A Method to Verify Convective Weather in TAFs Specific to Aviation Applications

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The Weather Company

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TWC Aviation Forecasting Services

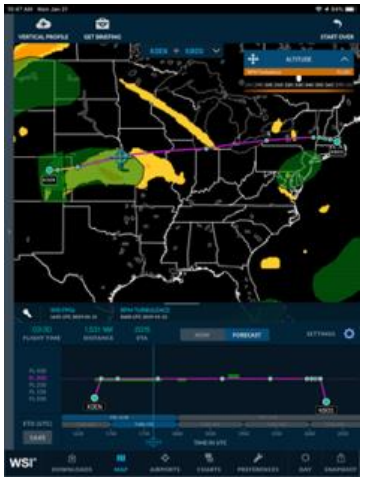
- TWC supports hundreds of aviation clients
- TWC mets embedded in operations two major US airlines
- About 50 meteorologists dedicated to aviation support
- Products include TAF, risk/event, Terminal Area Convective Risk (TrACR) Product, and turbulence (FPG) products
- TAF/risk products use our proprietary consensus model blend as their basis, with forecaster modification
- Global GRAF (MPAS-15) turbulence forecast

2-5 day forecast for a major global airline

Valid for Thursday 7 Feb 2019 00:00 to Monday 11 Feb 2019 23:00

DATE	ID	WIND	3000ft-WIND	TSTM	CV-CAT	SNOW	ICE	MIN-T	MAX-T	FORECAST CONCERNS
Thu Feb 07	EGKK							5	9	3000ft WSW 35-40kt. WSW wind 15-20KT G25-35KT. SHRA likely 00-07Z
	EGLC							7	10	3000ft WSW 35-40kt. WSW wind 15-20KT G25-35KT. SHRA possible 00-04Z.
	EGLL							6	9	3000ft WSW 35-40kt. WSW wind 15-20KT G25-35KT. SHRA likely 00-04Z
Fri Feb 08	EGKK							7	10	3000ft SW 40-55kt SW wind 20-25KT G30-40KT. RA likely 01-18Z
	EGLC							8	11	3000ft SW 40-55kt SW wind 20-25KT G30-40KT. RA likely 03-18Z
	EGLL							7	11	3000ft SW 40-55kt SW wind 20-25KT G30-40KT. RA likely 03-18Z
Sat Feb 09	EGKK							7	10	3000ft 00-14Z WSW 50-40kt. WSW wind 15-20KT G25-30KT AM. RA likely 15-24Z
	EGLC							8	11	3000ft 00-14Z WSW 50-40kt. WSW wind 15-20KT G25-30KT AM. RA likely 18-24Z
	EGLL							7	10	3000ft 00-14Z WSW 50-40kt. WSW wind 15-20KT G25-30KT AM. RA likely 17-24Z
Sun Feb 10	EGKK							4	8	W wind 10-15KT G20-25KT AM. RA likely 00-16Z. Risk 00-07Z cloud 1000ft. Evening Min Temp
	EGLC							6	9	W wind 10-15KT G20-25KT AM. RA likely 00-15Z.
	EGLL							5	8	W wind 10-15KT G20-25KT AM. RA likely 00-15Z. Risk 04-07Z cloud 1000ft

IMPACT KEY	WIND	3000ft-WIND	TSTM	CV-CAT	SNOW	ICE	MIN-T	MAX-T
No Impact								
Moderate Impact	>20KTS	>25KTS	>30%	IFR C<=1100ft V<=4500m	>0mm	>0mm		>30C
High Impact	>30KTS	>35KTS	>50%	LIFR C	>2cm	>5mm		>35C



