Analysis of DAA Well Clear Criteria Using the Flown Trajectories

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***Abstract*—This paper proposes an airborne conflict and collision risk metric that is a modified version of the Detect and Avoid Well Clear (DWC) alerts. Previous works that directly applied DWC calculations to assess risk were able to identify regions and situations where the risks are relatively higher. However, because DWC assumes a constant velocity for all flights at each time step to represent the future position, it cannot reflect future maneuvers caused by the inherent route structure or controller instructions. When applying DWC criteria to historical manned aircraft trajectories, it was discovered that a large number of false alerts were detected due to this extrapolation. In order to study the effects of maneuvers, this paper proposes a method to calculate equivalent DWC alert levels using actual flown trajectories as future positions. This redefined method is referred to as Trajectory DWC (TDWC). Horizontal Miss Distance, vertical separation, and modified tau, parameters used in the calculation of DWC, are redefined using the actual flown trajectories from the current time step. To test this new metric, DWC, and TDWC alerts are calculated using Automatic Dependent Surveillance-Broadcast data from aircraft that passed through the Incheon Flight Information Region in 2018. Based on the results, the number of pairs and duration of DWC and TDWC alert events are analyzed. Depending on the DWC criteria or alert levels, TDWC resulted in 20 to 80 percent fewer alert pairs and duration. It was confirmed that TDWC can correctly exclude false risk situations and can be a better risk metric.**

***Index Terms*—Airborne Conflict and Collision Risk, Detect-and-Avoid (DAA), DAA Well Clear (DWC), Automatic Dependent Surveillance-Broadcast (ADS-B)**

I. Introduction

For data-driven analyses of aviation safety, quantifying the airborne conflict or collision risk is one of the most important steps. One of the difficulties in quantifying the risk is that event-based measures such as violation of a specific horizontal or vertical separation threshold or actual reported alerts from the aircraft such as Traffic Collision Avoidance System Resolution Advisory [1]–[3] are used to track the risk in real-life operations. These events are sparsely recorded because the air traffic is carefully managed with multiple layers of safety measures, which makes them not suitable for analyzing the relative risk and for finding ways to lower the risk.

Several efforts have been made to define continuous risk metrics such as NASA's Conflict Intrusion Parameter which uses a combination of aircraft's horizontal and vertical separation distance to assess collision risk [4]. [5] created a conflict detection metric by predicting the trajectory of an aircraft using a multivariate Gaussian random variable, and [6] proposed fuzzy sets to determine both the probability and severity of event outcomes. [7] used a hybrid approach that uses Monte Carlo simulation to predict the position of the aircraft and dynamic event trees to assess the risk to obtain a quantitative value. These methods propose a quantitative value but have limitations caused by their stochastic character. [8] developed a three-dimensional collision risk model to assess the safety of flight airspace.

With the recent advancements in Unmanned Aircraft Systems, quantification of the conflict and collision risk made progress, which resulted in the definition of Loss of Well Clear (LoWC) with three other risk levels. This metric is presented in Radio Technical Commission for Aeronautics DO-365 Minimum Operational Performance Standards (MOPS) [9] and referred to as DAA Well Clear (DWC). Initially, DWC was defined only for the en-route operations, but with subsequent revisions of DO-365, it was expanded to the terminal area [10].

Studies have been conducted to determine the conflict and collision risk inside the Incheon Flight Information Region (FIR) [11]–[13]. These studies were able to identify the general hot spots for the conflict and collision risks; however, excessive false alerts were detected due to the extrapolation, mainly because the DWC standards are developed to be used for the DAA system in the actual operation, not for the post-analysis of the recorded trajectories. In this paper, the metrics for calculating DWC, horizontal miss distance (HMD), vertical separation (d_h), and modified tau (τ_{mod}) are redefined using the recorded trajectory, and this calculation method is referred to as Trajectory-DWC (TDWC). When calculating DWC levels at the current time step, all the aircraft are assumed to fly at a constant velocity, which is the velocity at the current time step. Unlike DWC, TDWC uses the actual flown trajectory from the current time step to represent future positions. The modified definitions of HMD and τ_{mod}, and how those parameters are computed are described in detail in the subsequent sections.

To confirm the usefulness of TDWC, both the previous

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metric DWC and the new metric TDWC are calculated using the Automatic Dependant Surveillance-Broadcast (ADS-B) data of the flights inside the Incheon FIR in the year 2018. The number of conflict pairs and the durations of the alerts are computed using DWC and TDWC definitions with Phase 1 and 2 criteria.

TDWC results in fewer occurrences and pairs compared to DWC, indicating that this metric can address false alerts caused by DWC's extrapolation. Based on the results, this paper presents the durations and pairs analyzed by aircraft status and Incheon FIR airspace.

Following this introduction, Section II describes the DWC and the newly defined TDWC. Section III describes the data used for calculating the risk and presents several examples. In Section IV, the results of the DWC and TDWC analyses of flights in Korean National Airspace are presented.

II. DWC and TDWC Definitions

A. DAA Well Clear Definition

DWC is a metric developed for DAA systems that allows unmanned aircraft to maintain adequate separation from neighboring aircraft. It is determined by calculating the τ_{mod} that means the remaining time until the distance threshold (DMOD) is violated on the horizontal plane between two aircraft, the HMD that means the minimum horizontal separation distance, and the d_h that means the vertical separation distance. The formulas used to calculate these parameters are presented in [10]. Fig. 1 is a visualization of the DWC boundary.

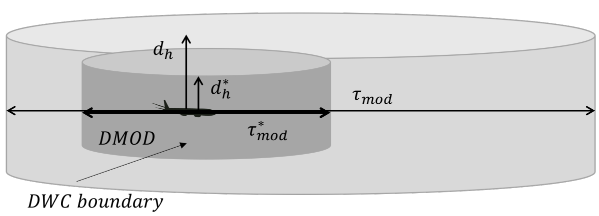

Fig. 1. DWC boundary.

