Investigation of TC track uncertainty using multiple ensembles for the official TC forecast

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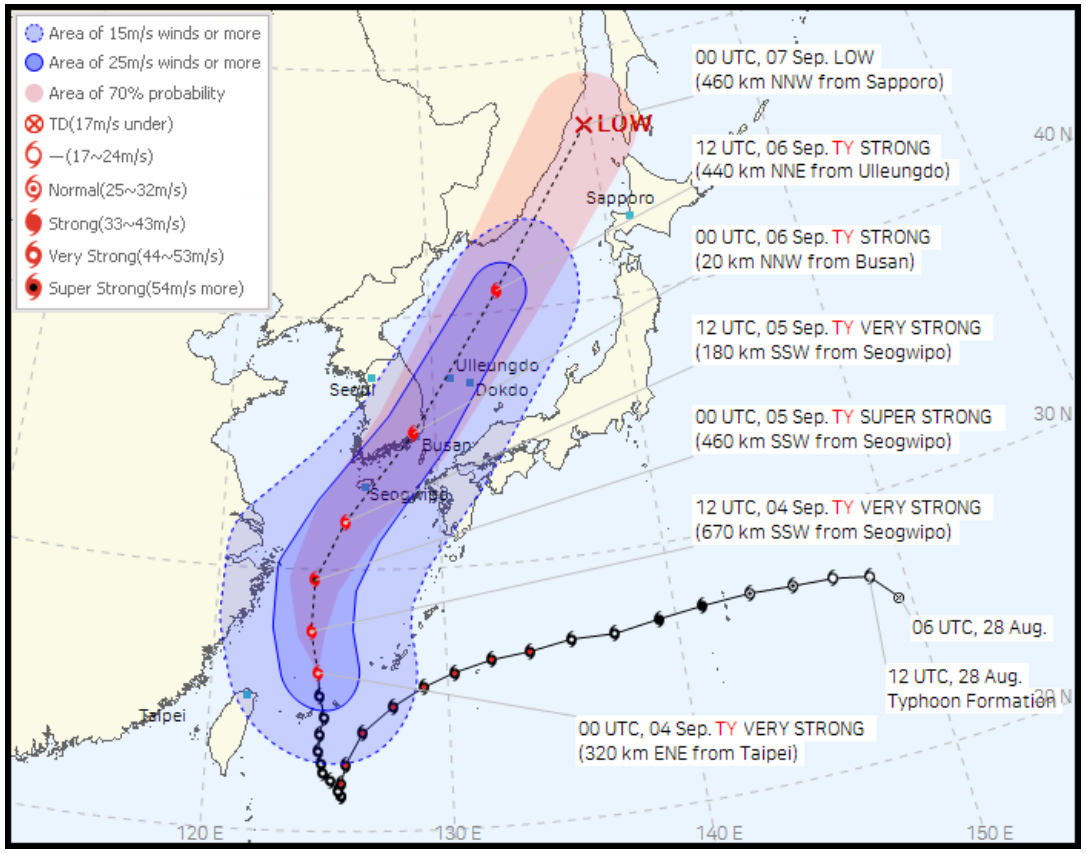
Introduction

KMA TC information

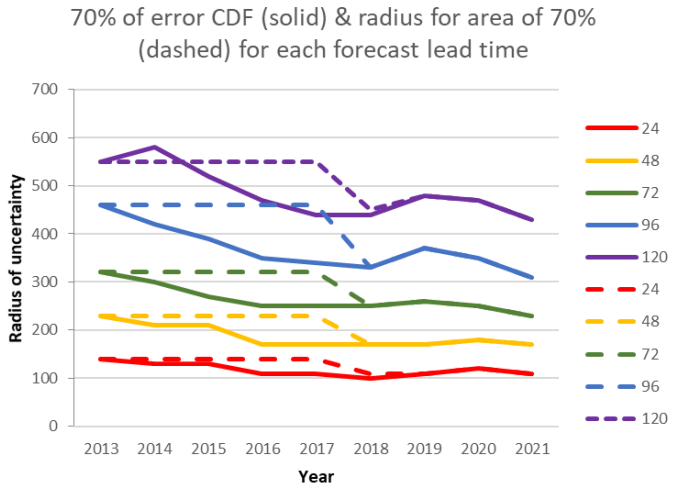


Area of 70% probability

- The **purpose** is to show uncertainty of the TC track

Methodology

- Statistical values from the previous 3 year's TC track errors
  - ✓ 70th percentile of an error CDF
- Update the values at the beginning of every year
- Apply identical values to every TC for one year



Limitations

- Cannot represent the uncertainty of an individual TC track forecast, which is always different
- Depends on the TC forecasters' skill (unreliable)

Previous research

Kawabata and Yamaguchi (2020)

- Showed that a multiple ensemble composed of four global ensembles was capable of predicting the situation-dependent uncertainties of TC track forecasts in the **along-track** (AT) and **cross-track** (CT) directions; therefore, an **elliptical instead of circular** shape can be used to represent the forecast uncertainties associated with TC tracks.

Hamill et al (2011)

- Proposed a decomposition of ensemble spread and errors in eigenspace.

Zhang and Yu (2017)

- Generated the probability ellipse of Hamill et al (2011).
- ECMWF-EPS probability ellipse was clearly better up to 48 h. Afterward the improvements became negligible.

