CHINA/EUROPE

中国/欧洲

COMPARISON OF OPERATIONAL ANS PERFORMANCE

航空运行效率对比报告

CAAC & EUROCONTROL

中国民用航空局

欧洲航行安全组织

2024 EDITION

2024年版本

中国民航

CAAC

EUROCONTROL

China/Europe Comparison of Operational ANS Performance

CAAC and EUROCONTROL

1 Executive summary

This report is a joint publication by Civil Aviation Administration of China (CAAC) and the European Organisation for the Safety of Air Navigation (EUROCONTROL). It represents the second iteration of the bi-regional ANS Performance comparison between China and Europe. The report was jointly developed by the Civil Aviation Administration of China Operation Supervisory Center (CAACOSC), Civil Aviation University of China (CAUC), Aviation Data Communication Corp. (ADCC), and the Performance Review Unit (PRU) of EUROCONTROL.

The objective was to make a factual high-level comparison of operational air navigation system performance in China and Europe. The initial focus was to develop a set of comparable performance measures and harmonised data feeds in order to create a sound basis for such a factual high-level comparisons between both regions. The specific performance indicators are based on best practices from both groups and ICAO's Global Air Navigation Plan.

This report covers the period January 2019 through December 2022. Accordingly, the results also show the influence on operational performance caused by the unprecedented constraints on air transportation during the COVID pandemic and the subsequent recovery thereof.

Despite this, the comparison shows similarities and differences in the air navigation service provision and observed performance in both regions.

- In terms of air traffic service provision, the airspace in which China's ATMB provides services is about 82.2% of the European continental airspace in 2022. Traffic volumes in both regions differ. In 2019, the regional air traffic in China ranged with 5.8 million flights at approximately 53% of the European traffic of 11.1 million flights. Overall, the reduction of air transportation demand in 2020 was significantly milder in China with a reduction of about 30% compared to the 55% reduction observed in Europe. The actual resulting annual traffic levels were similar, i.e., China/4.1 million vs Europe/5.0 million flights.
- In 2021, overall traffic numbers in China overtook the European traffic volume in the first half of the year. During the second half of the year, the observed traffic volume in Europe significantly surpassed the level of traffic in China. With a total of 6.2 million

flights in the whole of 2021, Europe observed about 30% more of traffic compared to China (4.3 million flights).

- The European traffic in 2022 reached 82% of 2019 traffic levels signifying a steady recovery, whereas Chinese traffic volumes reached 53% of 2019 traffic levels indicating a further reduction of traffic due to continued COVID-19 restrictions.
- China and Europe have established system-wide air navigation services and air traffic practices to ensure that traffic flows do not exceed what can be safely handled by air traffic controllers, while trying to optimize the use of available capacity. In China, there is one air navigation service provider compared to the 37 en-route service provider in Europe. The aggregated number of approach and area control centers is similar, i.e., China/72 vs Europe/76. The number of air traffic controllers in 2022 servicing the air traffic is comparable in Europe and in China (approx. 17 thousand).

This report showcases the high value in regional comparisons and benchmarking of operational performance as it supports the identification of best practices and drivers for performance. The report identified a series of ideas for future research that will help to better understand similarities/differences in both regions, including the underlying operational concepts or technological enablers.

This report will be updated throughout the coming years. Future editions will also enable to complement the data time series and support the development of further use-case analyses. The lessons learnt of this joint project will also be coordinated with the multi-national performance benchmarking working group (PBWG) and ICAO GANP Performance Expert Group (GANP-PEG). This report may be useful to further harmonise the practice and development of the GANP KPIs.

2 Introduction

2.1 Overview

Air transport is a strategically important sector that makes a vital contribution to the overall economy. It is a driver for employment, growth, and provides pan-regional and international mobility. Despite the impact of the COVID-19 pandemic on air transport demand and connectivity, air traffic is expected to grow globally over the long term. Although different levels were observed, air traffic recovered across the globe.

There is a joint political goal to foster high levels of safety and operational efficiency for airspace users. ICAO promotes the application of a performance-based approach and invites States and (sub-)regions to engage and participate in performance benchmarking activities

This second edition of the China-Europe operational comparison report is jointly developed by the Civil Aviation Administration of China Operation Supervisory Center (CAACOSC), Civil Aviation University of China (CAUC), Aviation Data Communication Corp. (ADCC), and the Performance Review Unit (PRU) of EUROCONTROL. Both groups agreed to foster the understanding of operational performance in both regions based on commonly agreed data and metrics.

2.2 Purpose

The purpose of this report is to establish a regional comparison of operational air navigation system performance for China and Europe. This comparison builds on commonly agreed definitions, data, and performance metrics. It supports the assessment and evaluation of the system-wide characteristics and operational performance in both regions with a view to identify similarities and differences. The lessons learnt from these observations form the basis for future research and deeper analysis.

