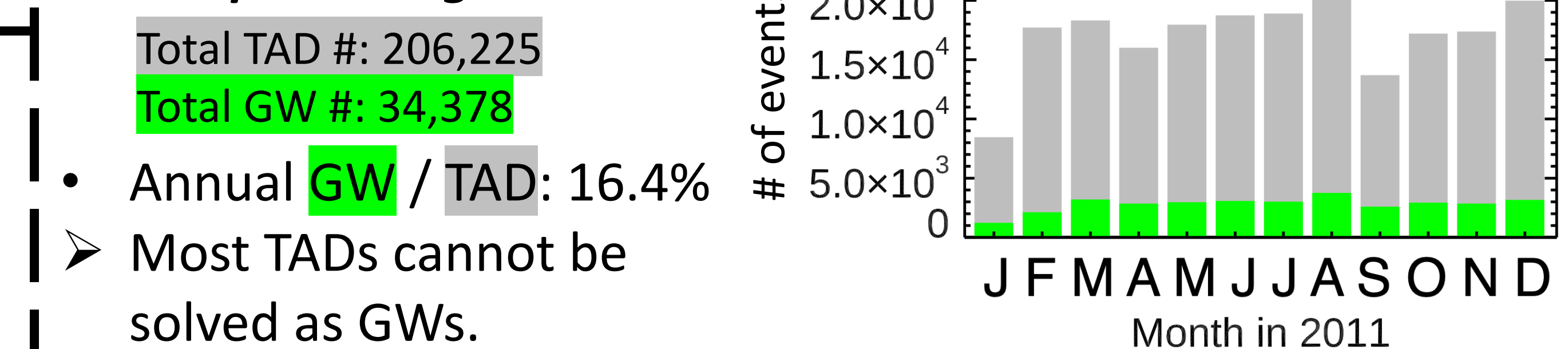(d) Histogram of ($\tilde\rho$ Amp.) in 2011

(a) λ_H peak at 550–650 km
(b) λ_H in equinoxes > in solstices.
(c) τ_{Ir} peak at ~15 min.
(d) $\tilde\rho$ Amp. peak at 1–2 %.

Statistics of GW propagation directions in 2011

(a) 2011, Jan + Feb + Dec
(b) 2011, Mar + Apr + May
(c) 2011, Jun + Jul + Aug
(d) 2011, Sep + Oct + Nov

- GWs over 30°–60°N in June solstice season mostly propagate **NE-ward**.

GW percentage

Total TAD #: 206,225
Total GW #: 34,378

- Annual GW / TAD: 16.4%
- Most TADs cannot be solved as GWs.

5. Summary

- Retrieved the **locations, amplitudes, and confidences of the TADs** along GOCE satellite tracks during quiet-time. **Identified and solved intrinsic parameters of GWs** among them.
- Predict reasonable GW parameters generated by Tohoku Tsunami on 11 Mar. 2011 **w/o any assumed limits from surface conditions**.
- Preliminary statistical monthly and seasonal results of thermospheric GWs observed by GOCE at z≈270 km.

References

- Torrence & Compo (1998) BAMS.
- Vadas & Nicolls (2012) JGR Space Phy.
- Garcia et al. (2014) JGR Atmos.
- Chen et al., (2016) JGR Space Phy.