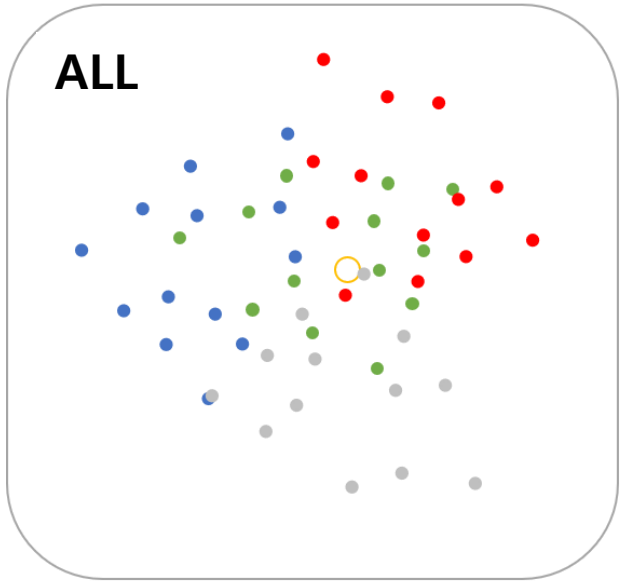
Data

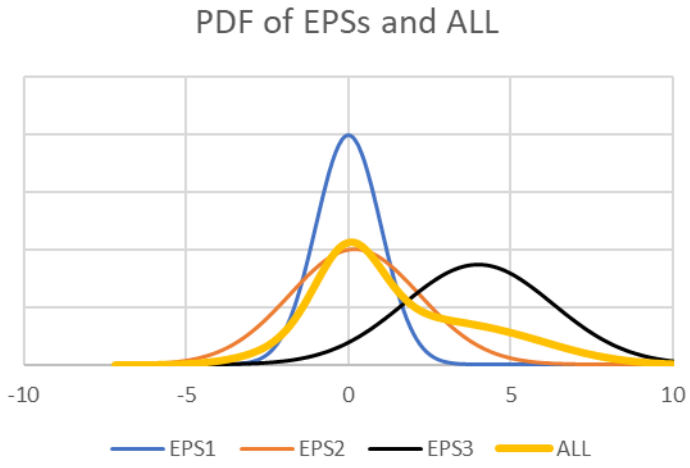
- ❖ Period: 3 years from 2019 to 2021
- ❖ Number of named TCs: 74
- ❖ Ensembles
  - Used the EPS data issued in the previous 12 hours.
  - Five single ensembles

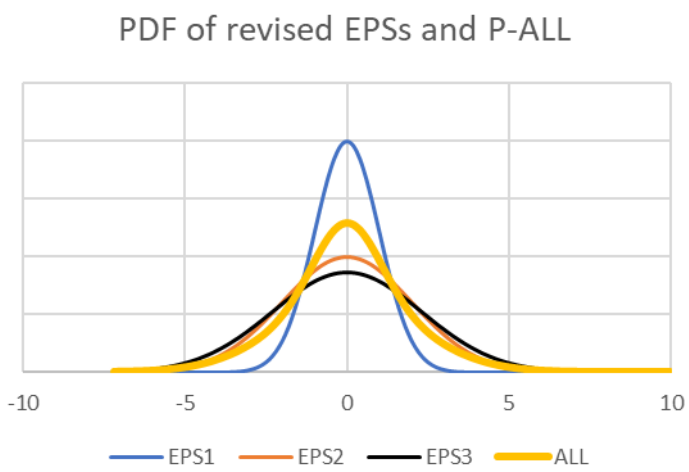
	KMA-UM	ECMWF	JMA	NCEP	UKMO-UM
Ensemble size	25	51	27 → 51('21)	21→ 31('20)	36

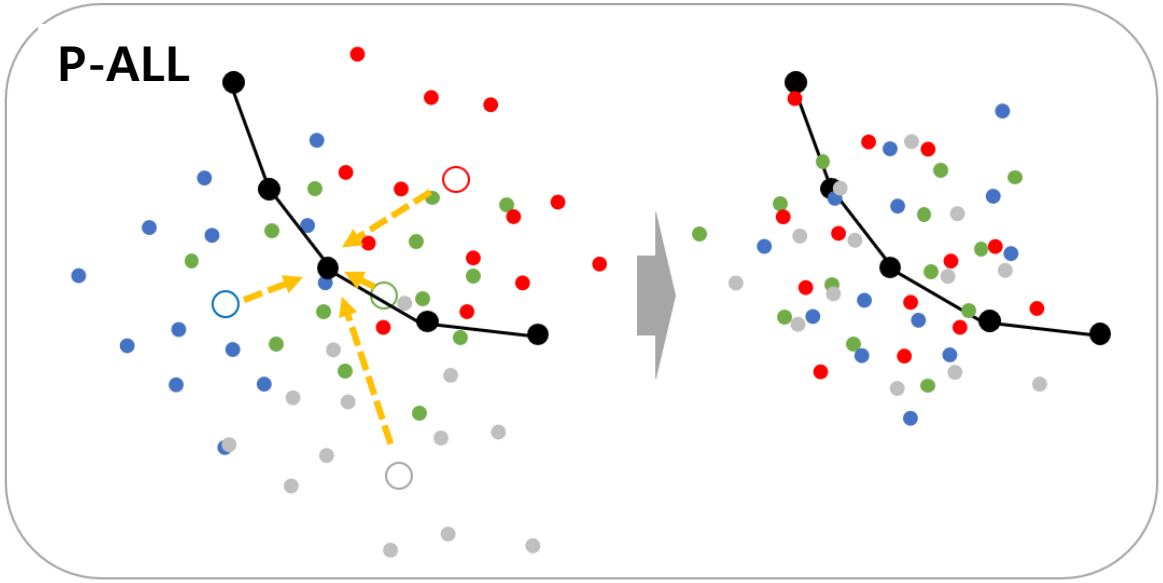
  - Two multiple ensembles : ALL and P-ALL. ("P-" for "processed".)
  - Ensemble size: 160 at start of period / 194 at end of period.
- ❖ Cases
  - For each ensemble, all members were excluded at a given forecast range if less than 70% of members were still TCs.
  - All EPSs were excluded at a particular forecast range if any EPS was unavailable