The guiding principle is to compare, understand, and improve air navigation system related operational performance in both regions. For this reason, both groups investigated available data sources and harmonised the underlying data processing to establish a set of comparable data. Further work revolved around the identification and refinement of performance indicators used within both regions and under the ICAO GANP Performance Framework. The work therefore serves as a reference for other interested parties to inform their operational performance analyses.

2.3 Scope

2.3.1 Geographical Scope

The geographical scope for this report comprises China and Europe[1]. In this context,

[1] Disclaimer: The designations employed and the presentation of material on maps in the report do not imply the expression of any opinion whatsoever on the part of EUROCONTROL or the European Commission

- China is defined as the volume of airspace where air navigation services are provided by China.
- Europe is defined as the volume of airspace where Member States of EUROCONTROL (i.e., 41 States) provide air navigation services.

The focus of this regional comparison report is on performance measures supporting the network and airport level comparison. For this report, 12 major airports of interest in terms of air transport movements in 2019 or in terms of local weather phenomena are chosen for which the data were available and comparable. These airports are listed alphabetically in the table below.

China	Name	Europe	Name
ZBAA	Beijing Capital	EDDF	Frankfurt
ZGGG	Guangzhou	EDDM	Munich
ZGSZ	Shenzhen	EFHK	Helsinki
ZLXY	Xi'an Xianyang	EGKK	London Gatwick
ZPPP	Kunming	EGLL	London Heathrow
ZSHC	Hangzhou	EHAM	Amsterdam
ZSNJ	Nanjing	LEBL	Barcelona
ZSPD	Shanghai Pudong	LEMD	Madrid Barajas
ZSSS	Shanghai Hongqiao	LFPG	Paris Charles de Gaulle
ZUCK	Chongqing	LIRF	Rome Fiumicino
ZUUU	Chengdu	LSZH	Zurich
ZYCC	Changchun	LTFM	iGA Istanbul

Figure 1 and Figure 2 provide an overview of both regions and the geographic location of the chosen study airports within the regions.

2.3.2 Temporal Scope

The scope of this report covers the period from January 2019 through December 2022. This allowed for the provision of a pre-COVID baseline by comparing the observed performance before and throughout the pandemic years. This baseline supports to assess the recovery in both regions and the associated response by both air navigation systems.

2.4 Data Sources

To ensure accurate performance indicators, data must be gathered from various sources. CAAC, CAUC, ADCC, and PRU collaborated to verify the consistency of the available data across regions. Their aim was to produce a standardized dataset suitable for performance benchmarking. This report builds on comparable data exchanged between both groups.

concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Figure 1: Geographical context of the China/Europe comparison: China

Figure 2: Geographical context of the China/Europe comparison: Europe

2.4.1 Chinese Data Systems

The Chinese dataset is obtained by integrating data from two major agencies. The collection of air traffic data is managed by ADCC, while punctuality, delay, and taxi data metrics come from CAAC's Flight Punctuality Statistics System.

For this report, the approved data is aggregated on a monthly basis. The CAAC's National Traffic Flow Management (NTFM) System plays a central role in China. It serves air traffic control units, aviation operators, and airports. The NTFM system is being used by 43 domestic operators and 37 significant domestic airports. It ensures effortless merging and coordination of civil aviation operation data, forming the bedrock for a unified traffic operation platform in China's aviation sector.

By 2022, the coverage of the NTFM System had grown. Various operational systems from regional air traffic management bureaus and their subdivisions were connected. Altogether, 112 local air traffic control systems channel data into the NTFM System. This data encompasses a broad scope, including but not limited to the integration of different sources, e.g., flight track and flight plan, ADS-B, tower electronic strip, ASMGCS. The system also includes flight-related data from 43 domestic operators' FOC systems and A-CDM systems of 24 domestic airports. Furthermore, essential air traffic flow data, including calculated take-off times (CTOT), is sent to the NTFM System from 97 ATC operational systems and 66 systems covering different operators and airports.

For distribution, the NTFM's terminal system has seen widespread deployment among various aviation entities. It serves 607 terminals in regional bureaus and subdivisions for Air Traffic Control, 106 terminals for 48 domestic airlines, and 185 terminals for 80 domestic airports.

Thanks to the NTFM System integration, there has been a significant decrease of -36.5% in the volume of flight flow control data disseminated by air traffic control. This setup bolsters the CAAC's capability to oversee traffic meticulously, causing a noticeable increase in flight punctuality. Figure 3 depicts the architecture of the NTFM system.

2.4.2 European Data Systems

Within the European aviation setting, the predominant sources of data for this report are the Enhanced Tactical Flow Management System (ETFMS) run by the Network Manager (NM) and the Airport (Operator) Data Flow (APDF).

Central functions of the ETFMS include traffic demand calculation that draws from flight plan details from aircraft operators via the Initial Flight Plan Processing System (IFPS) and computer-assisted slot allocation (CASA), which centers on accurate slot allocation and disseminating this information to the concerned parties.