TABLE I
DWC Phase 1 standards

	preventive	corrective	warning	LoWC
τ_{mod}^*	35 sec	35 sec	35 sec	35 sec
$HMD^*, DMOD$	4,000 ft	4,000 ft	4,000 ft	4,000 ft
d_h^*	700 ft	450 ft	450 ft	450 ft
Alert times	55 sec	55 sec	25 sec	0 sec

DWC calculation assumes that all aircraft maintains its velocity at the current time step and fly in a straight line. HMD is calculated first, and if it is greater than HMD^*, the DWC calculation advances to the next time step. If it is smaller than HMD^*, τ_{mod} and d_h are calculated for the alert time. For Phase 1, which calculates the risk in the en-route airspace, a time from the current time step is found within 55 seconds where τ_{mod} is smaller than 35 seconds and, at the same time, d_h is predicted to be smaller than 450 ft. If this time is at 0 seconds from the current time step, the situation is LoWC. If it is within 25 seconds, warning alert is raised, and if it is within 55 seconds, corrective alert is raised. If the above conditions are not met within 55 seconds, a time where τ_{mod} is smaller than 35 seconds and d_h is smaller than 700 ft within 55 seconds is searched. If found, preventive alert is raised. The computation advances to the next time step where the velocities of all aircraft are updated to the actual velocities at the next time step. When the Phase 2 criteria, which calculates the risk in the terminal area, are applied, only LoWC and warning alerts are found using different threshold values. The threshold values for each alert level are shown in Tables I and II for Phase 1 and Phase 2 criteria, respectively. Minimum average time of alert provided by MOPS is selected as the alert times in Tables I and II, which is used to limit the look ahead time in the future aircraft positions.

TABLE II
DWC Phase 2 standard

	warning	LoWC
τ_{mod}^*	0 sec	0 sec
$HMD^*, DMOD$	1,500 ft	1,500 ft
d_h^*	450 ft	450 ft
Alert times	45 sec	0 sec

In essence, the DWC is a current-time indicator of the conflict and collision risk, which is not ideal for the situations when future aircraft positions are known. Fig. 2 illustrates a situation where multiple DWC alerts are detected. Assuming that the two aircraft have the same altitude, at point 1, the intersection of the two tangential lines denoted by a yellow star represents a predicted LoWC. If this LoWC is predicted 45 seconds from point 1, point 1 is regarded as a corrective alert. Similarly, if the intersection of the two tangential lines at point 2 denoted by an orange star is the predicted LoWC which is 25 seconds from point 2, a warning alert will be issued. However, the two aircraft maintain separation due to horizontal maneuvers until point 6 when the two aircraft actually comes very close.

B. TDWC Definition

The trajectory of an aircraft can change based on controller instructions, the structure of the route, or flight procedures. For example, if the route structure is such that the two routes becomes gradually closer up to a certain point and then stay parallel, DWC alerts will be detected around the position where the two routes become parallel. If a maneuver instruction was issued to resolve a conflict by a controller, DWC computation is likely to detect an alert some time before an aircraft started to maneuver. This alert might correlate with controller workload. However, assuming the conflict was properly resolved, the risk stayed at a low level.

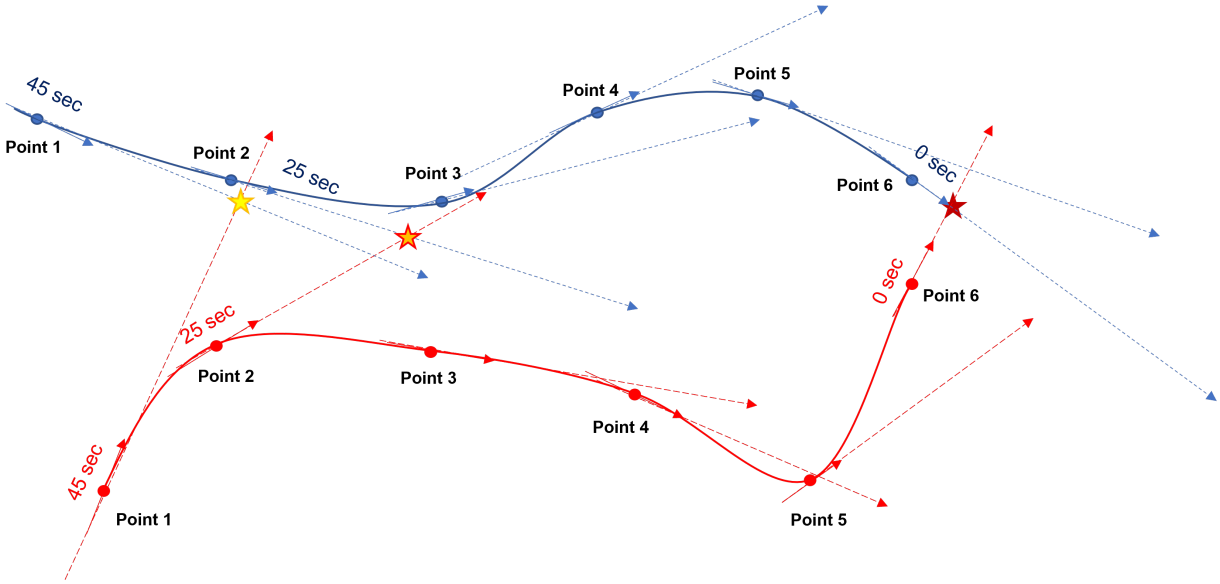

Fig. 2. Comparison of actual trajectory and the constant velocity assumption at each time step.

TDWC metric is constructed by redefining the parameters HMD, τ_{mod}, and d_h. In DWC, HMD is the predicted minimum horizontal distance based on the current speed and heading. In TDWC, HMD is the actual minimum horizontal distance between two aircraft. However, if the horizontal distance between two aircraft is plotted as a function of time as shown in Fig. 3, multiple local minima can exist. Among those multiple local minima, ones that are smaller than the threshold value, HMD^*, are marked as HMD situations, and those minimum distances are the HMD values as shown in the purple circles. For d_h, instead of the predicted altitude difference from the current time step, the actual altitude difference is used in TDWC.

The right after the HMD, when the horizontal distance between the two aircraft is increasing and when the separation distance is larger than HMD^* is defined as the recovery phase in this paper.