Multiple Ensembles









EPS member

Mean of each EPS

Mean of multiple EPS

Operational Forecast

❖ **ALL**

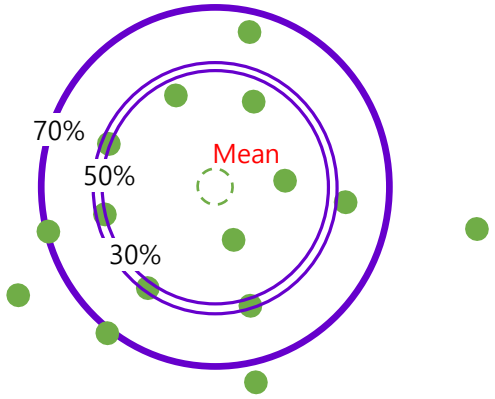
- Simple multiple ensemble
- Regards a single member in the single EPS as a single member in the multiple ensemble

❖ **P-ALL**

- Processed multiple ensemble
- Make the ensemble means of the EPSs coincide

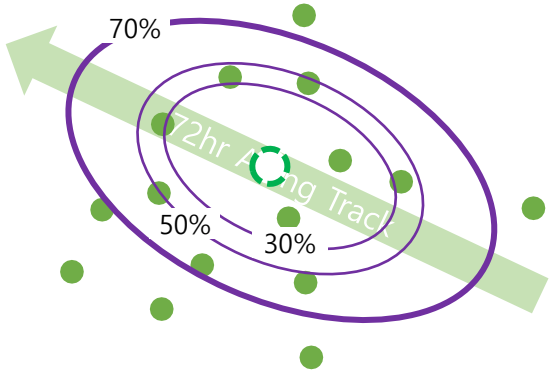
Probability circle and ellipse methods

Circle



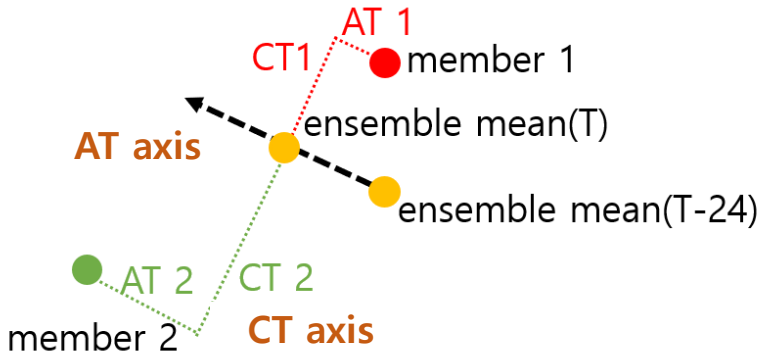
- Radius which includes the 70% of the EPS members that are closest to the ensemble mean
- Simple and easy

Ellipse (AT-CT)



- Axes are determined by the AT and CT directions relative to the previous 24 h position
- Radii are determined by the 70% of AT and CT differences closest to the ensemble mean
- It cannot include 70% of members, so the probability area is relatively small

Ellipse (EV)



Probability circle and ellipse methods

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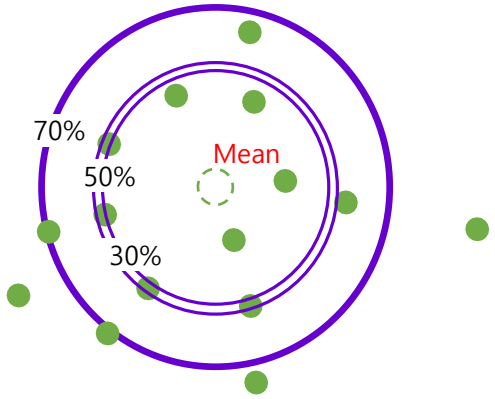

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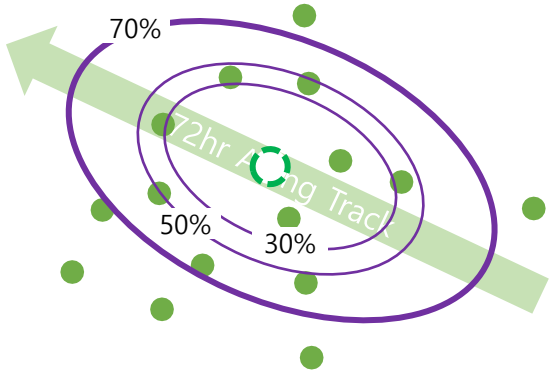