The ETFMS consists of several essential components. The Flight Activation Monitoring (FAM) handles pre-departure traffic demand, enhancing ATFM slot use and minimizing delays. Entry and sector occupancy counts keep an eye on flight traffic in sectors, which aids

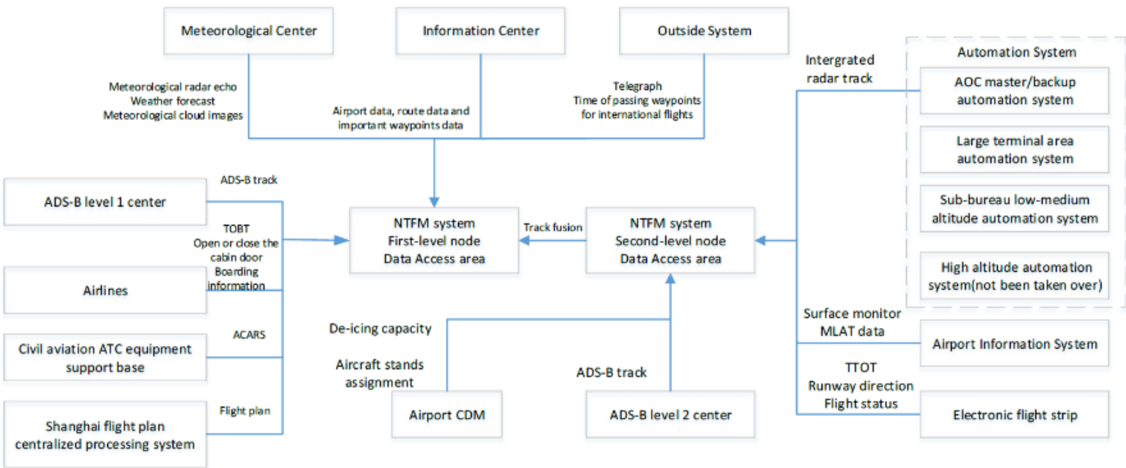

Figure 3: Chinese Data Processing System Architecture

in making well-informed traffic management choices. Flight profile calculations take advantage of real-time data to refine flight profiles for precision, accommodating occurrences such as flight reroutes. Data distribution is responsible for broadcasting crucial flight updates to stakeholders through the Data Distribution Service (DDS).

Merging the ETFMS data with the Airport (Operator) Data Flow (APDF) provides a dataset capable for Operational Performance Review. This collective data aids in formulating monthly performance reports under both the EUROCONTROL Performance Review System and the Single European Sky Performance and Charging Scheme.

For a visual overview of these systems, see Figure 4.

2.5 Structure of the Report

This second edition of the China-Europe operational performance comparison report is organised as follows:

- **Introduction** – overview, purpose and scope of the comparison report, including a short description of data sources used;
- **Air Navigation System Characteristics** – high-level description of the two regional systems, i.e., areas of responsibility, organisation of ANS, and high-level air navigation system characteristics;
- **Traffic Characterisation** – air traffic movements, peak day demand, and fleet composition observed at the study airports;
- **Efficiency** – analysis of additional taxi-in and taxi-out time and additional time in terminal airspace;
- **Punctuality** – observed arrival and departure punctuality;
- **Weather Impact Analysis** – initial comparison of performance impacting weather phenomena; and