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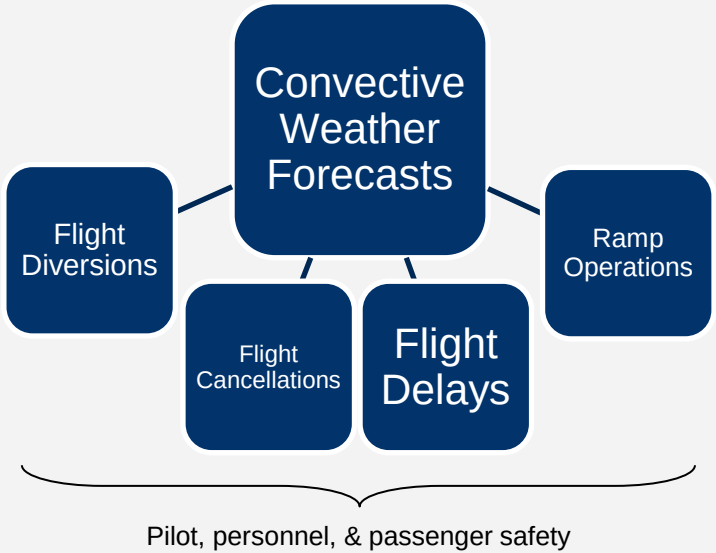
Introduction & Motivation

The primary operational forecast of airport conditions is provided by Terminal Aerodrome Forecasts (TAFs). Through FAA approval, The Weather Company (TWC) forecasters provide routine/amended TAFs when they feel as though they can add value to NWS TAFs.



Monthly Aggregated TAF Statistics

Include POD, F, CSI for Ceilings, Visibility, and Present Weather (including thunderstorms) with comparisons to NWS TAFs

Event-Based Verification

The metrics and aggregation above aren't sufficient for aviation needs, as they **do not**:

1. Support communication of forecast performance of a given event to leadership
2. Support the granular data needs of data analytics teams
3. Assess the overuse/misuse of VCTS in current TAFs

TWC collaborated with major airline partner to co-develop a new, automated penalty-based verification methodology to assess the accuracy and applicability of convective TAFs issued by TWC and the NWS.

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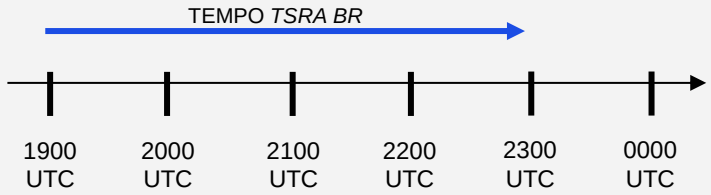
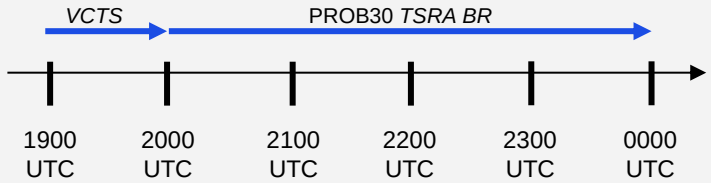
Convective Forecasts Verified in TAFs

Convective forecasts are commonly provided in the following TAF groups:

- PROB30 (probability 30-39%)
- TEMPO (temporary conditions, generally < 1 hour)
- Main Body Thunderstorm (FM)
- VCTS (vicinity thunderstorms)

For verification, VCTS (vicinity thunderstorms) are treated as their own forecast category. TEMPO and FM are combined to represent impacts to the field. Non-convective forecasts are designated as “None”.

NWS	(KGSP) KCLT 141354Z 1414/1518 22005KT P6SM FEW011 BKN100 BKN250 TEMPO 1414/1415 BKN011 FM141600 24007KT P6SM SCT050 TEMPO 1419/1423 1SM TSRA BR OVC025CB FM142300 17005KT P6SM SCT050 BKN110 FM151000 18003KT 6SM BR FEW005 SCT015 FM151300 18005KT P6SM SCT050=	
TWC	(KWSI) TAF KCLT 141528Z 1416/1516 27005KT P6SM BKN030 FM141900 23006KT P6SM VCTS BKN050 PROB30 1420/1500 30015G25KT 3SM TSRA BR BKN035 FM150100 17005KT P6SM SCT050 BKN250 FM150900 VRB03KT 6SM BR BKN015 RMK VCTS 1419/1501 ALQDS MOVG SE 15KT	

