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Comparison of Selected Weather Translation Products

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Abstract

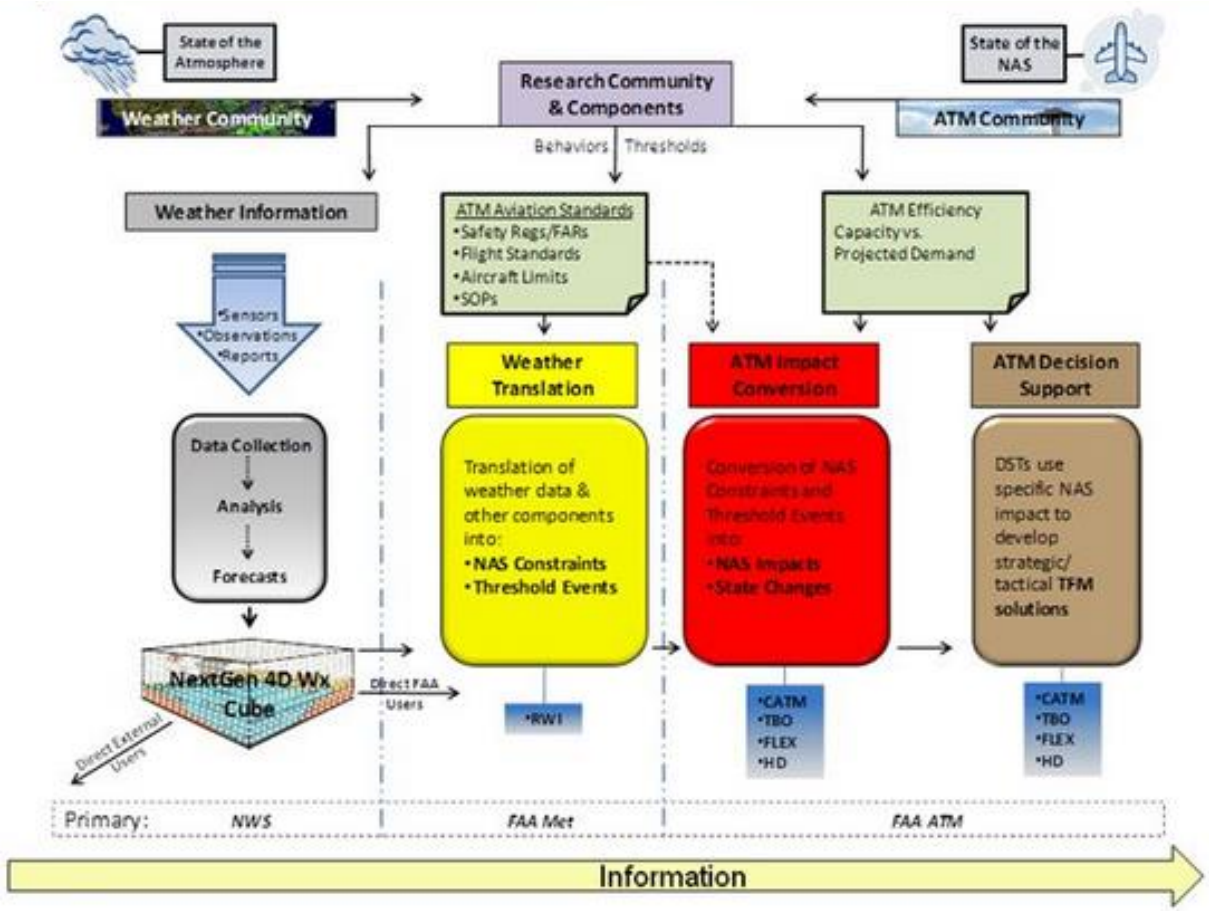
Weather is a primary contributor to the air traffic delays within the National Airspace System (NAS). At present, it is the individual decision makers who use weather information and assess its operational impact in creating effective air traffic management solutions. As a result, the estimation of the impact of forecast weather and the quality of ATM response relies on the skill and experience level of the decision maker. FAA Wx-ATM working groups have developed a Wx-ATM integration framework that consists of weather collection, weather translation, ATM impact conversion and ATM decision support. Some weather translation measures have been developed for hypothetical operations such as decentralized free flight, whereas others are meant to be relevant in current operations. This paper does comparative study of two different weather translation products relevant in current operations and finds that these products have strong correlation with each other. Given inaccuracies in prediction of weather, these differences would not be expected to be of significance in statistical study of a large number of decisions made with a look-ahead time of two hours or more.