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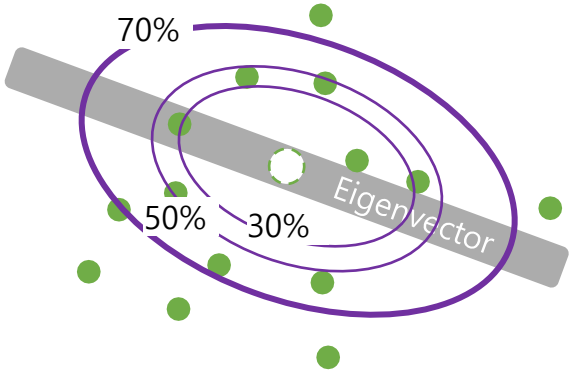
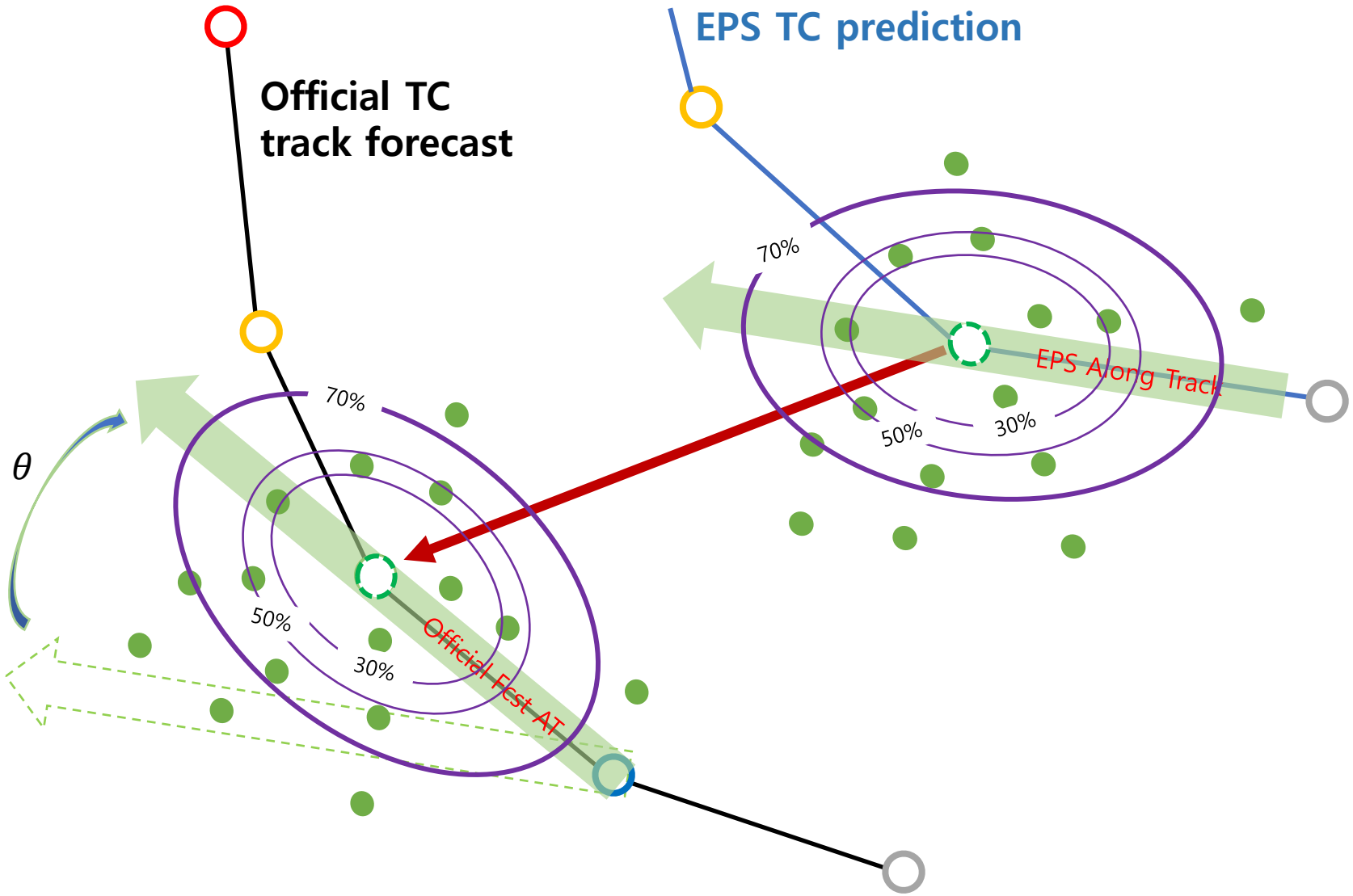


- Concentration area of the EPS members
- Major and minor axes are determined from eigenvectors in the eigenspace of members
- By changing two axes every 10 km, the smallest area keeping 70% of ensemble members around the ensemble mean are adopted