In DWC, τ_{mod} is the predicted time remaining until the horizontal separation becomes smaller than $DMOD^*$. Consequently, for a HMD situation, the horizontal separation will become $DMOD^*$ before reaching HMD, which will be referred to as the violation point in this paper. At the current time step, time to the violation point is defined as τ_{mod}. τ_{mod} is zero while the horizontal separation is smaller than $DMOD^*$ and infinity when the horizontal separation becomes larger than $DMOD^*$ while the horizontal distance is increasing, basically when in the recovery phase. In Fig. 3, the violation points are expressed in red circles, and τ_{mod} becomes smaller than τ^*_{mod} from the time expressed in black lines.

In this study, the threshold values of TDWC are the same as the DWC presented in Tables I and II. As in DWC, the HMDs are identified first. If an HMD is found, τ_{mod} and d_h are calculated for the duration of the alert time. For Phase 1, the time interval where τ_{mod} is smaller than 35 seconds is

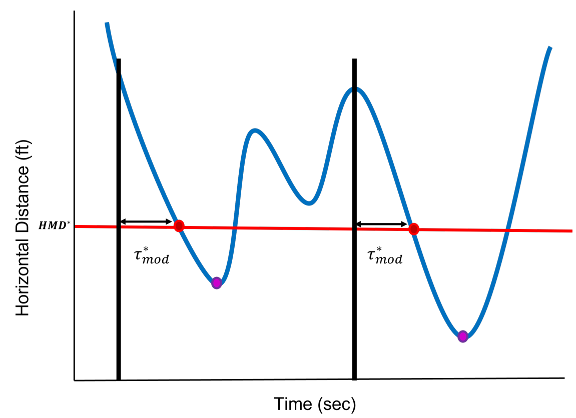

Fig. 3. Identification of HMD and τ_{mod} in TDWC.

found within 55 seconds from the current time step. At the same time, another time interval where d_h is smaller than 450 ft within 55 seconds from the current time step is identified. The intersection of the two-time intervals represents the LoWC state. If the current time step is within 25 seconds from the beginning of the LoWC state, the risk level is a warning alert, and if the difference is larger than 25 seconds, the risk level is a corrective alert. If no intersecting interval is identified, a larger threshold value for the altitude difference, 700 ft, is used to find a new interval. If an intersecting interval is found, the risk level is a preventive alert. If there still is no intersecting interval, no alert is issued. When applying the Phase 2 criteria, only LoWC and warning alerts are determined using the corresponding threshold values.

Figs. 4 to 6 show the progression of TDWC alerts. For each time step, the horizontal distance between the two aircraft is represented by a red arrow when it is smaller than $DMOD^*$, and a blue arrow when it is greater than $DMOD^*$. The violation point is at Point 3, and the horizontal distance between the two aircraft becomes the minimum at Point 4. If the horizontal distance at Point 4, HMD, is greater than HMD^*, no alert is issued. If Point 2 represents the beginning of the interval where τ_{mod} is smaller than τ^*_{mod}, and d_h is smaller than d^*_h, LoWC starts at Point 2. If Point 1 is between 25 and 55 seconds from Point 2, it is in the corrective alerts state. If Point 1 is within 25 seconds from Point 2, it is in the warning alert state.

Fig. 5 shows that the aircraft pair is in the beginning of the LoWC state. From Points 3 to 5, τ_{mod} is zero. Fig. 6 shows the aircraft pair is at the HMD situation. The recovery state starts at Point 5 where τ_{mod} becomes infinity because the horizontal distance is increasing and the separation is larger than $DMOD^*$. LoWC state can end before Point 5 depending on the altitude difference, but cannot extend after Point 5. After the recovery state, the process has to repeat if there is another HMD situation as shown in Fig. 7.

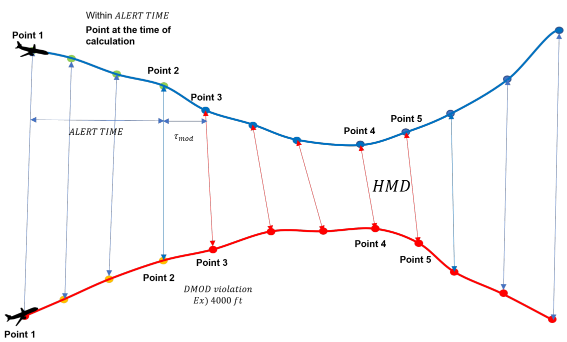

Fig. 4. Corrective or warning alert state.

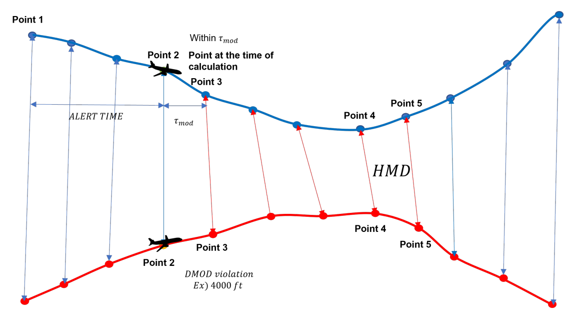

Fig. 5. LoWC state.

III. Collision Risk Assessment Using TDWC

A. Trajectory Data

The recorded trajectory data of all flights in the Incheon FIR in the year 2018 are used to test the proposed TDWC metric. A total of 1,056,678 ADS-B trajectories obtained from FlightRadar24 are used. Fig. 8 shows a visualization of the trajectories in February 2018.

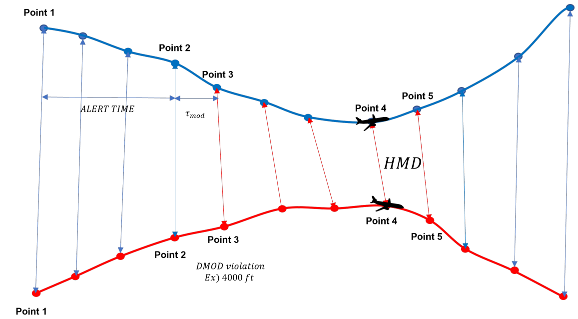

Fig. 6. HMD and recovery state.