I. Introduction

Weather is a primary contributor to the air traffic delays within the National Airspace System (NAS). At present, it is the individual human decision makers who use weather information and assess its operational impact in creating effective air traffic management solutions. As a result, the estimation of the impact of forecast weather and the quality of ATM response relies on the skill and experience level of the decision maker [FAA07]. In some cases, the difficulty of ATM problems associated with weather makes it impossible for human decision makers to come up with optimal solutions.

To address this problem, a FAA-industry working group created an ATM - Weather Integration framework roadmap [BPH11] shown in figure 1. It consists of weather collection, weather translation, ATM impact conversion and ATM decision support. The first element, Weather Collection collects most of the weather data used in the national airspace operations. For the purposes of ATM-Weather Integration, weather observations and forecasts are used by software related to the second element, Weather Translation (yellow box). Through a set of filters which consider the effects of such things as safety regulations, operating limitations and standard operating procedures, the weather information is translated into a NAS constraint or a threshold event. Both are defined using non-meteorological parameters that show their ability to alter the capacity of a NAS element. A NAS constraint is a non-meteorological expression associated with the aircraft-specific permeability of the NAS element in the presence of weather. Capacity of weather-impacted NAS element can be calculated from a NAS constraint. For airport constraints, a threshold event indicates a possible alteration in minimum spacing between aircraft or airport runway configuration resulting from airport weather conditions such as visibility dropping below a threshold.

Figure 1. ATM Weather Integration Roadmap



Translated weather information is used by the third component called ATM Impact Conversion (red box). Software associated with this task finds the aircraft expected to be in the impacted NAS element, computes the aircraft - specific, weather - constrained capacity of the impacted NAS element and then converts the NAS constraint or threshold event into a NAS impact or state change. The fourth component, ATM Decision Support (brown box), uses the impact information from ATM Impact Conversion and creates one or more ATM solutions to lessen the impact of the forecast or actual weather constraint.

Several research organizations have proposed ways to translate en route convective weather observations and forecasts into weather translation measures. Mitchell, Polishchuk, and Krozel [MPK06] and Krozel et al. [KMP07] developed techniques to estimate weather impacted capacity of a generic airspace region by modeling an en route airspace where aircraft paths may conform to the geometry of hazardous weather constraints and by examining the relationship between capacity and weather severity under various operational conditions. Decentralized Free Flight, where all pilots are free to select any route, is modeled by randomization. Centralized packing aims to maximize throughput in a given airspace, according to a centralized packing scheme. Under the specified conditions, the authors use min-cut algorithms compute the theoretical maximum capacity and compare it to algorithmic solutions.

Song et al. [SWG07] and [SGW09] created a model for weather-impacted sector capacity as a function of traffic flow pattern in that sector. The model utilizes a Weather Avoidance Altitude Field (WAAF) that pilots would deviate around based on CWAM model. The model also uses min-cut approach to calculate the flow capacity ratio of each flow in the expected traffic flow pattern. The weather-impacted sector capacity is the summation of sector capacity ratio times the normal sector capacity for all flows in the predicted traffic flow pattern. The model can be considered as another approach to assess sector capacity by examining flow patterns within a sector.