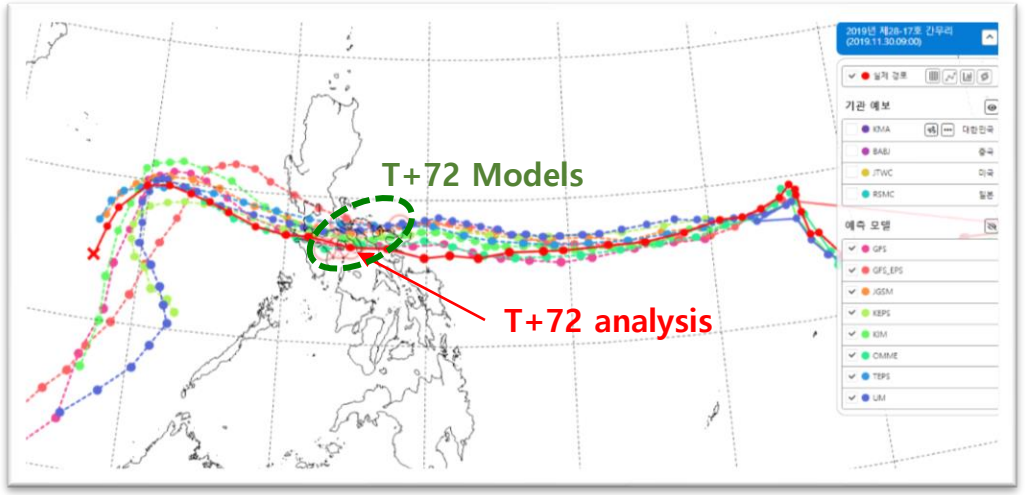
Apply to the official TC forecast



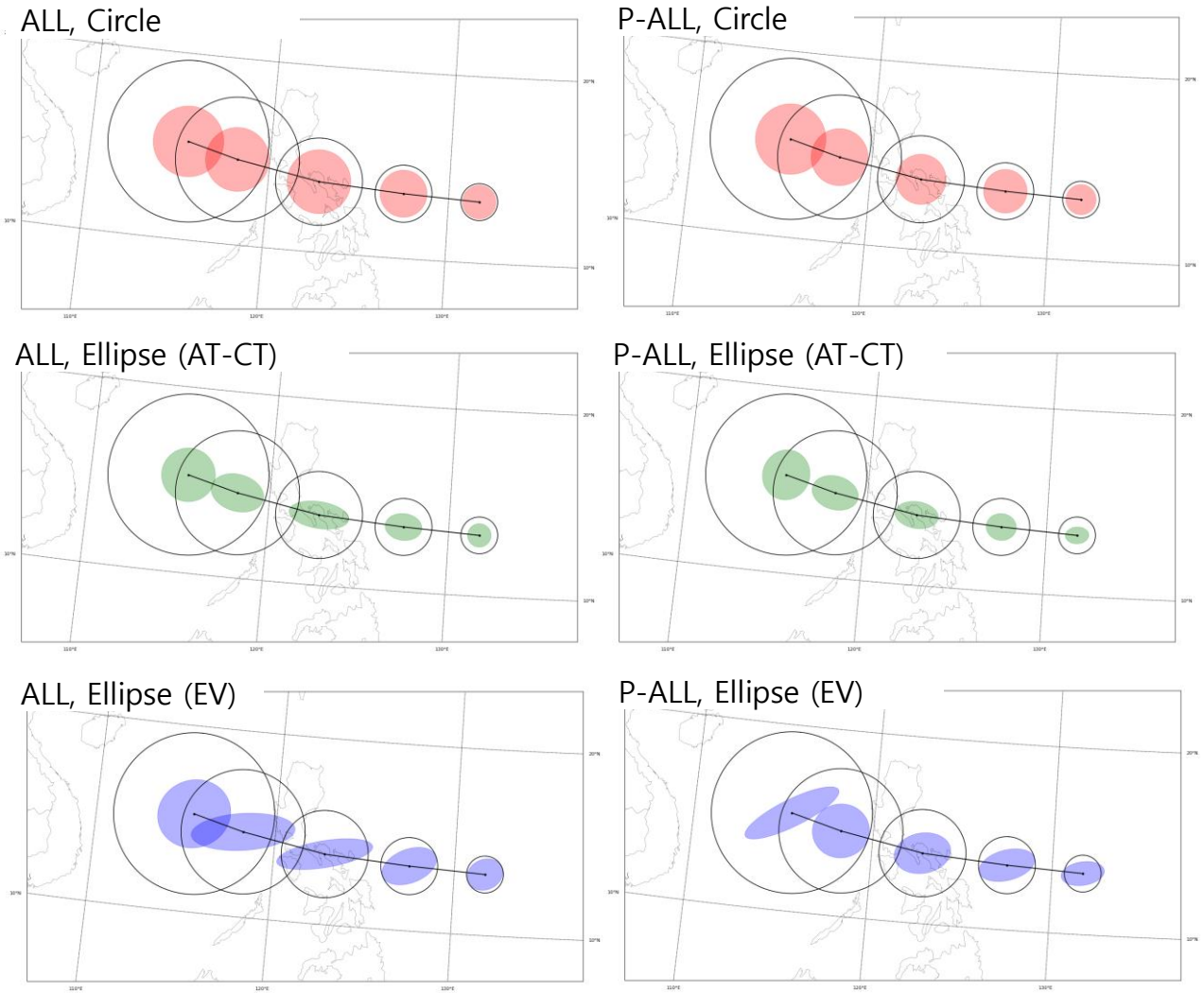
- The circle or ellipse is applied to the official TC forecast
- **Only for the ellipse (AT-CT) method**, the direction of axes is rotated by the angle difference between the EPS mean direction of movement and the direction of movement of the official TC forecast.