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Observation Sources

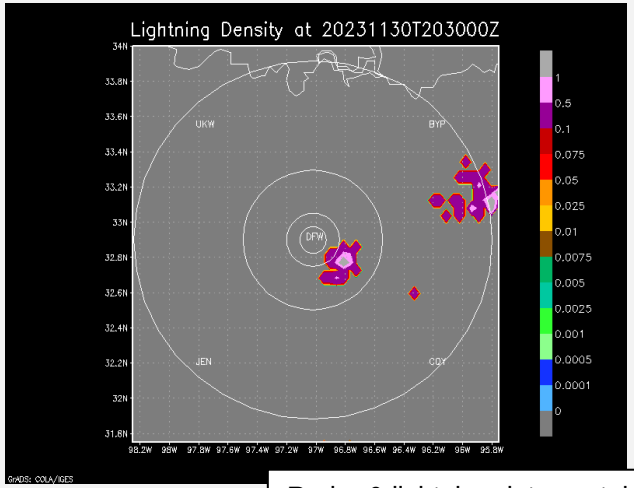
METeorological Aerodrome Reports (METARs)

KDFW 302028Z 15003KT 2SM -RA BR BKN005 OVC010 16/16 A2964 RMK AO2 SFC VIS 3 RAB28 P0000 T01610156

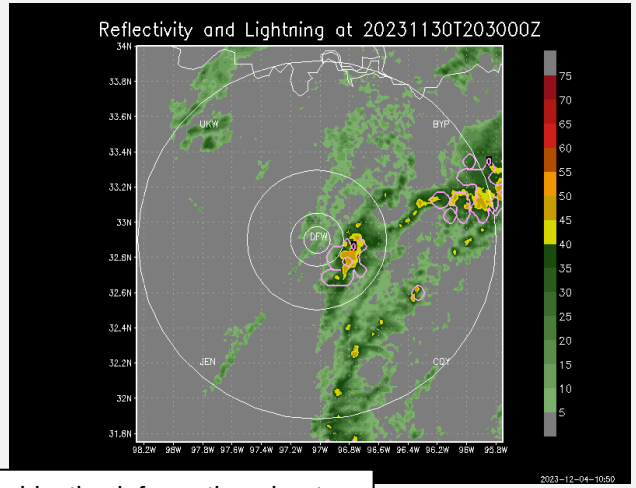
METARs are commonly used to assess TAF skill, but are subject to significant inconsistencies:

- In reporting thunderstorms and their distances from the airport between the automated & human observations
- Among airports

Gridded Lightning Density (4 km)



TWC Radar Reflectivity Mosaic (NOWrad; 1 km)



Radar & lightning data contain objective information about the distance of convection from the terminal, as identified by reflectivity pixels and/or non-zero lightning density.

- TSTM over Field (< 5 mi)
- VCTS (5–10 mi)
- VCTS (10–25 mi)
- TSTMs within Gates (25 mi – furthest gate)
- No TSTM

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Observation Sources
Mapping to Observation Categories

Observations available at 5-10 min intervals

Radar and lightning strike density observations are collected and appropriately assigned to each range ring

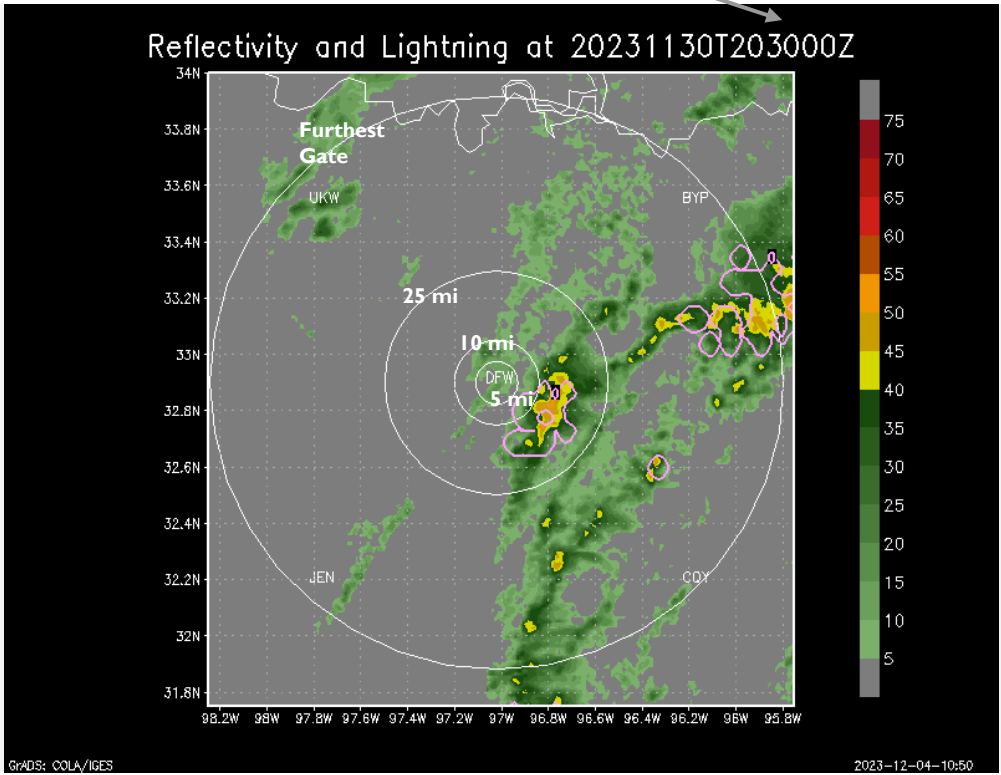
Observed thunderstorm:

- Radar: min 16 pixels ≥ 35 dBZ in range ring
- Lightning: any lightning strikes (nonzero lightning density) in range ring

Observation	Radar	Lightning
TSTM over Field (< 5 mi)	-	-
VCTS (5–10 mi)	-	✓
VCTS (10–25 mi)	✓	✓
TSTM within Gates (25–68 mi)	✓	✓

This process is repeated for each observation available within an hour time window. The ring closest to the field with an observed thunderstorm is used for verification.

Both (1) lightning and (2) radar observations from hourly time windows are used separately to verify each TAF.



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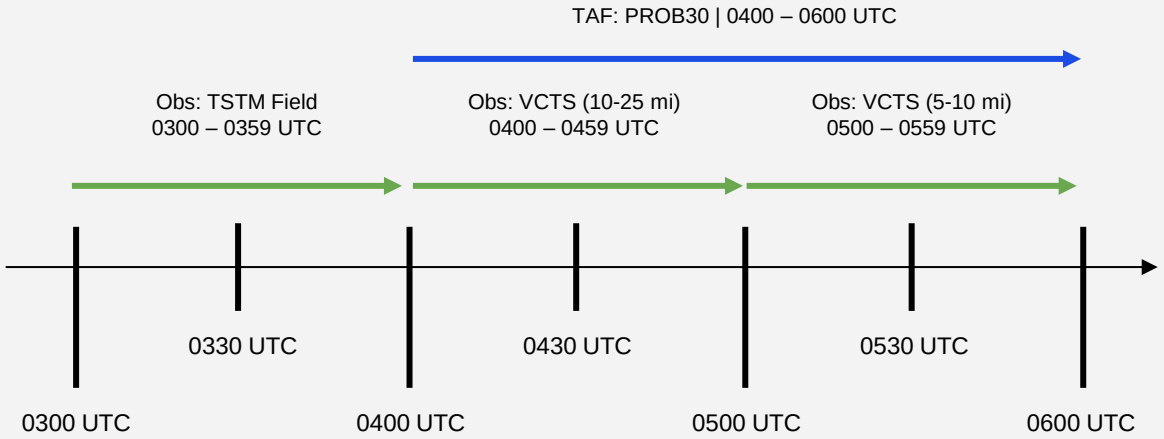
Verification Requirements & Design
Temporally Mapping Forecasts and Observations

Verification reports are automatically generated on a daily basis, with focus on two general TAF issuance times (23/00 UTC, 14/15 UTC) from both TWC and NWS.

Convective TAF forecasts and observations are mapped into hourly time windows to enable an hour-by-hour, penalty-based verification.