Klein et al. [KCW08] created an airspace capacity estimation technique based on augmented Weather Impacted Traffic Index (WITI) metric. WITI was obtained by considering weather impacted traffic flow patterns in an airspace (center, sector, airport, etc.). It used the spread of convection blocking a traffic flow to calculate the capacity degradation of the airspace. The airspace capacity estimates were developed by reducing clear-weather throughput counts with the calculated airspace capacity degradation.

Matthews [MDV15] defines Airspace permeability as a metric of translated weather impact. Permeability is a quantification of the extent to which traffic flows are blocked by convective weather in a particular airspace region. Permeability can also be converted into a categorical impact metric (e.g., none, moderate, severe) or a metric of the achievable or sustainable traffic flow rates in a given airspace. Airspace regions for which permeability is computed can be of any size, orientation and in any location. Different permeability is associated with an airspace region depending on the orientation. Permeability was computed from Convective Weather Avoidance Model (CWAM) and Weather Avoidance Field (WAF). For this work, CWAM was processed across relevant routes and combined to compute the permeability in an airspace region. The translation of weather into permeability and the forecast of permeability and its uncertainty for 0-12 hour was a part of a real-time decision support display called the Traffic Flow Impact (TFI) tool. TFI performance was assessed at selected FAA and airline facilities during the convective weather season as part of the FAA's ongoing CoSPA program.

Some of these weather translation measures [MPK06, KMP07] have been developed for hypothetical operations such as decentralized free flight and capture possible flights that can be flown through tubes through weather, whereas others are meant to be relevant in current operations and primarily capture the degree to which flights flown along current routes would be blocked. Previous work by Wang [WG10] has done comparison of some of these products. This paper extends that work by doing comparative study of two weather translation measures relevant for current operations and that capture blockage of flow by weather.

The paper is organized as follows. Section II describes two weather translation models used for comparison. The experimental results for select high-volume sectors are presented in Section III. Finally, concluding remarks are presented in Section IV.

II. Modeling Methodology

A description of the two models that were used to estimate the sector-level weather impacts are provided in the following subsections.

A. Weather Impacted Traffic Index (WITI) Model

A simple metric of weather impact on a sector would be the percent of sector airspace occupied by weather. A shortcoming of this metirc is that it does not explicitly account for the location of air

traffic flows within a sector. As a result, weather impacting a region of a sector in which relatively few flights travel is given the same level of importance as a weather system impacting a heavily traveled region of airspace. To correct this deficiency, a model similar to the one presented in [KCW08] was developed which accounts for traffic and weather patterns within a sector through the calculation of the sector-level weather impacted traffic index. [KCW08] It has been shown to correlate well with air traffic delays [CS04, K07, HX13, SWK09]. The normalized WITI index for the kth flight level at a particular time *t* is defined as follows:

$$WITI_k = \sum_{(i,j)\in S} T_{i,j,k} W_{i,j,k} \Big/ \sum_{(i,j)\in S} T_{i,j,k}$$

Here $T_{i,j,k}$ and $W_{i,j,k}$ are two-dimensional grid cell elements that cover the weather impacted sector at the kth flight level. The element $T_{i,j,k}$ is used to store the number of flights occupying grid cell *(i, j)* at flight level *k* at a particular time, and $W_{i,j,k}$ is set to a value of one if severe weather is present in grid cell *(i, j)* at flight level *k* at a particular time t or zero otherwise. As is typically the convention, $T_{i,j,k}$ are calculated using a clear weather reference traffic data set. Finally, *S* is the set of all two-dimensional grid cell elements, *(i, j),* within the sector of interest.

Once $WITI_k$ is calculated, the weather impacted traffic index for the entire sector is defined as

$$WITI = \sum_{k=1}^{N_{FL}} w_k \times WITI_k$$

Here N_{FL} and w_k are defined as was done in Section II.A. A variation of WITI is a metric called Percent WITI. Percent WITI captures percent of aircraft that encounter weather as against absolute number of aircraft encountering weather.