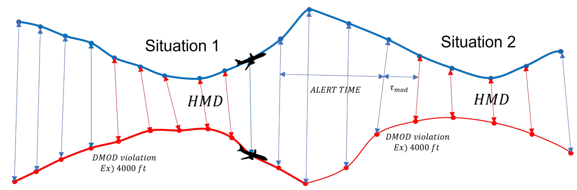

Fig. 7. Two consecutive HMD situations.

B. Calculating DWC and TDWC

ADS-B trajectory data are not at regular time interval. In addition, there are times when data is not received, depending on the situation of the aircraft or the ground receiver. So, time synchronization is necessary to compare the relative positions and speeds. Since the location information in the ADS-B data is expressed in latitudes and longitudes, it is converted to a Cartesian x, y coordinate system. Lambert conformal conic projection is used with the reference parallels and position shown in Table III. Projected x, y coordinates are time-synchronized at a regular one-second interval using linear interpolation.

Fig. 9 shows a case where only DWC alerts are detected. Fig. 10 shows the altitudes of the flights. It can be seen that the flight depicted by the black line is initially descending and the one depicted by the blue line is initially climbing,

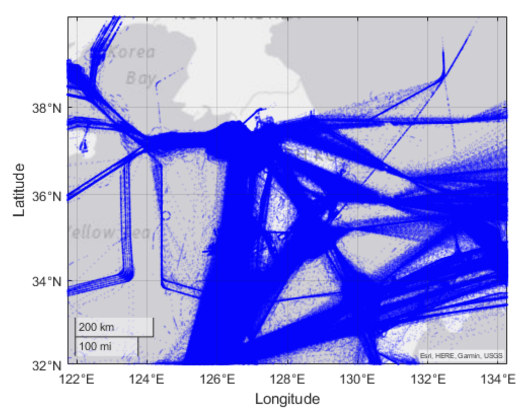

Fig. 8. ADS-B data in Incheon FIR in February, 2018.

TABLE III
LAMBERT VALUES

Threshold	Standard Parallel 1	Standard Parallel 2	Origin PositionC
latitude	33^o	38^o	33^o
longitude	125^o	127^o	126^o

which resulted in a small predicted altitude difference in DWC. As both the flight actually levels out and maintains sufficient altitude separation, no alerts are detected in terms of TDWC.

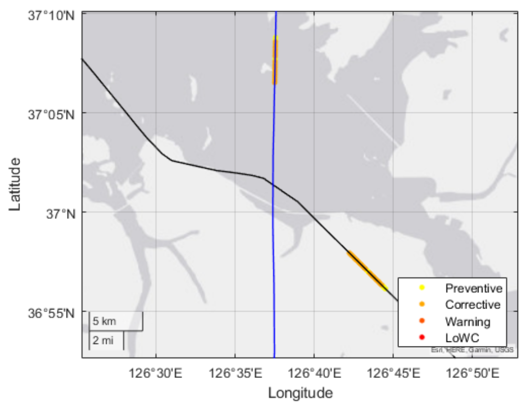

Fig. 9. DWC Example 1.

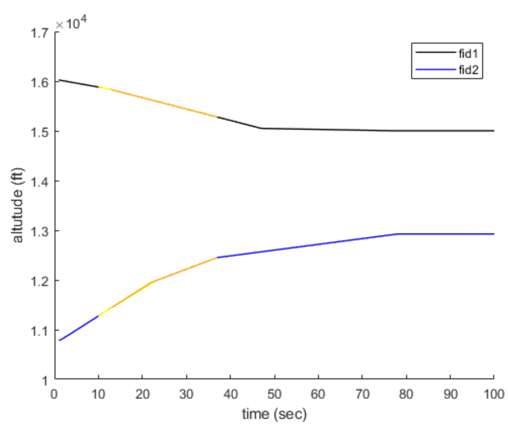

Fig. 10. DWC Altitude 1.

In the subsequent figures, the blue and black areas are the trajectories presented in the ADS-B data. The areas where the risk of a collision between the aircraft occurred are colored differently depending on the risk, with the areas where LoWC occurred colored red. The closest points between the two trajectories are marked with red circles.

Figs. 11 and 12 show the alerts of using TDWC and DWC, respectively. Both aircraft are flying towards South and the almost parallel paths are slowly becoming closer. Three parameters, predicted HMD, predicted τ_{mod}, and the absolute value of the minimum predicted altitude difference from the current time step are plotted in Figs. 13 and 14 for TDWC and DWC cases, respectively. In this example, the two cases show similar alert progression. However, it can be seen that the small velocity variation at each time step causes the parameters to fluctuate in the DWC case shown in Fig. 13. As a result, the warning alert occurs slightly earlier with the DWC. The actual separation is achieved by changing the vertical distance before reaching the HMD.

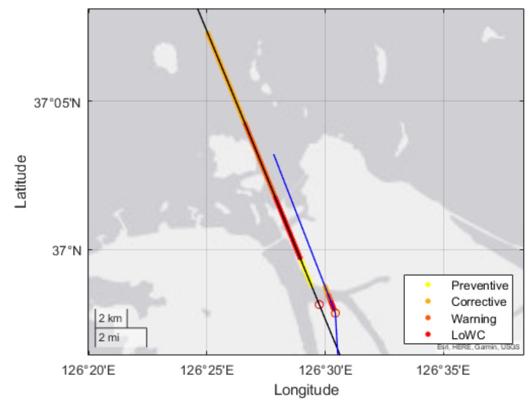

Fig. 11. TDWC Example 2.

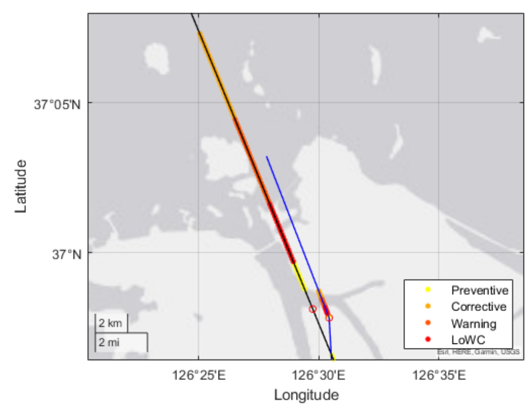

Fig. 12. DWC Example 2.