Verification Example:



Valid Time	0300 UTC	0400 UTC	0500 UTC
Forecast	None	PROB30	PROB30
Observation	TSTM Field	VCTS (10–25 mi)	VCTS (5–10 mi)

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Verification Requirements & Design
Penalty Values

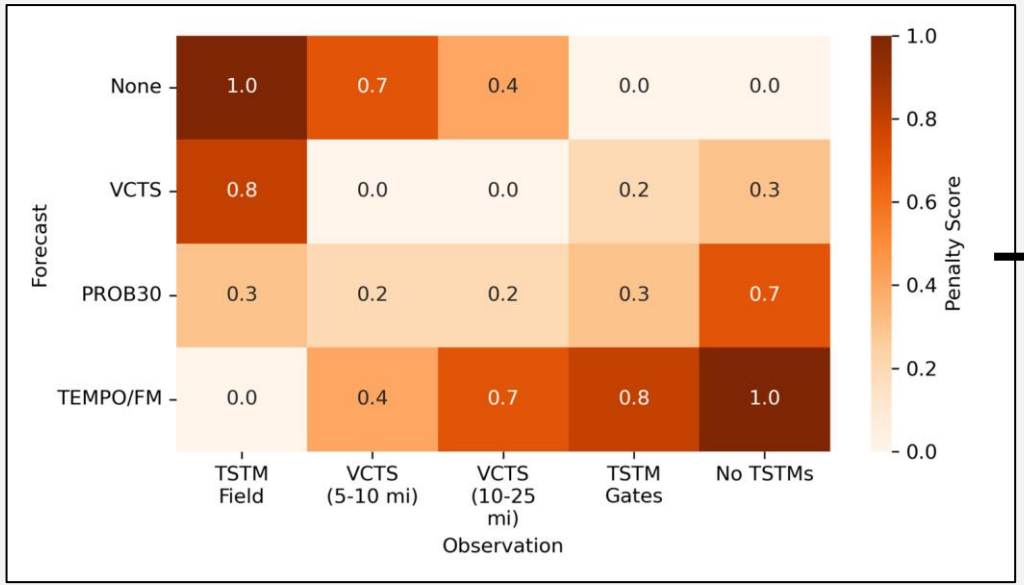
*

Penalty values

0.0 → **1.0**

Significance of the mismatch between the forecast and observed convection

Airline agnostic (or specific) penalties ranging from 0–1 are identified for each combination of TAF forecast and observation category.*



TAFs are scored on an hour-by-hour basis with weighted penalties through first 24 hours after TAF issuance time. To determine the final TAF penalty, weights that decline as a function of TAF lead time are applied to the penalties at each valid time.

Lead Hours	Penalty Weight
0 – 5	1.0
6 – 11	0.8
12 – 17	0.6
18 – 23	0.4
24+	0.0

The intent of these penalties in aggregate is to capture TAF convective forecast skill in an operationally relevant manner, ***not*** the potential impact of the forecast on any specific operational decision.

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Convective TAF Verification Product

- Desire for single verification product to be both human- & machine-readable.
- Sheets are automatically generated and provided to airline partner on daily basis for multiple airport locations
- Verification product can be made available to other airline partners with their own or generic penalty table

	A	B	C	N	O	P	Q	R	S	T	U	AR
1	TAF	Issue Time	Source	07/16 10Z	07/16 11Z	07/16 12Z	07/16 13Z	07/16 14Z	07/16 15Z	07/16 16Z	07/16 17Z	Total Weighted Penalty
2	20230716T0000	152326Z	NWS	VCTS	VCTS	VCTS	VCTS	VCTS				
3	20230716T0000	152313Z	WSI			VCTS	VCTS	VCTS	VCTS			
4	20230716T1500	161500Z	NWS						TEMPO	TEMPO	VCTS	
5	20230716T1500	161459Z	WSI						TEMPO	VCTS	VCTS	
6	Observations		METAR				VCTS 5-10		TSTM Field			
7	Observations		Radar	TSTM Gates	TSTM Gates	TSTM Gates	VCTS 10-25	TSTM Field	TSTM Field	VCTS 10-25	VCTS 10-25	
8	Observations		Lightning			TSTM Gates	VCTS 10-25	TSTM Field	TSTM Field	VCTS 10-25	VCTS 10-25	
9	Verification		LightningOnly									
10	20230716T1500	161459Z	WSI						0	0	0	0
11	20230716T1500	161500Z	NWS						0	0.4	0	0.4
12	20230716T0000	152313Z	WSI	0	0	0.18	0	0.36	0.36	0.36	0.36	1.62
13	20230716T0000	152326Z	NWS	0.4	0.4	0.18	0	0.36	0.6	0.36	0.36	2.66
14	Verification		RadarOnly									
15	20230716T1500	161459Z	WSI						0	0	0	1.8
16	20230716T1500	161500Z	NWS						0	0.4	0	2.2
17	20230716T0000	152313Z	WSI	0	0	0.18	0	0.36	0.36	0.36	0.36	2.34
18	20230716T0000	152326Z	NWS	0.24	0.24	0.18	0	0.36	0.6	0.36	0.36	3.06
19												
20		Observed			Forecast							
21	TSTM Field			TEMPO/FM								
22	VCTS 5-10			PROB30								
23	VCTS 10-25			VCTS								
24	TSTM Gates			No TSTMs								
25	No TSTMs											