B. Permeability Model

Permeability computation uses multi-directional scanning algorithm developed by MOSAIC ATM under a NASA SBIR with convective forecasts from the HRRR and convection diagnostic from NCWD. [M17] Each sector is scanned in multiple directions with sets of closely spaced parallel scan lines to compute directional permeability. For a given direction, permeability is calculated as the percentage of scan lines crossing the sector in the given direction that do not intersect non-permeable convection. Non-permeable convection is defined as any hexagon with an average convective intensity greater than a threshold level. Finally, it uses 18 scanning directions and weighs directional permeability by directional traffic demand for aggregate total in 15-min increments. More details of the approach can be found in [M17]. This work uses permeability data provided by MOSAIC ATM.

III. Results

This section contains the results of using the models proposed in Section II to calculate the weather impacts on the six high-demand, high-altitude sectors that were described in Section III. Data used is for July 13, 2016. A comparison of the actual and forecasted sector-level weather

impacts is presented in Section III.A. The correlation between two models of sector-level weather impacts is presented in Section III.B..

A. Correlation between Actual and Forecasted Model Results

The correlations between the actual and forecasted values of permeability calculated using HRRR weather forecasts and actual NCWD now-cast observations are listed in Table 1 for the six representative high-altitude sectors. The correlations between forecasts and observations varied appreciably between the sectors. This suggests that the ability to forecast weather translation measures depends the sector's characteristics such as size, shape, and location.

Correlation coefficients in Table 1 vary from .35 to .77. Thus, the correlations between the actual and forecasted values of permeability are not strong.

Table 1. The correlation between WITI and HRRR forecast permeability

Sector	NCWD permeability vs 1 hour HRRR permeability	NCWD permeability vs 2 hour HRRR permeability	NCWD permeability vs 3 hour HRRR permeability
ZAU52	.83	.58	.36
ZID80	.76	.50	.53
ZKC12	.65	.35	.28
ZKC30	.65	.45	.34
ZKC32	.87	.65	.11
ZKC84	.77	.77	.27

Scatter plots of the data used to calculate the correlation coefficients for 1 and 2 hour forecasts appearing in Table 1 is presented in Table. 2.