Case1: KAMNURI at 00 UTC on 30 Nov 2019

TC forecast tracks of the deterministic models and EPS means

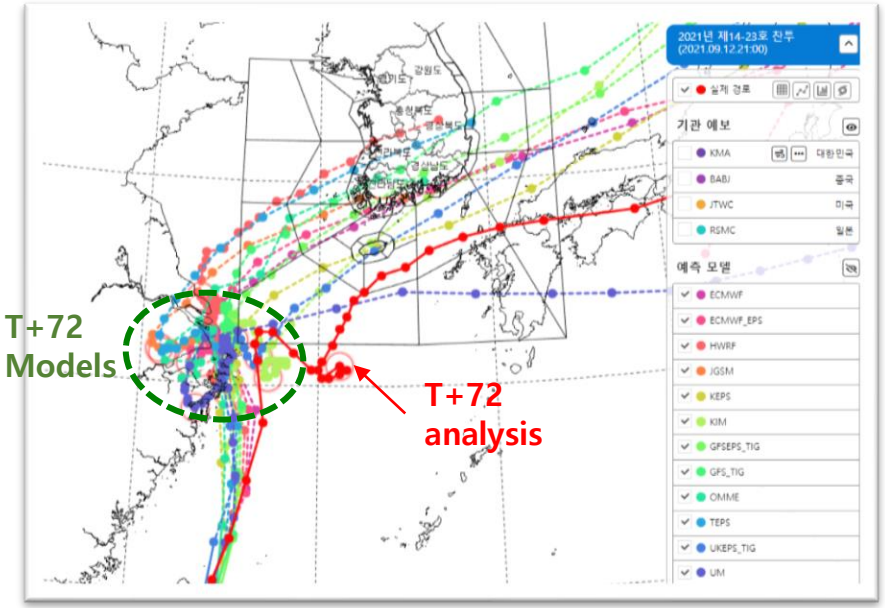


- Small spread and high confidence
- All methods have smaller area than the operational circles of 70% probability
- EPS-based uncertainty circles or ellipses have the benefit narrowing warning areas of TC track forecasts