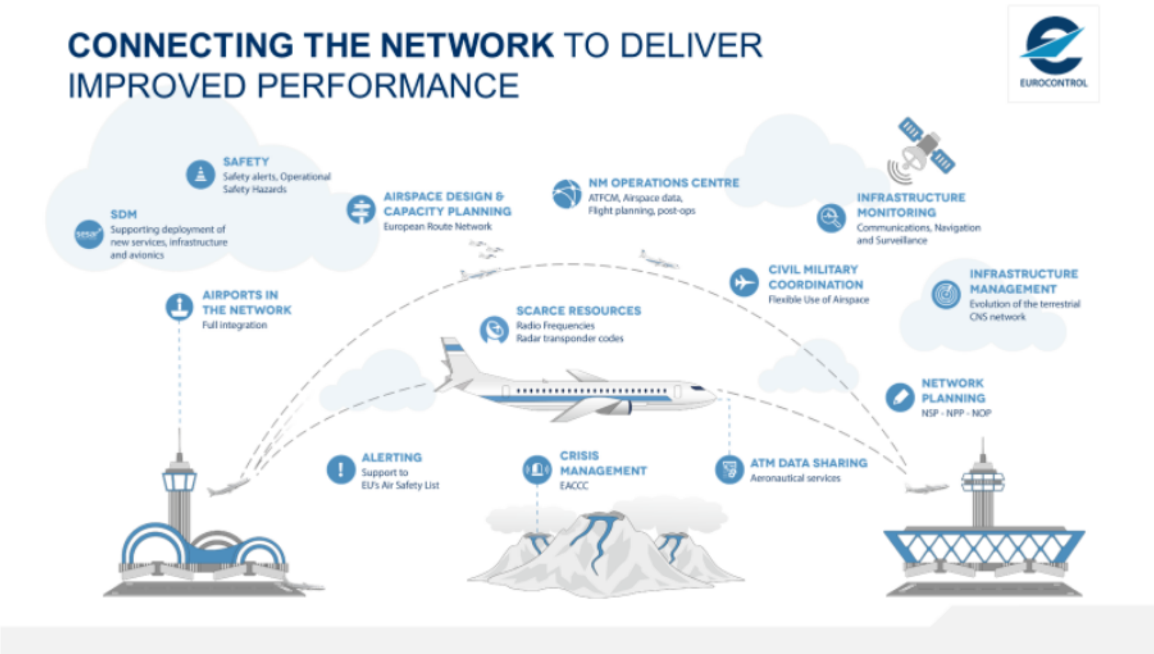

Figure 4: European Data Processing Systems Architecture

- **Conclusions** – summary of this report, associated conclusions and next steps.

3 Air Navigation System Characterisation

In general terms, air navigation services are provided in China and Europe with similar operational concepts and procedures, and supporting technology. However, there exists a series of differences between the two regional systems. This section provides a general background on the characteristics of the Chinese and European air navigation system. These characteristics form an integral part to explain the similarities and differences in the performance indicators reported throughout this report.

3.1 Organisation of Air Navigation Services

The key difference between the Chinese and European air navigation system can be seen in the organisation of air navigation services (ANS). In China, air navigation services are established through the Civil Aviation Administration, with air traffic services provided by the Air Traffic Management Bureau (ATMB) and the Operation Supervisory Center (OSC) responsible for the air traffic flow management, flight plan processing, including flight security and emergency management. In Europe, each member state has assigned the service provision to national or local providers, and thus a variety of service providers exists with cooperation in terms of flow management on the European level. The air traffic flow management function is performed by EUROCONTROL's Network Manager.

China has one air traffic service provider, i.e., ATMB, servicing air traffic within China's territorial airspace. Air traffic services are provided within an area of 10.81 million square kilometers in total, accounting for about 82% compared to the European area. The airspace in China is structured in 11 flight information regions, respectively located in Beijing, Shanghai, Guangzhou, Wuhan, Lanzhou, Shenyang, Kunming, Urumqi, Sanya, Hong Kong and Taipei. The central air traffic management platform approved by the Civil Aviation Administration of China was officially put into use on June 30, 2021, effectively covering and connecting the three major operating parts: air traffic control centers, airports and airlines, improving the cooperative operation effectiveness and further enhancing the flight efficiency. Flight plans are centrally processed by the center in Shanghai. Since December 2018, the center also manages flight plans of international inbound flights to China.

The European airspace spans over an area of 13.5 million square kilometers. As concerns the provision of air traffic services, the European approach results in a high number of service providers, i.e., there are 39 different en-route ANSPs with varying geographical areas of responsibility. Dependent on the size of the member state, the airspace is organised in multiple lower and upper flight information regions. Next to a limited number of cross-border agreements between adjacent airspaces and air traffic service units, air traffic service provision is predominantly organised along state boundaries/FIR borders. Maastricht UAC represents the only multi-national collaboration providing air traffic services in the upper airspace of northern Germany, the Netherlands, Belgium, and Luxembourg. The Integrated Initial Flight Plan Processing System (IFPS) is a centralised service designed to rationalise the reception, initial processing and distribution of flight plan data across the different European air traffic service units.

The level of civil-military integration varies from country to country in Europe. Models range from stand-alone to collocated or fully integrated service units. Within the European context, air traffic flow management (ATFM) and airspace management (ASM) are provided/coordinated centrally through the Network Manager. The design of airspace and related procedures is no longer carried out or implemented in isolation in Europe. Inefficiencies in the design and use of the air route network are considered to be a contributing factor towards flight inefficiencies in Europe. Therefore, the development of an integrated European Route Network Design is one of the tasks given to the Network Manager under the European Commission's Single European Sky initiative. This is done through a collaborative decision making (CDM) process involving all stakeholders. A further task of the Network Manager is to ensure and coordinate that traffic flows do not exceed what can be safely handled by the air traffic service units while trying to optimise the use of available capacity. For this purpose, the Network Manager Operations Centre (NMOC) monitors the air traffic situation and proposes flow measures coordinated through a CDM process with the respective local authorities. This coordination is typically affected with the local flow management position (FMP) in an area control centre. The NMOC then implements the respective flow management initiative on request of the authority/FMP.