Table 2. 1 and 2 Hour Forecast vs Actual Permeability

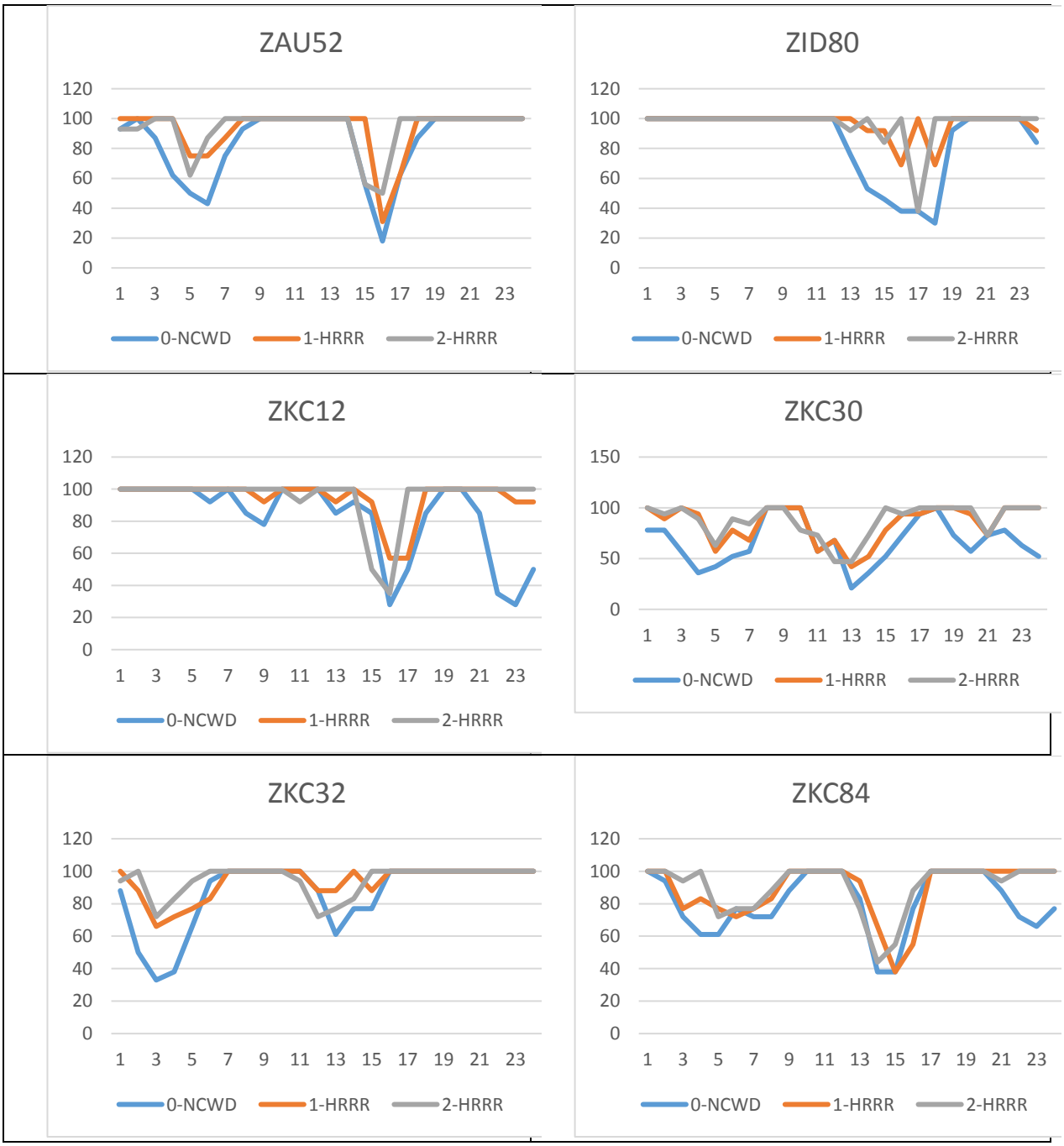


Table 3. Permeability