Fig. 15 shows a case where alerts are detected only with TDWC. The aircraft on the black line is flying toward West and the other aircraft on the blue line is flying towards Southeast. As can be seen from the red circle in Fig. 15, HMD is detected after the horizontal maneuver that triggered TDWC alerts.

IV. ANALYSES OF THE RESULTS

A. Analyses by Flight Phases

DWC and TDWC alerts are categorized by the flight phases, climb, cruise, and descent, of the aircraft resulting in six pairs. In this study, if an aircraft's vertical speed is above 100 fpm, it is considered to be in a climb phase. If it is below -100

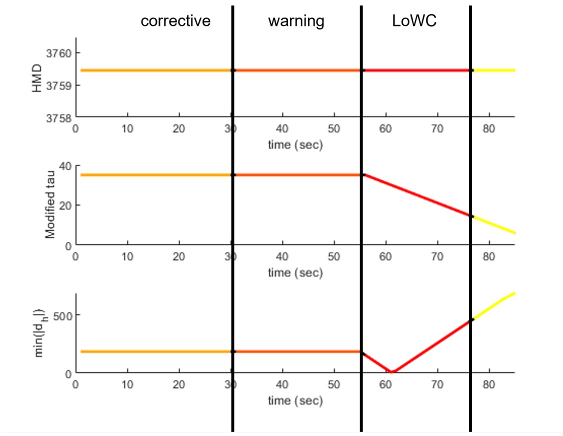

Fig. 13. TDWC parameter Example 2.

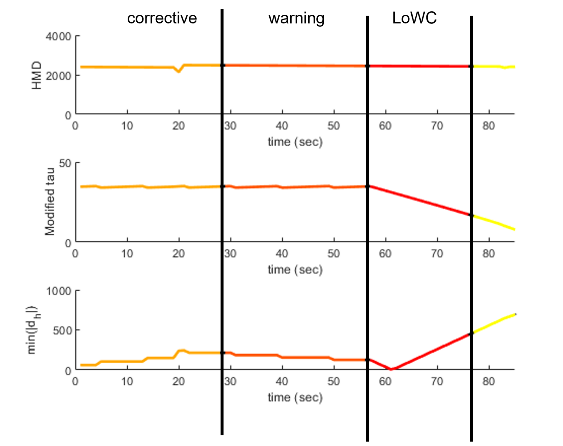

Fig. 14. DWC parameter Example 2.

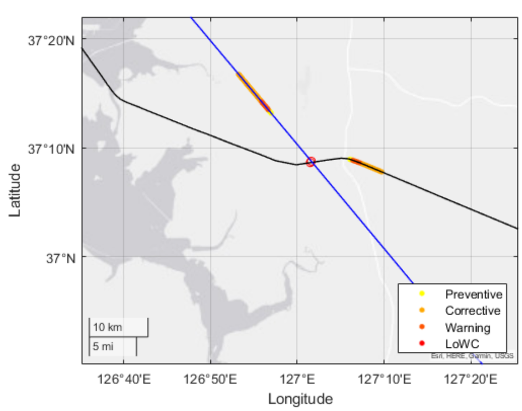

Fig. 15. TDWC example 3.

fpm, it is in a decent phase, and if it is between those two thresholds, it is in a cruise phase.

The DWC and TDWC results of applying the Phase 1 criteria in Figs. 16 and 17 show that the largest number of conflict pairs are detected between one aircraft in the cruise phase and the other aircraft in the descent phase for both the TDWC and DWC. In terms of the number of LoWC pairs, 1200 pairs are detected in DWC while it is reduced to around 800 pairs in TDWC. In addition, the difference among the different alert levels are much smaller with the TDWC, which suggests that it was able effectively to reduce the number of false alerts.

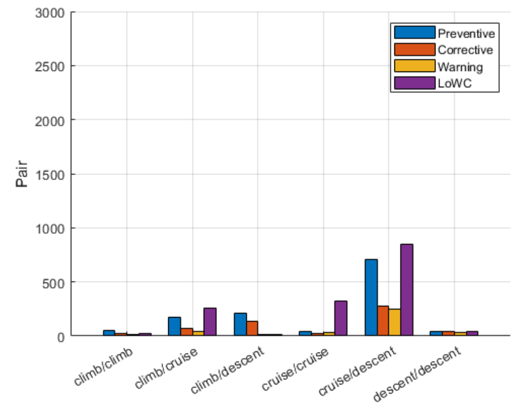

Fig. 16. Number of TDWC conflict pairs by alert levels and flight phase combinations (Phase 1 criteria).

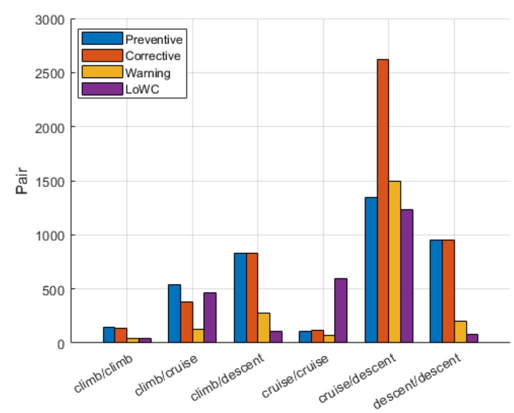

Fig. 17. Number of DWC conflict pairs by alert levels and flight phase combinations (Phase 1 criteria).

With TDWC, there are relatively larger number of pairs in the preventive alert state compared to the DWC case. It suggests that the difference in the predicted altitude and the actual altitude is one of the major factors. Another notable point is that the significant reduction in the number of conflict pairs in corrective and warning alert state for the descent-descent case. It suggests that TDWC can better reflect the risk near busy terminal areas where the arrival traffic is carefully managed.

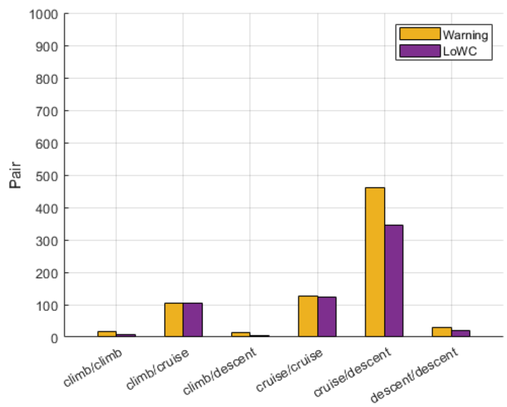

Fig. 18. Number of TDWC conflict pairs by alert levels and flight phase combinations (Phase 2 criteria).