3.2 High-Level System Comparison

In China, air traffic services are provided by a single ANSP, while in Europe a number of national and local ANSPs assume responsibilities. Within the en-route environment, there are 39 different ANSPs in Europe compared to a single provider, i.e., ATMB, in China. Europe has a slightly higher number of APP and ACC facilities, i.e., Europe: 76 vs China 72. The number of ATCOs in operations is comparable in China and Europe. In 2022 China controlled about 32% of the traffic handled in Europe.

The table below summarises the key characteristics of the Chinese and European air navigation system.

KPA	China	Europe
Geographic area (million square km)	10.81[2]	11.5 (non-oceanic)
Number of en-route ANSPs	1 (CAAC ATMB)	39
Number of towers	45[3]	381
Number of APP	48	16 (stand alone)
Number of ACC	24	60
Number of ATCOs in OPS	16980	16785[4]
Controlled IFR flights (2022)	3.0 million	9.3 million

Figure 5 shows the overall trend in terms of air traffic development in both regions. The Chinese continental airspace is about 17% smaller than the European one. In 2012 traffic levels in China ranged about 35% of the European traffic volume. Air traffic grew stronger in China than in Europe over the period 2012 to 2019. In 2017 China handled about 50% of the European traffic numbers and in 2019 about 53%.

As will be shown throughout the report both regions faced similar challenges responding to the COVID pandemic. The nature of the European air navigation system is characterised by a multitude of countries. This resulted in a mix of policy measures and constraints on air travel as also intra-European traffic was subject to international air traffic restrictions.

The following sections will show the development of air traffic and the observed performance from 2019 until end of 2022. China and Europe observed similar total annual traffic levels in 2020, i.e., China/4.1 million vs Europe/5.0 million flights. In 2021 European and Chinese traffic started a slow trajectory towards recovery, China serviced about 4.3 million vs Europe 6.2 million. In 2022, recovery in Europe continued to total 9.3 million flights whereas China's traffic decreased to 3 million. To monitor the further developments, CAAC and EUROCONTROL agreed to update this report on a regular basis.

[2]The area of airspace ATMB provides air traffic services.
[3]Towers attached to ATMB.
[4]2020, excluding Georgia and Canary Island.

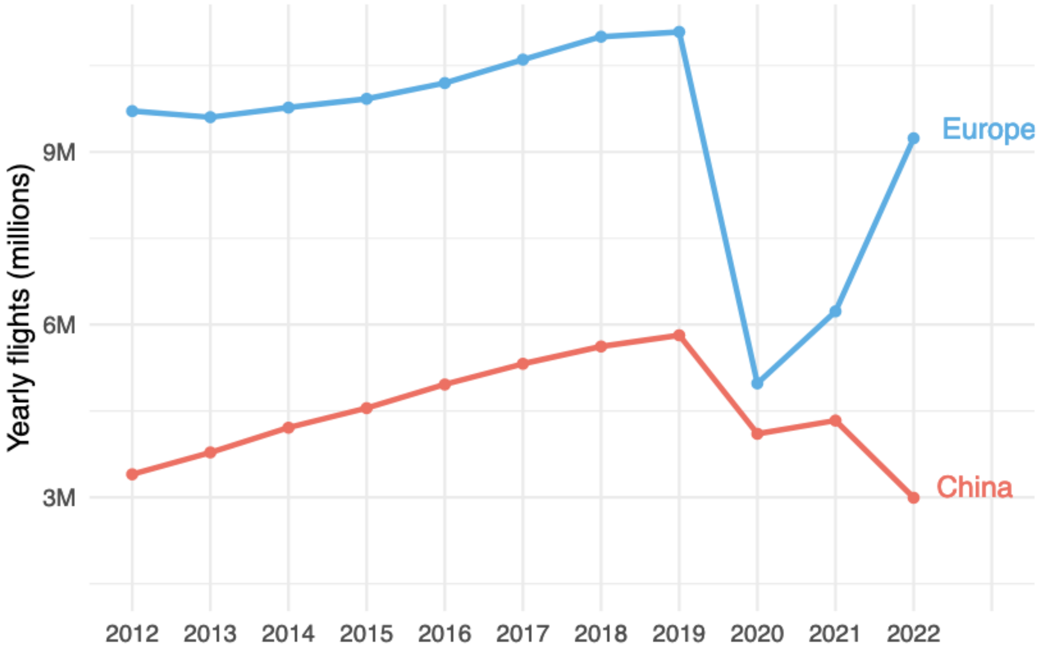

Figure 5: Traffic evolution in China and Europe 2012 - 2021

3.3 Civil-Military Cooperation Comparison

In China, all the flights within the territory are implemented as a unified management under the authority. Based on ensuring national defense and security whilst also considering the needs of civil and military aviation and public interests, the State plans airspace in a unified manner. This includes flight performance requirements, flight control capabilities and construction of communication, navigation and radar facilities. To ensure the effective use of airspace, the state considers airport distribution and environmental protection, organization of airspace users (including military and civil aviation).