Vs WITI for multiple sectors

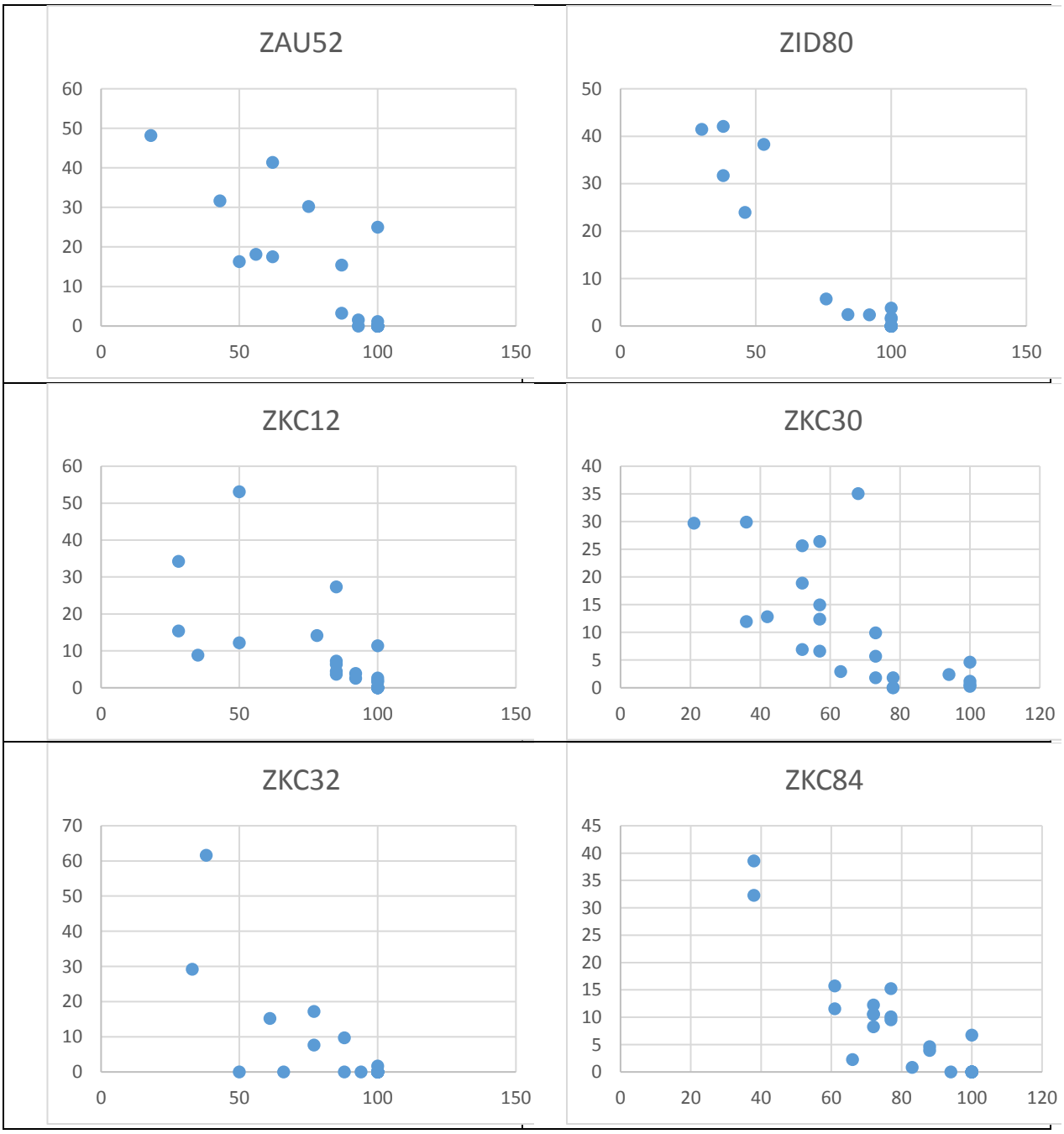
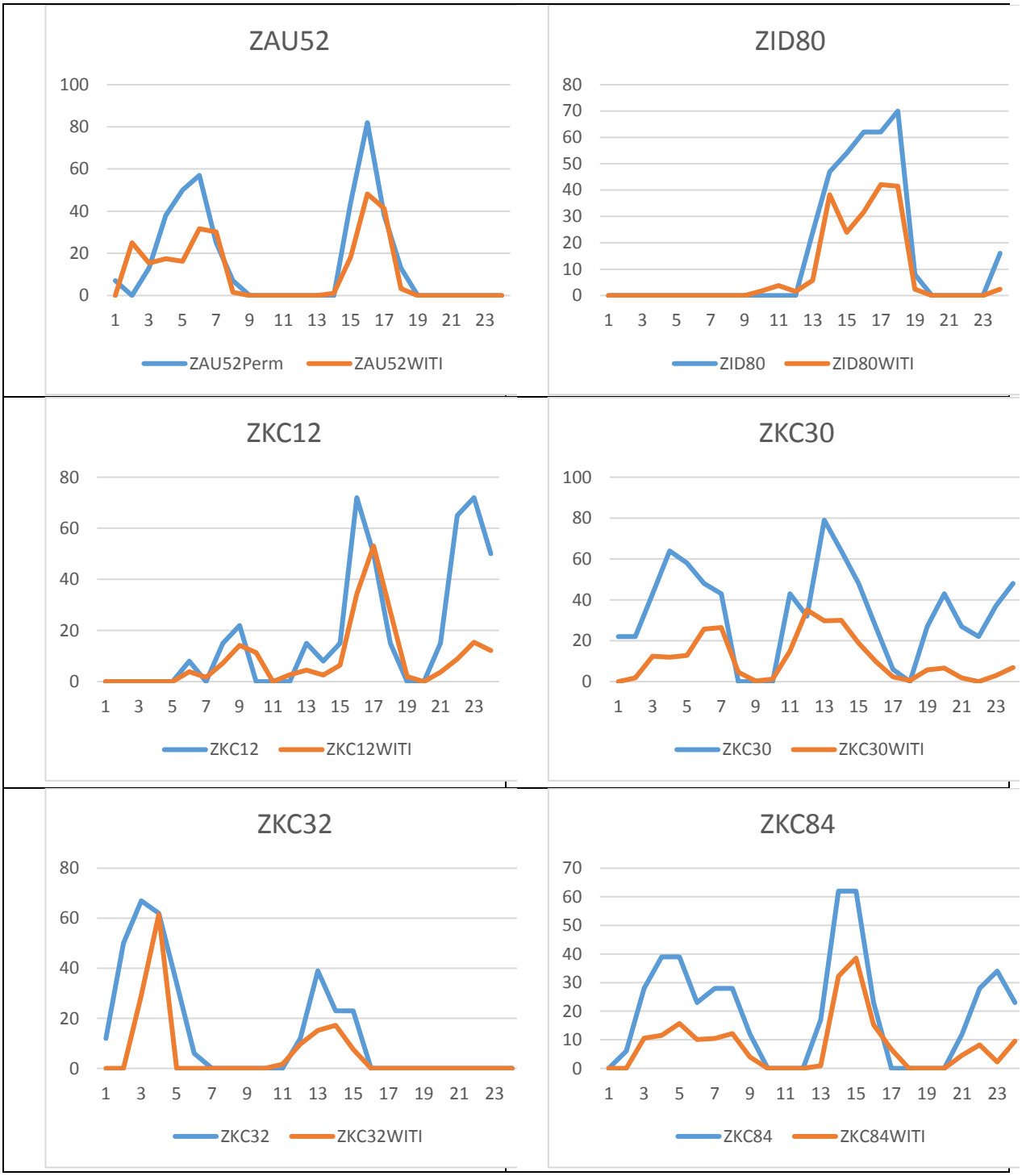