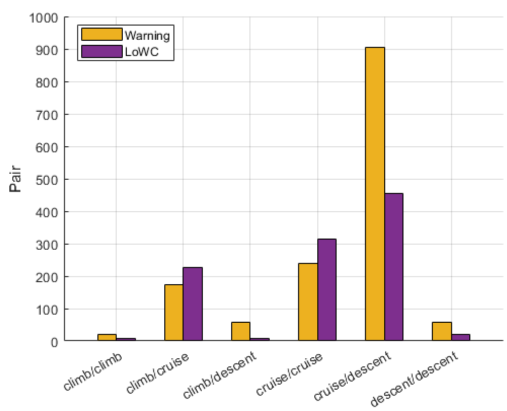

Fig. 19. Number of TDWC conflict pairs by alert levels and flight phase combinations (Phase 2 criteria).

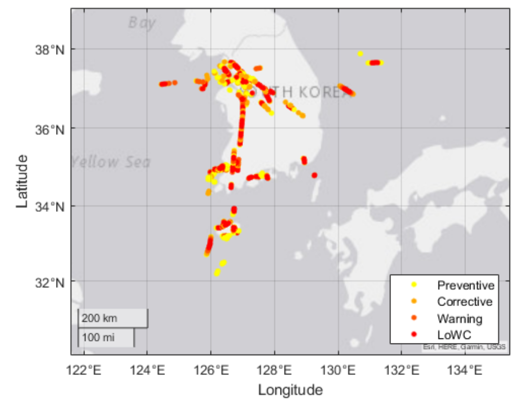

Fig. 20. TDWC alerts between cruise-descent pairs (Phase 1 criteria).

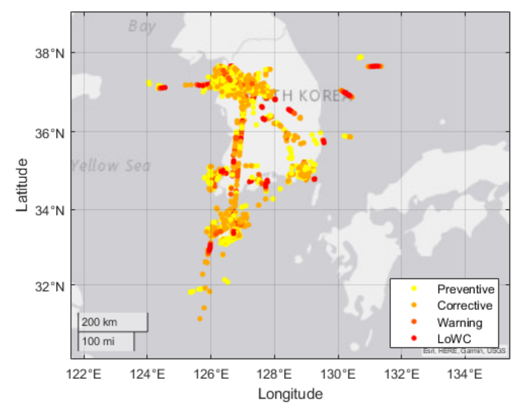

Fig. 21. DWC alerts between cruise-descent pairs (Phase 1 criteria).

The number of conflict pairs for the six flight phase combinations are shown in Figs. 18 and 19 for TDWC and DWC, respectively when the Phase 2 criteria are applied. The general trend is similar to the Phase 1 criteria.

Figs. 20 and 21 compare the location of TDWC and DWC alerts for the cruise-descent conflict pairs when the Phase 1 criteria is applied.

B. Analyses by Airspaces

Figs. 22 and 23 show the TDWC and DWC alerts in the entire Incheon FIR, respectively when the Phase 1 criteria is applied. Figs. 24 and 25 show the TDWC and DWC alerts, respectively when the Phase 2 criteria is applied. The analysis shows that the cumulative duration of all the alerts for the TDWC has decreased by 33 percent compared to DWC in Phase 1 and Phase 2. In terms of the individual alert levels, the total duration in preventive alert increased by 50 percent, while the duration in corrective alert, warning alert, and LoWC decreased by 70, 70, and 20 percents, respectively.

In terms of conflict pairs, the difference between TDWC and DWC is larger. The total number of pairs in any of the alert states is reduced by 70 percent for Phase 1 criteria and by 40 percent for Phase 2 criteria.

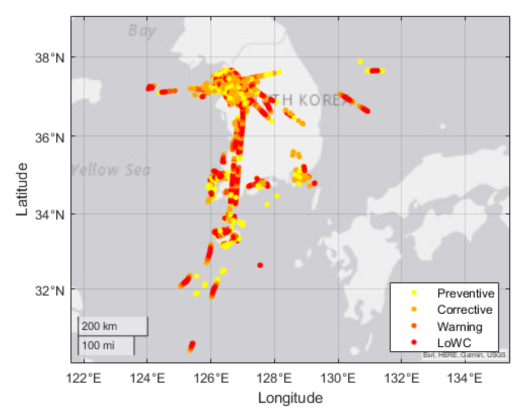

Fig. 22. TDWC alerts in Incheon FIR (Phase 1).

The airspace of Incheon FIR is divided into 12 sectors and 14 Terminal Maneuvering Areas (TMAs). The 14 TMAs are subdivided into a total of 55 blocks. The analyses results for all 12 sectors and three selected TMA blocks are presented

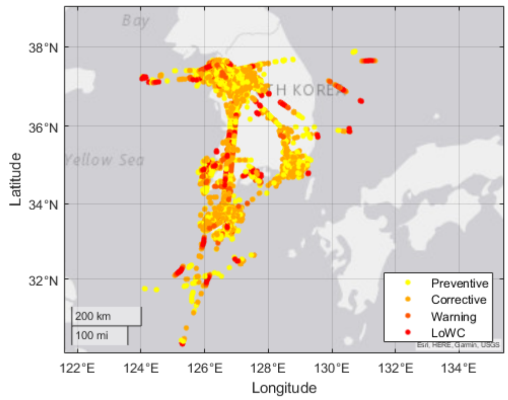

Fig. 23. DWC alerts in Incheon FIR (Phase 1).