Both, the states and FIRs, have established military-civilian coordination mechanisms with corresponding levels. The function carries out military-civilian coordination at the national or regional level. There are information notification agreements between military and civil control units at each level to inform each other of flight activity plans that may have an impact on the safe operations of civil and military air traffic.

On the European side, the level of civil-military integration varies from country to country. Models range from stand-alone military units to collocated or fully integrated service units. Airspace sovereignty and identification of flights within the European airspace is a national responsibility.

A significant share of the European countries are member of NATO and share the air defense tasks under the umbrella of an integrated air defense system. Coordination processes and principles are in place for member states not part of NATO or adjacent to a non-NATO member. This also includes the coordination with the respective civil units servicing civil air traffic.

The level of system exchange between civil and military units varies dependent on the prevailing coordination agreements and level of organisation. This is facilitated by a mix of system integration, inter-connectivity, and unit-to-unit communication.

Both China and Europe are actively working on the coordinated development of military-civilian integration. These new developments will allow the use of airspace to be more flexible, and in the future, military-civilian information will be more interconnected by means of digital transformations.

4 Air Traffic Characterisation

4.1 Air Traffic Evolution

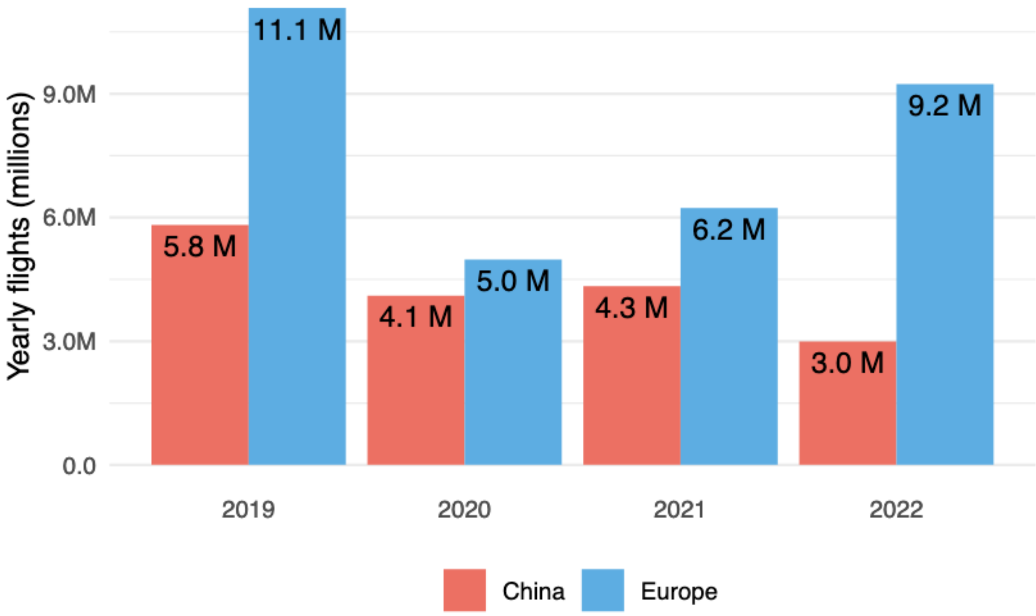

Figure 6: China/Europe - annual traffic volume

Figure 6 shows the annual traffic volume for the years 2019 through 2022.

China's air traffic volume in 2019 ranged at about 53% of the European traffic levels. The year 2020 was characterised by the impact of COVID-19 in both regions. With a multitude of international and regional travel constraints in Europe, traffic levels in Europe dropped significantly to 5.0 million flights (about -55% when comparing 2019 to 2020). The overall reduction in number of flights was milder in China with a reduction of about 1.7 million flights to 4.1 million (approx. -30% compared to 2019). To overall observed annual traffic in 2020 showed hence only approx. 20% difference between China and Europe.

Both the European and Chinese air traffic are slowly recovering throughout 2019 to 2021 from the pandemic as associated air traffic restrictions are lifted. On average, the initial restrictions had a significantly lower impact in China, while Europe suffered from a fragmented approach driven by varying national policies. In that respect China profited from a more central and unified approach regulating travel policies and air traffic demand.

The trend in 2022 shows a break in the Chinese recovery and a continuation of the European recovery with 3.0 million flights in China (roughly 52% of 2019) and 9.2 million flights in Europe (83% of 2019). However, following up in 2023, it is noted that due to a relaxation of COVID-19 measures in China, the air traffic in 2023 is expected to recover quickly in China as well. This will be followed up in an future iterations of the report.