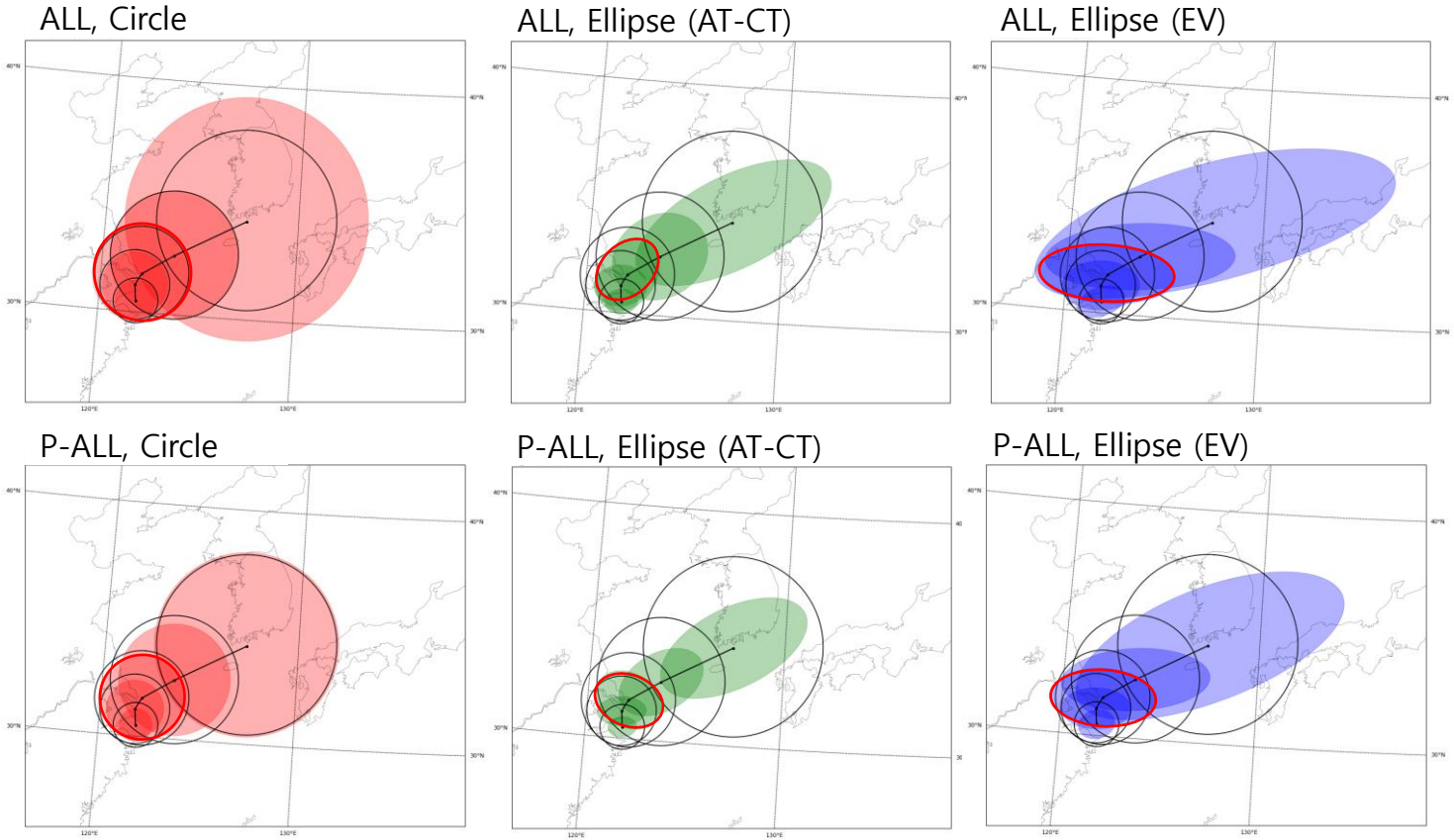


Case2: CHANTU at 12 UTC on 12 Sep 2021

TC forecast tracks of the deterministic models and EPS means

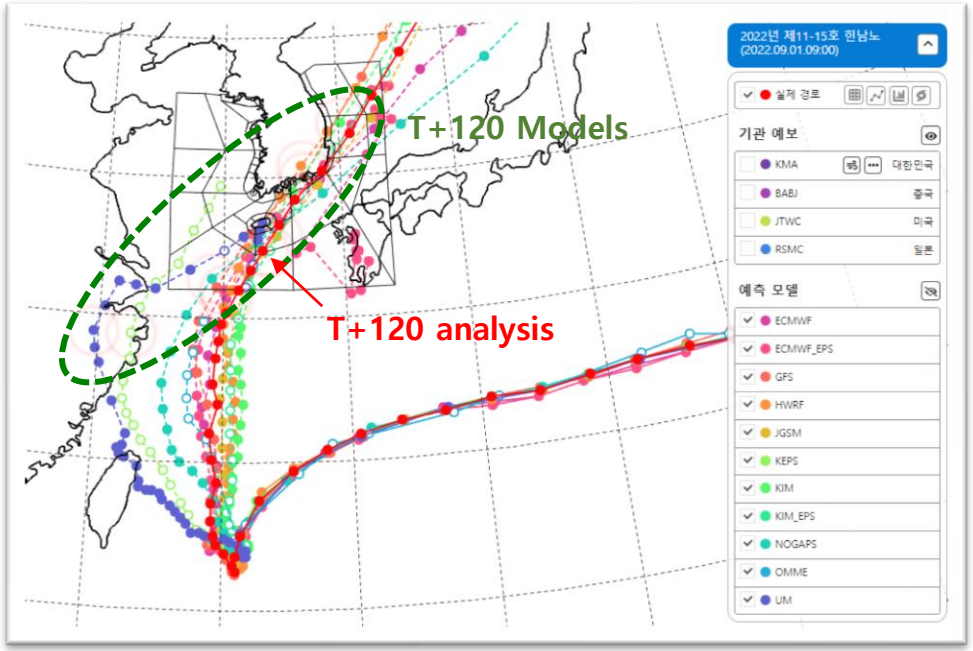


- TC predictions are located west of the analysis position at T+72
- Ellipse (AT-CT), which doesn't include 70% of ensemble members, is too narrow to represent the uncertainty.



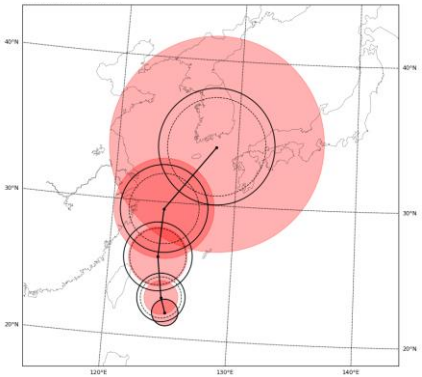
Case3: HINNAMNOR at 00 UTC on 1 Sep 2022

TC forecast tracks of the deterministic models and EPS means

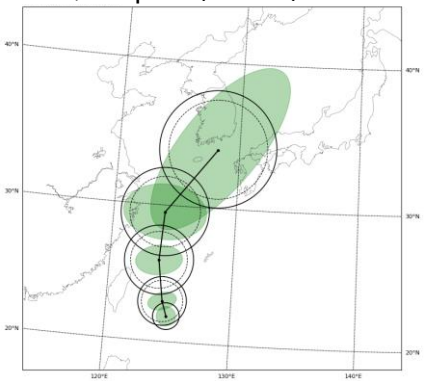


- TC predictions influenced by the jet steam are elongated in the SW-NE direction at T+120.
- Ellipse (AT-CT), rotated according to the official track, may be suboptimal, especially when there are large differences of AT directions between the official forecast track and the ensemble mean track.
- (It seems it's better to keep all EPS distribution)

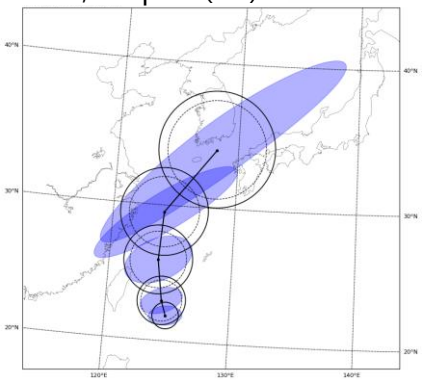
ALL, Circle



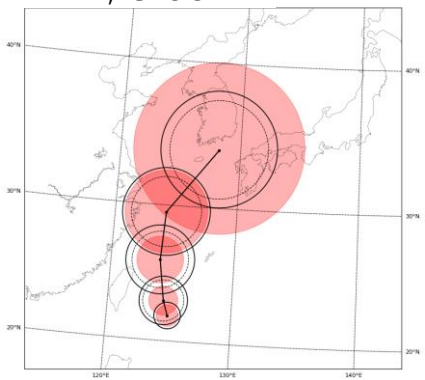
ALL, Ellipse (AT-CT)