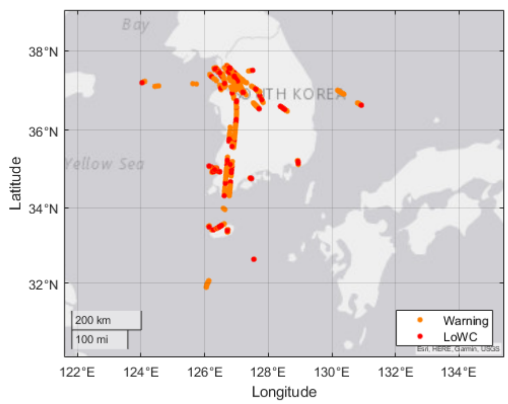

Fig. 24. TDWC alerts in Incheon FIR (Phase 2).

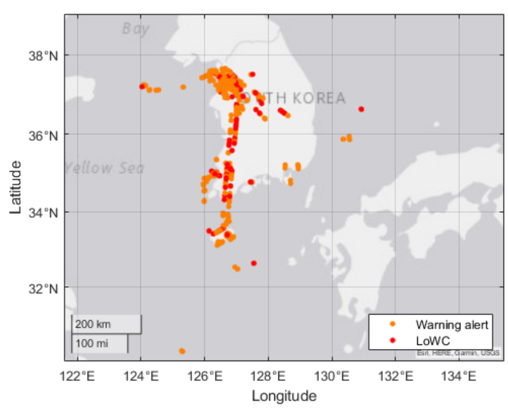

Fig. 25. DWC alerts in Incheon FIR (Phase 2).

in Tables IV through VII. The three TMA blocks are T01 of the Seoul TMA that includes Incheon International Airport and Gimpo International Airport, T29 of Gwangju TMA that includes Gwangju Airport, and T23 of Jeju TMA that includes Jeju International Airport (CJU). The total duration is in seconds, and the number of pairs is shown inside the parenthesis next to the duration.

TABLE IV
DWC DURATION AND NUMBER OF PAIRS BY AIRSPACE (PHASE 1 CRITERIA).

Airspace	preventive	corrective	warning	LoWC
Daegu Area	371 (69)	677 (93)	76 (18)	192 (5)
East Sea	21 (2)	50 (3)	61 (3)	77 (3)
Gangneung Area	29 (7)	2 (2)	0 (0)	0 (0)
Gunsan East	1254 (244)	1364 (169)	244 (28)	322 (35)
Gunsan West	186 (27)	301 (31)	63 (6)	97(7)
Gwangju East	401 (75)	2485 (168)	1754 (128)	3045 (107)
Gwangju West	1171 (109)	2238 (196)	372 (68)	344 (17)
Incheon North	726 (97)	1181 (133)	108 (24)	70 (10)
Incheon South	218 (26)	244 (22)	167 (15)	224 (14)
Jeju Area	55 (8)	93 (11)	70 (4)	108 (4)
Pohang Area	266 (48)	270 (39)	30 (6)	107 (6)
South Area	38 (7)	32 (5)	0 (0)	8 (1)
T01 Seoul	8055 (1144)	10788 (1176)	1738 (201)	885 (75)
T29 Gwangju	3756 (105)	731 (62)	571 (46)	1281 (31)
T23 Jeju	8048 (730)	18271 (1184)	8272 (537)	18973 (334)

TABLE V
TDWC DURATION AND NUMBER OF PAIRS BY AIRSPACE (PHASE 1 CRITERIA).

Airspace	preventive	corrective	warning	LoWC
Daegu Area	563 (23)	321 (14)	115 (4)	231 (4)
East Sea	66 (3)	60 (2)	50 (2)	111 (3)
Gangneung Area	7 (3)	0 (0)	0 (0)	0 (0)
Gunsan East	1479 (95)	1630 (63)	994 (48)	1310 (58)
Gunsan West	106 (8)	301 (11)	250 (10)	300 (11)
Gwangju East	149 (9)	157 (6)	145 (6)	1540 (26)
Gwangju West	4670 (146)	757 (34)	150 (12)	159 (14)
Incheon North	2828 (83)	343 (16)	103 (8)	288 (18)
Incheon South	436 (40)	436 (25)	239 (15)	294 (17)
Jeju Area	64 (3)	120 (4)	100 (4)	145 (4)
Pohang Area	148 (8)	72 (4)	25 (1)	184 (6)
South Area	1 (1)	0 (0)	0 (0)	7 (1)
T01 Seoul	7572 (316)	3338 (172)	1421 (70)	2461 (90)
T29 Gwangju	415 (20)	225 (11)	129 (7)	303 (12)
T23 Jeju	13785 (402)	3992 (149)	1733 (85)	6142 (86)

TABLE VI
DWC DURATION AND NUMBER OF PAIRS BY AIRSPACE (PHASE 2 CRITERIA).

Airspace	warning	LoWC
Daegu Area	34 (5)	9 (3)
East Sea	2 (1)	5 (1)
Gangneung Area	0 (0)	0 (0)
Gunsan East	182 (28)	56 (18)
Gunsan West	32 (7)	11(3)
Gwangju East	1423 (81)	456 (38)
Gwangju West	476 (53)	92 (12)
Incheon North	11 (6)	22 (8)
Incheon South	108 (15)	12 (4)
Jeju Area	4 (1)	0 (0)
Pohang Area	50 (10)	16 (3)
South Area	3 (1)	2 (1)
T01 Seoul	456 (78)	185 (43)
T29 Gwangju	637 (29)	129 (15)
T23 Jeju	10120 (388)	4735 (167)

TABLE VII
TDWC DURATION AND NUMBER OF PAIRS BY AIRSPACE (PHASE 1 CRITERIA).

Airspace	warning	LoWC
Daegu Area	158 (3)	6 (2)
East Sea	84 (2)	4 (1)
Gangneung Area	0 (0)	0 (0)
Gunsan East	1662 (49)	39 (18)
Gunsan West	198 (6)	11(4)
Gwangju East	379 (17)	334 (15)
Gwangju West	298 (17)	32 (9)
Incheon North	259 (17)	29 (9)
Incheon South	380 (16)	7 (4)
Jeju Area	45 (1)	0 (0)
Pohang Area	195 (5)	15 (3)
South Area	6 (1)	1 (1)
T01 Seoul	2545 (79)	234 (50)
T29 Gwangju	419 (10)	21 (7)
T23 Jeju	2982 (81)	1198 (43)

In terms of the risk, T23 of Jeju TMA is identified as having the largest number of conflict pairs and duration, which suggest that the area near the CJU is very congested and requires particular attention. The reduction in the total duration is 50 percent and the number of pairs is 75 percent from DWC to TDWC. It suggests that, with the busy traffic, false alerts can be easily detected if the metric is not carefully designed.