Rows 2–5: TWC & NWS TAFs mapped to convective forecast categories for each valid hour

Rows 6–8: METAR, Radar, and Lightning observations mapped to convective observation categories

- *Future improvement:* blend radar & lightning data as a single source of observation truth

Rows 10–13, 15–18: Time-weighted penalty table values assigned to TWC & NWS TAFs using lightning, radar observations

Final column: Sum of penalty values across all valid hours to aid in comparisons between competitors and generation times

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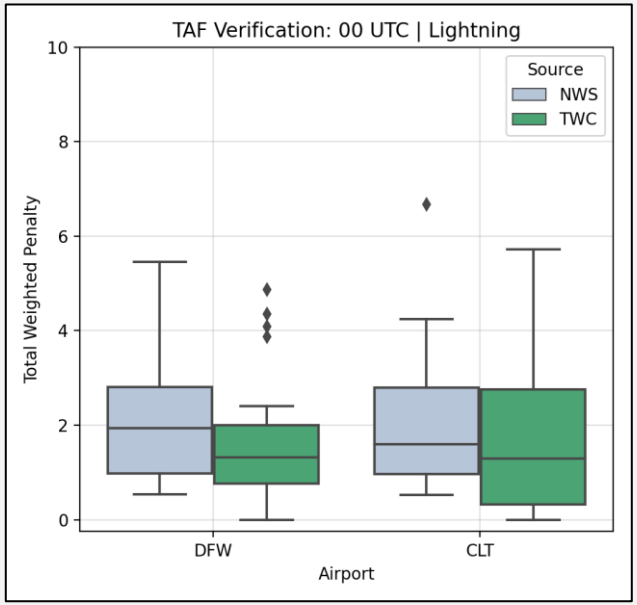
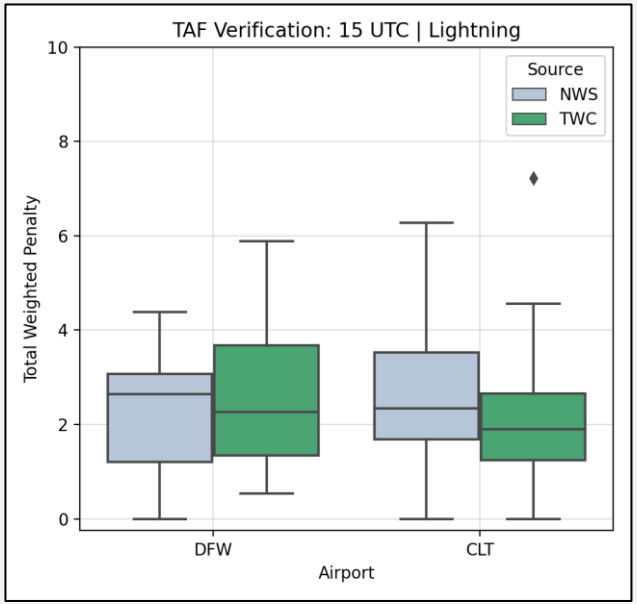
Convective TAF Verification:
Potential for Temporal Aggregation of Penalties





- When penalty values differ between TWC and NWS, TWC TAFs tend to be more performant than the NWS, with the exception of 15 UTC TAFs issued at DFW.
- When considering both issuances and lightning density observations, TWC TAFs tend to be more performant than the NWS TAFs at CLT (67.6%) than at DFW (52.3%).
- Data are aggregated from 1 June – 31 August 2023
- The penalties assigned to each forecast and observation pair are still under evaluation. As such, data analysis is still ongoing.

