Analysis and forecast using dropsonde data from inner-core region of tropical cyclones obtained during the aircraft missions of T-PARC II

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The Western North Pacific (WNP) is the region where violent TCs occur most frequently.
Anomalous high tide
TC Haiyan (2013)

Storm surge

Maximum Gust 81.1m/s
TC Dujuan (2015)

Wave

High wave
TC Lionrock (2016)

Max. total rainfall 3000 mm
TC Morakot (2009)
Forecast skill of TCs in WNP by RSMC Tokyo

- Track forecasts have been improved in the last three decades.
- Intensity forecasts also have been improved since 2017.
- Further improvements are important for disaster prevention.
Number of Violent TCs (>54 m/s of 10-min winds)

- Large discrepancy between JTWC and RSMC Tokyo best track after the US aircraft reconnaissance was terminated in 1987.
The need for a ground truth of TC intensity

- Dvorak technique: satellite-based cloud image recognition
  Satellite-based CI-number $\rightarrow$ (regression line) $\rightarrow$ TC intensity
- Residual of each aircraft data from a regression line is 13 hPa.
  $\rightarrow$ We cannot verify the TC intensity forecast skill less than this.
- The discrepancy between JTWC and RSMC is large for CI $> 6.0$.
Direct measurements with aircrafts in WNP after 1987


Eye penetration were only made by military-purpose planes. Is it possible to safely observe a TC inner-core with a jet aircraft?
At what altitude can we penetrate safely?

Radial-height sections of a simulated TC ($P_{\text{min}}=911.2\,\text{hPa}$) → Shear and icing do not seem severe in the upper level (>13km)

Strong Horizontal shear (up to 4.7 m/s/km)

Can we fly?

Heavy icing of supercooled droplets
Upper-Tropospheric Recon (Gray, 1979, BAMS)

- In the upper troposphere, winds become significantly weak and turbulence is generally less intense (if we avoid the region with strong echoes).
- No special crew training would be required.
- Measurement of the upper warm core may contribute to typhoon intensity estimation.
- This idea had never come true in WNP.

In the recon of Typhoon Lan (2017):
- Weak eyewall echoes and weak winds at 43,000 ft enabled us to enter the eye without suffering severe turbulence.
- Dropsounding from this level enabled us to examine the thermodynamic features of the eye up to 13 km of altitude.
- This was the first attempt of Gray (1979)’s proposal in WNP.
T-PARCII
Tropical Cyclones-Pacific Asian Research Campaign for the Improvement of Intensity Estimations/Forecasts
PI: Prof. Kazuhisa Tsuboki (Nagoya Univ.), FY2016-2020

A dropsounding system was newly developed by Meisei Electric. Flight level is 43,000 ft (~13.8 km) during penetration of a typhoon.
In-Flight Works

Dropsonde deployment and signal processing

Weather Avoidance Radar

Navigation using the weather radar

Severe Turbulence
Moderate Turbulence
21 Oct. 2017

Moderate
Severe

Eyewall Penetration
Penetration Flights into the Eye of strong TCs

- TC Lan (2017) and TC Trami (2018) were successfully observed by 26 and 65 dropsondes dropped from 13.8 km.
- We collaborated with DOTSTAR in both cases, and we collaborated with SATREPS project for the Trami case.

(Univ. Ryukyus / T-PARCII)
Double warm-core structure in a deep, dry layer of the eye could be captured by dropsondes. A possible physical explanation for the lower one is given in Yamada et al. (submitted to JMSJ).
Analysis and forecast with dropsondes

- The inner core of TC Lan was observed on 21–22 October during the first missions of T-PARCII.
- We evaluated the impact of dropsondes on the intensity analysis and forecast skill.

06:52:30 UTC 21 October 2017

01:15:00 UTC 22 October 2017
Comparison of $P_{min}$

- Large discrepancies among the datasets
  - RSMC Tokyo*: Intensifying (935 hPa $\rightarrow$ 915 hPa)
  - The others: Neutral or weakening
- We can verify recently proposed methods such as microwave-based one.

(Ito et al., 2018, SOLA)
DA experiments: CTRL & TPARCII

- DA and forecast experiments to evaluate the impacts of T-PARCII observations
  - NoTPARCII: Fcst following DA without T-PARCII dropsondes
  - TPARCII: Fcst following DA with T-PARCII dropsondes

(Ito et al., 2018, SOLA)
### Common setting

<table>
<thead>
<tr>
<th>Setting</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA system</td>
<td>JMA-NHM-based 4D-Var (JNoVA) (Sawada and Honda, 2009)</td>
</tr>
<tr>
<td>DA window</td>
<td>3 hours</td>
</tr>
<tr>
<td>Observations</td>
<td>Conventional sonde, ship, wind profiler, bogus, TPW, aircraft (including DOTSTAR)</td>
</tr>
<tr>
<td>Grid spacing</td>
<td>DA: 15 km &amp; 5 km; Forecast: 5 km</td>
</tr>
<tr>
<td>Microphysics</td>
<td>DA: Large-scale cond.; Forecast: KF, MYNN3</td>
</tr>
</tbody>
</table>