Next to T23, T01 of Seoul TMA and Gwangju East, Gwangju West, Gunsan East, and Incheon North Sectors contain a large number of conflict pairs. One interesting aspect is the T01. Both the number of conflict pairs and duration increased with TDWC when the Phase 2 criteria are applied. Further investigation is required, but it is speculated that the previous DWC metric was underestimating the risk in T01.

Figs. 26 and 27 present the airspace where TDWC and DWC occurred in T23 with Phase 1 criteria. Figs. 28 and 29 show the T01 Seoul TMA in Phase 2.

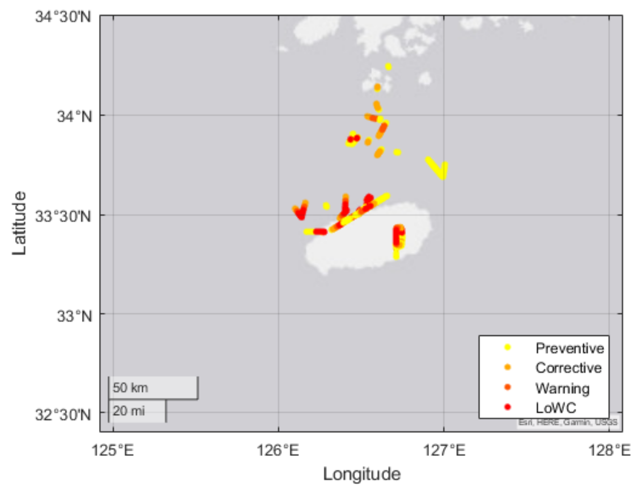

Fig. 26. TDWC alerts in T23 Jeju (Phase 1 criteria).

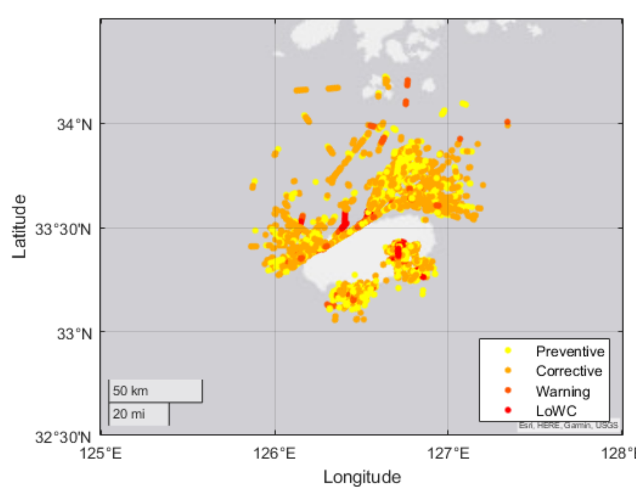

Fig. 27. DWC alerts in T23 Jeju (Phase 1 criteria).

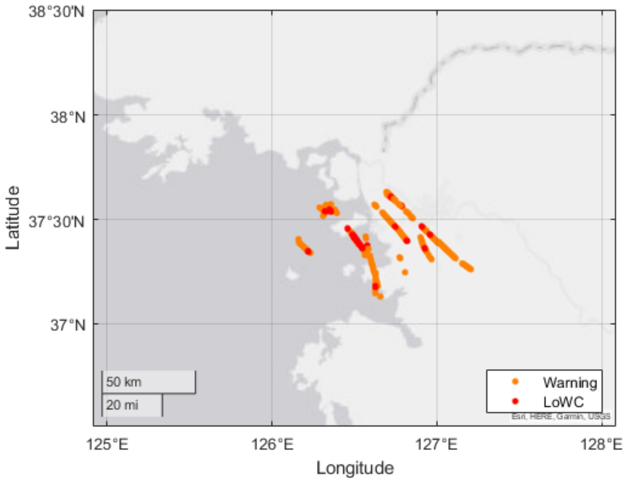

Fig. 28. TDWC alerts in T01 Seoul (Phase 2 criteria).

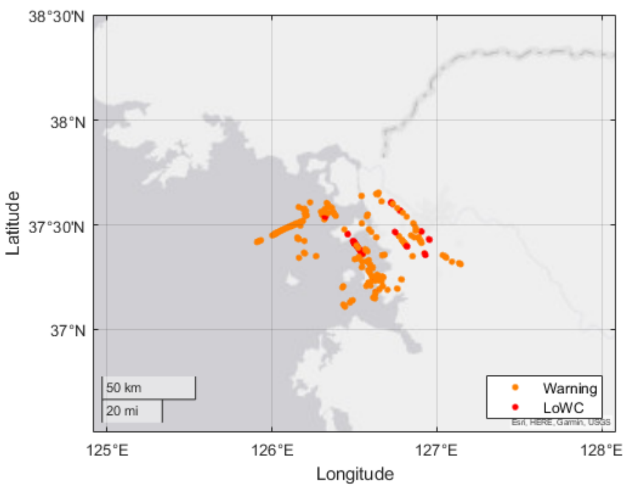

Fig. 29. DWC alerts in T01 Seoul (Phase 2 criteria).

Conclusions

In this study, to address the shortcomings of using DWC in calculating the risk of conflict and collision between aircraft, a new metric called TDWC is presented. TDWC is calculated by modifying the HMD, τ_{mod}, and d_h definitions of DWC to reflect the actual flown trajectories. To show that TDWC is better aligned with the risk levels with smaller number of false alerts, both the metrics are computed and analysed using the ADS-B data in the Incheon FIR in 2018. The calculation results show that with the Phase 1 criteria, the total duration in the alert state decreases by 33 percent compared to DWC while the number of pairs is reduced by nearly 70 percent. While examining individual cases, it is confirmed that TDWC better reflects the risk by excluding false alerts and including new risks caused by maneuvers that were not considered in DWC. Further investigation will be performed to evaluate the new risk metric. In addition, if trajectory prediction becomes more accurate in the future, TDWC can be more widely used.

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