Table 4. Hourly Impermeability and WITI



B. Correlation between WITI and Permeability

The correlations between NCWD now-cast permeability and WITI are listed in Table 5 and the correlations between the forecasted values NCWD permeability and WITI are listed in Table 2.

For better visualization we define impermeability to be difference between 100 and permeability. Plots of impermeability and WITI are shown in Tables 3 and 4. Signatures of WITI and impermeability are similar in these plots. However, impermeability values are generally higher. In the entire data set, average impermeability is about 2 times average WITI. Correlation coefficients in Table 5 are significantly higher than those for 2 hour and 3 hour forecast in Table 1. These are lower than those for 1 hour forecast in Table 1 for some sectors. For decisions that are made with 2 or more hours of look-ahead, prediction error is far more significant compared differences in the two measures that are listed. If one is interested in weather translation under very specific conditions, then one or other models may sometimes offer advantages.

Table 5. The correlation between NCWD permeability and WITI

Sector	NCWD permeability vs WITI
ZAU52	.84
ZID80	.96
ZKC12	.66
ZKC30	.68
ZKC32	.75
ZKC84	.89

IV. Concluding Remarks

Different weather translation measures have been developed for hypothetical operations such as decentralized free flight, whereas others are meant to be relevant in current operations. This paper does comparative study of two different weather translation products relevant in current operations and finds that these products have strong correlation with each other. Given inaccuracies in prediction of weather, these differences would not be expected to be of significance for studies of observations over a long period of decisions made with a look-ahead time of two hours or more.

V. Acknowledgement

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