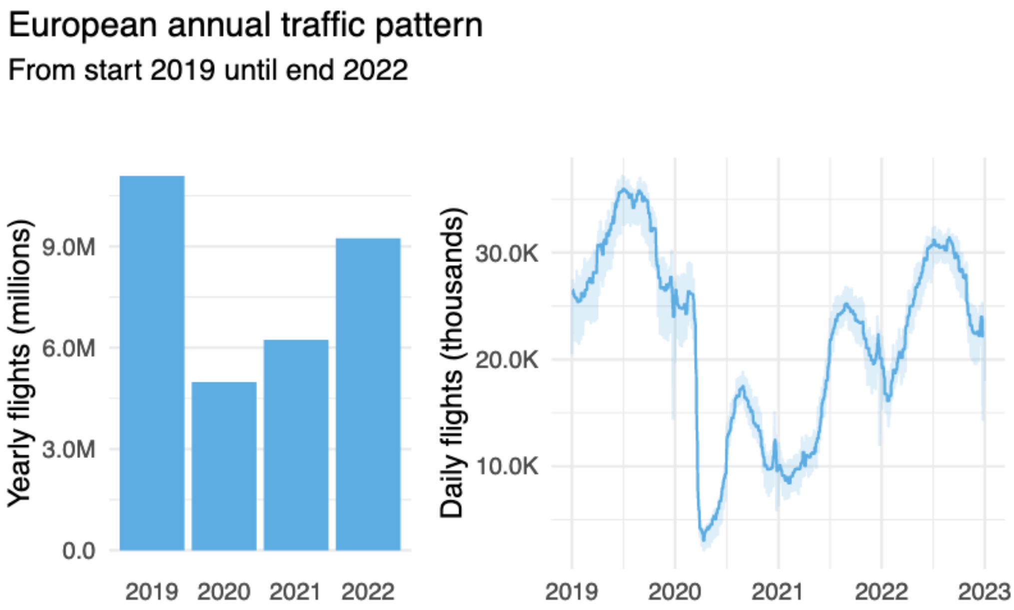

Figure 7: Evolution of daily traffic in European network

Figure 7 depicts the evolution of daily traffic within the European region. European traffic showed a pronounced seasonal pattern in 2019 with the daily traffic exceeding 35.000 flights during the summer months. COVID-19 related travel restrictions kicked in with March 2020 and resulted in an approximate 70% drop of air traffic for April 2019 compared to the beginning of the year. Throughout the second quarter of 2020, an initial recovery of air traffic was observed in Europe with multiple states relaxing their travel constraints. Following this opening, a second COVID-19 wave struck Europe and resulted in a fragmented approach to COVID, i.e., varying policies and national travel constraints. Air traffic declined in the autumn and winter season 2020 to around 300.000 monthly flights. Beginning of 2021 saw a continual increase in vaccination rates across Europe. As of March 2021 a variety of States lowered travel restrictions and accepted travelers from different countries. Although there was no European-wide agreed policy on regional (i.e., intra-European) travel, air traffic demand continually increased again for the summer season. Traffic levels during summer 2021 exceeded for the first time 20.000 daily flights. The beginning of 2022 showed an initial decrease of daily traffic coinciding with the lower activity levels in the winter season. Traffic levels recovered continuously throughout 2022 with the summer peak ranging around 30.000 daily flights reaching about 85% of pre-COVID levels.