### Dropsonde data treatment in the TPARCII experiment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>U, V, T, RH, Psfc</td>
<td>QCed by Meisei Electric</td>
</tr>
<tr>
<td>Thinning</td>
<td>U, V, T, RH to the designated levels and classified into hourly time slots</td>
</tr>
<tr>
<td>Obs. error</td>
<td>Same as conventional sondes obs. error in JMA MA</td>
</tr>
<tr>
<td>Outer QC</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Considering horizontal drift during the fall</td>
</tr>
</tbody>
</table>
Time schedule

• Twelve DA cycles:
  ➢ 1st cycle: 03-06UTC 21Oct (First dropsondes)
  ➢ 12th cycle: 12-15UTC 22Oct (Just before landfall)

• At the end of each DA cycle, the forecast experiment was conducted (12 forecasts).

• NoTPARCII and TPARCII differ only for assimilation of dropsondes in the cycles 1, 2, and 8.
Innovation (obs – first_guess) of V

- $|V_{\text{obs}} - V_{\text{first\_guess}}| \sim 10-20 \, \text{m/s}$
- Large deviation detected in the west of TC center → Improvements expected

(Courtesy of Cybernet Inc. Co. Ltd.)
Wind at 850hPa in the analysis (Cycle 1)

- Adding T-PARCII dropsondes yielded
  - Weaker southward wind → TC Lan moves faster to the north in TPARCII
  - The structure becomes more asymmetric with additional dropsondes.
Double warm cores

- The lower warm core was reproduced by assimilating dropsondes in the inner core region.
TC position change (Fcst from cycle 1)

• TPARCII
  ➢ TC Lan displaces to the north by 60km
  ➢ Northward wind stronger by $\sim0.5\text{m/s}$ on average

• Consistent with the best track and DA result

(Ito et al., 2018, SOLA)
Track forecast (averaged over 12 cycles)

- Track forecast error decreases up to 16% in TPARCII.
- Very encouraging result!

➢ The assimilation of the inner-core observations with a high-resolution mesoscale DA system may enhance the track forecast skill.

![Chart showing track forecast error improvement](chart.png)

(Ito et al. 2018, SOLA)
Rainfall forecast (averaged over 12 cycles)

- Threat score = hit / (hit + false alarm + miss)
- Threat score becomes higher for the strong rainfall by adding T-PARCII observations.
- It is consistent with the improvement in track forecast improve

(Ito et al., 2018, SOLA)
**P_{\text{min}}** forecast (averaged over 12 cycles)

- **P_{\text{min}}** forecast “error”: Difference from the RSMC Tokyo best track
- **P_{\text{min}}** forecast “error” is generally larger in TPARCII.

(Ito et al., 2018, SOLA)
Comparison of $P_{\text{min}}$

- Large discrepancies among the datasets
  - RSMC Tokyo*: Intensifying (935 hPa $\rightarrow$ 915 hPa)
    *published before T-PARCII level-2 data became available
  - The others: Neutral or weakening
- We can verify recently proposed methods such as microwave.

(Ito et al., 2018, SOLA)
If we employ JTWC Pmin as a reference...

- Pmin forecast “error” (re-defined): Difference from the JTWC best track
- Pmin forecast “error” decreases in TPARCII (!)
TC Trami (2018)

- Discrepancies of $P_{\text{min}}$ were less than 10 hPa.
- Large uncertainty in the track forecast
Forecast with a global DA system for Trami

- Assimilation of dropsondes and following forecasts were tested for Trami with a JMA-operational global DA system.
- Assimilation of T-PARCII and DOTSTAR data yielded the better results than CTL, and further investigation is needed.

(Yamaguchi et al., in prep.)
TAHOPE – PRECIP - TPARCII

Taiwan USA Japan

• Joint international field campaign for baiu/meiyu and TCs in Taiwan and Okinawa during May-August 2020.

• NCAR S-Polka, CSU SEA-POL, aircrafts (US, Japan, Taiwan)
Concluding remarks

• The best track is not a ground truth. TC intensity forecast skill cannot be evaluated beyond the level of their uncertainties.

• In the WNP, the number of ground truths is limited.

• T-PARCII: New strategy for deeply observing the inner core of a TC with a jet-engine aircraft
  → Important for the forecast skill evaluation, validating new intensity estimation techniques and investigating a deep structure.

• These data also contribute to the accurate track and rainfall forecast through a high-resolution DA system.

• We have not tested a developing TC.

• The dropsonde data with a rapid QC is transferred to GTS since 2018. The full T-PARCII data is available upon request one year after an aircraft mission.
Thank you