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Convective TAF Verification Product
Strengths & Weaknesses

Strengths

1. **Objective observation data used for verification** rather than subjective and potentially inconsistent METARs.
2. Lightning and radar data allow us to **distinguish between thunderstorm proximities to airport** and to score forecasts accordingly.
3. Penalty tables capture **relative magnitude of impact for all forecast and observation mismatches**, providing a metric relevant to airline operations.
4. Verification methodology allows for **objective comparison** between TWC and NWS TAFs, **helping to quantify value added by TWC forecasters**.

Weaknesses

1. Lightning and radar identified **convection thresholds are arbitrary**, not fully accounting for storm size, severity, or longevity.
2. **Penalty values are subjective** and may not capture the true operational impact of forecast and observation mismatches.
3. **No partial credit awarded** if location/duration of convection is correctly predicted but timing is off.
4. **Contingency table penalty scoring could be gamed** by issuing forecasts that are likely to produce lower penalties even when that reduces their true usefulness.

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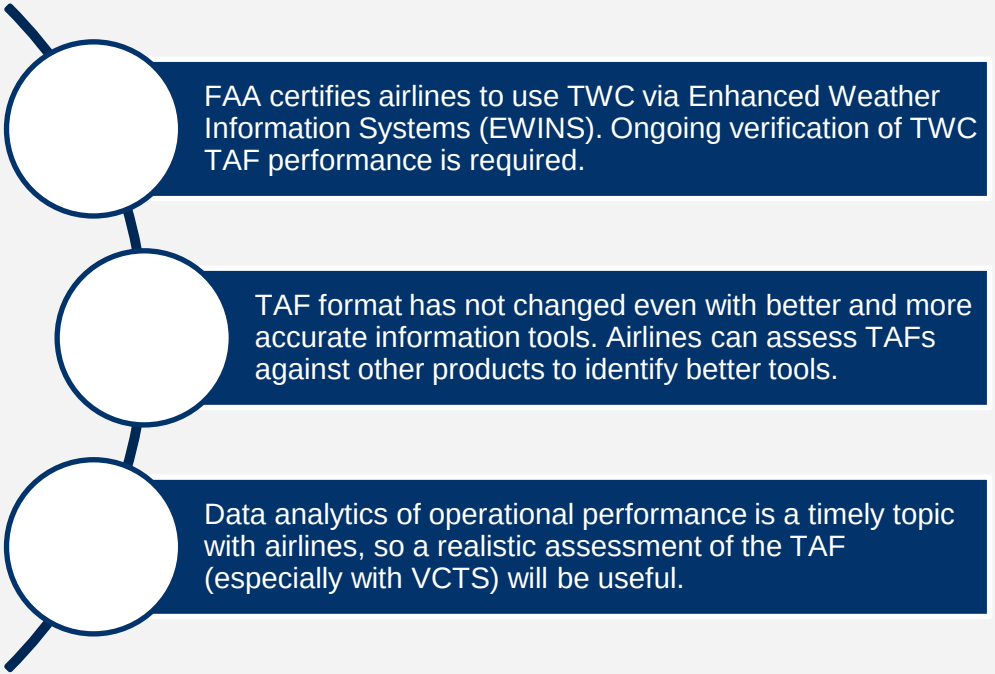
Value of Convective TAF Verification to Aviation Partners

A more comprehensive and granular TAF assessment can be used to benefit airline and aviation interests in a variety of ways



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Summary

Conclusions:

- A new penalty-based method to verify both the standard (00 UTC and 15 UTC) issued TAFs scored against both lightning density and radar observation “ground truth” was introduced.
- The use of lightning density and radar data allowed not only for the identification of convection, but also the location of the convection relative to the airport of interest.
- When assessing skill over the 2023 Summer season at CLT and DFW, TWC TAFs tended to outperform the NWS at both of the considered issuance times when using lightning observations as ground truth.

Future Improvements and Continued Work:

- The penalties assigned to each forecast and observation pair are still under evaluation. As such, data analysis and modifications are ongoing.
- Blending radar and lightning density observations may provide the most robust identification of convective weather
- Airline’s analytics team is including the verification results in their event descriptors as well as their debrief and business processes and will derive insights via further analysis of these data.
- Automated verification of the convective TAFs will continue to be generated and provided to one of TWC’s major airline partners on an ongoing basis, which will also allow feedback to be provided to TWC forecasters and product developers.

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