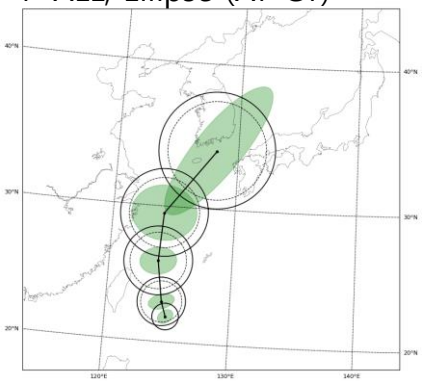
ALL, Ellipse (EV)



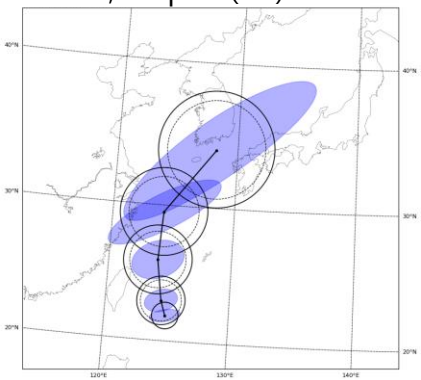
P-ALL, Circle



P-ALL, Ellipse (AT-CT)



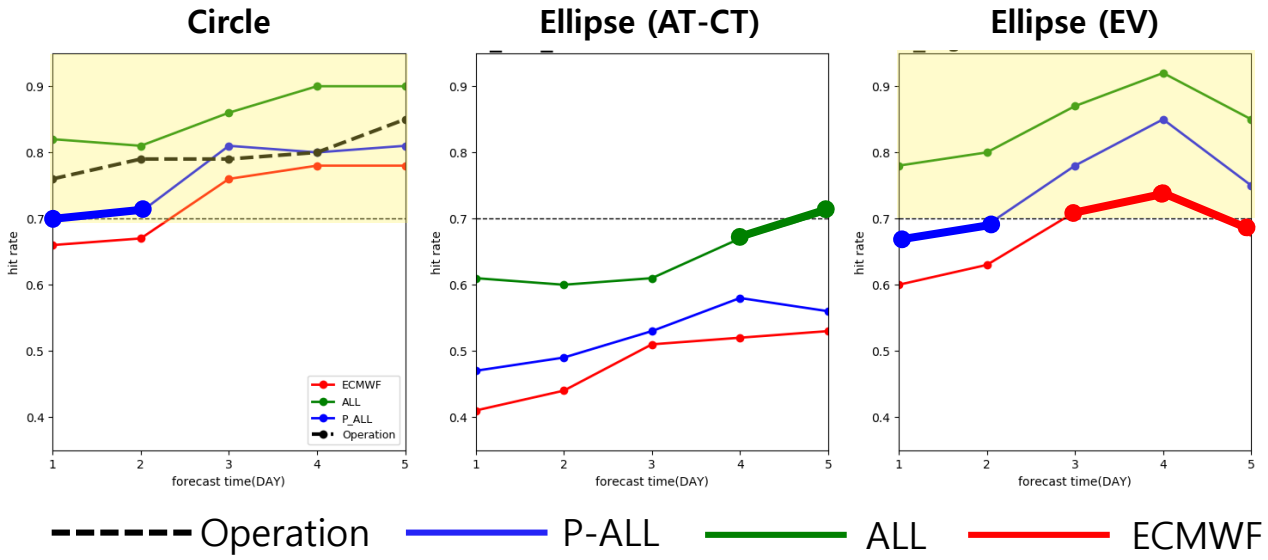
P-ALL, Ellipse (EV)



Verification

Hit rate (or detection rate)

The hit rate is defined as the percentage of the observed TC central positions within the 70% probability circle or ellipse.



- The operational radii have over 0.7 hit rate, around 0.8, for all forecast times. (It means the official forecast skill is getting better year by year)
- Ellipse (AT-CT), which has the smallest area because of the methodology, has the lowest hit rate. Therefore, the method needs to be improved.
- With the circle method and the ellipse (EV), ALL shows worse results than the operational method due to overdispersion.
- P-ALL reduces the hit rate compared to the ALL. It is almost 0.7 in both the circle and the ellipse (EV) at 1 and 2 forecast days
  - The five single EPSs were under-spread at the early lead time. P-ALL could improve the performance
  - In addition, since the distribution of the ensemble members is relatively isotropic at this time, the circle and the ellipse (EV) methods give quite similar result
- After 3 days, any single EPS is better than P-ALL and the ellipse (EV) is better than the circle for a single EPS

Summary

- We investigated the possibility to replace the area of 70 % probability circle, based on statistics from the previous 3 year's operational track errors, with an ensemble-based method: circle, ellipse (AT-ET), or ellipse (EV).
- For 24 and 48 forecast hours, the processed multiple ensemble (P-ALL) for both the circle and ellipse (EV) method outperformed the operational method.
- After 72 forecast hours, even the processed multiple ensemble is too overspread, so that a single ensemble is more likely to be consistent with the 70% probability area.
- Therefore, it is required to apply different methods according to the forecast time

- It may be a problem to apply a method based on the ensemble spread to the official TC track forecast, which differs from the ensemble mean track, as we saw for the ellipse (AT-CT) method, which was worse than the operational method.
    - Nevertheless, we have to try to utilizing ensembles for TC forecasts, since they provide the best method for estimating uncertainty, and situation-dependent uncertainty is valuable information.

Thank you