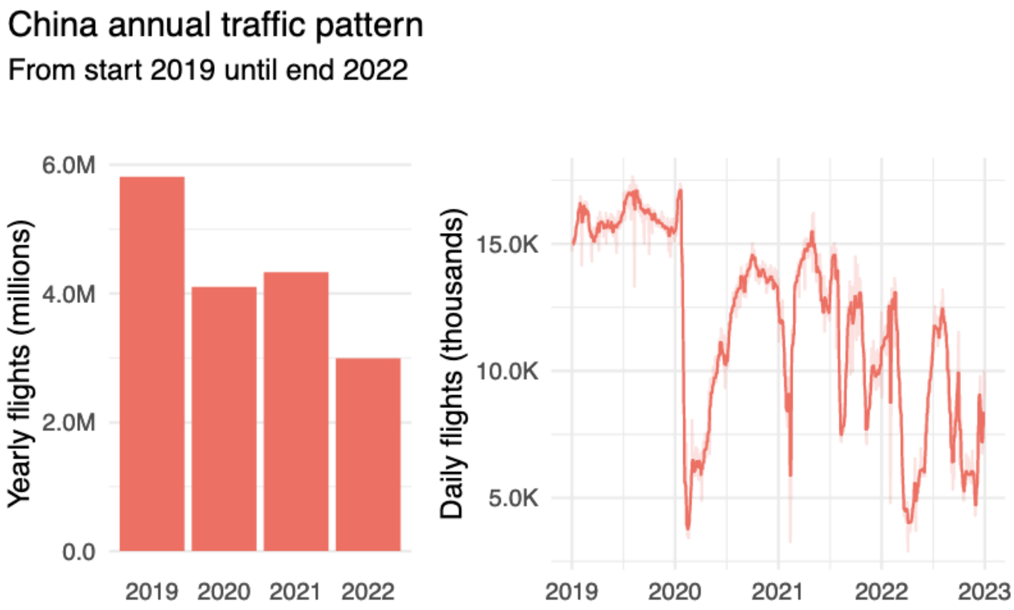

Figure 8: Evolution of daily traffic in Chinese network

Figure 8 depicts the evolution of daily traffic within the Chinese region. COVID-19 related travel restrictions kicked in early 2020 and resulted in a significant drop in traffic. Throughout the second quarter of 2020, a quick recovery of air traffic was observed. Following this initial opening, multiple travel restrictions in 2021 and 2022 or secondary waves reduced traffic significantly. The effect of concerted action can be clearly seen in China. The moment health measured were implemented and an outbreak was under control, traffic restrictions were immediately revoked and resulted in an immediate recovery. This pattern can be observed multiple times during the pandemic phase.

Figure 9 shows the monthly traffic volume for the period January 2019 through December 2022. Air traffic in China and Europe followed a different monthly pattern in the first quarter for 2020. In February 2020, China's air traffic volume reached rock bottom with about 150 thousand flights. In Europe, COVID-19 related travel restrictions kicked in after the WHO made its pandemic declaration on 11 March 2020. The traffic decline reached its bottom after that date and then leveled off. April 2020 showed the lowest monthly traffic level in Europe.

Both regions experienced an initial recovery for the 2nd quarter in 2020 and the summer months. However, both regions also encountered a phase of higher travel constraints due to

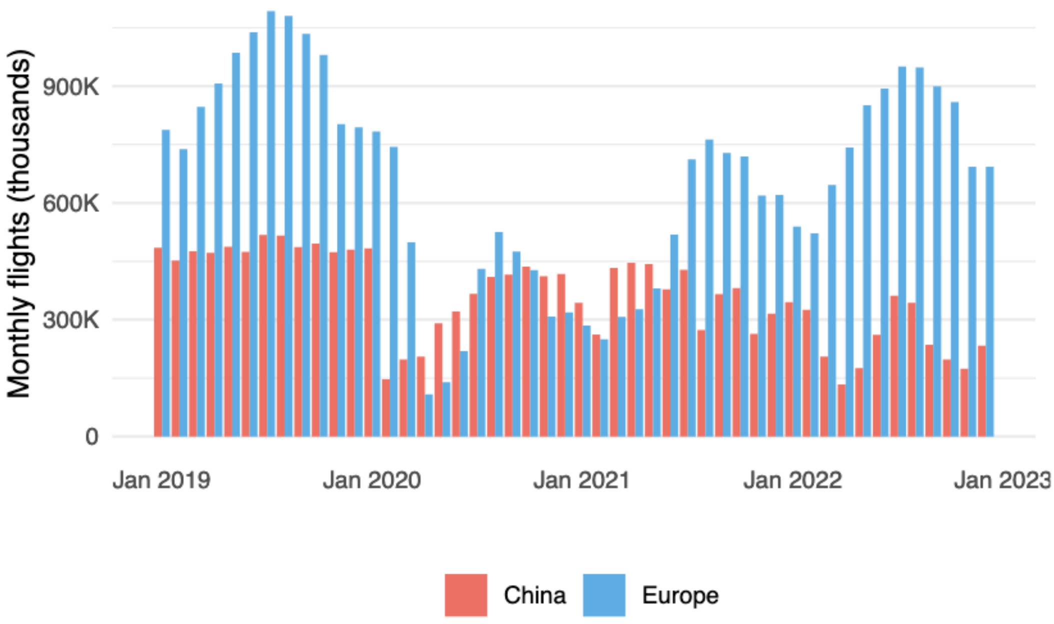

Figure 9: China/Europe - monthly traffic volume

surges of COVID-19 cases and associated restrictions on travel.

The pattern for China followed a more linear and steady increase from March through August 2020 and then leveled off for the rest of the year. Early 2021 saw a traffic decrease again in response to another increase in infection cases. With the increase in vaccination rates and success of the travel restrictions, travel demand increased significantly again for March, April, and May 2021. Traffic in June 2021 dropped by about 14% in comparison to the previous month. Due to intermittent surges of COVID-19 cases travel restrictions are present throughout 2021 and 2022. Most notably impacted are the months April and November 2022.

Europe observed an increasing recovery rate in May and June 2020 accommodating increased travel demand for the summer holiday season and the initial reduction of travel constraints. However, with increasing infection rates across multiple countries, travel and social distancing restrictions were widely reintroduced resulting in a decline of air traffic in autumn and winter 2020. The lower level of air traffic demand reached into early 2021 (i.e., January and February). As of March 2021 Europe observed a steady recovery with an step-increase of about 25% in June compared to May. Traffic in June 2021 totals just under 516 thousand flights, similar to the peak month of 2020 (i.e., August 2020: approx. 525 thousand flights). A decrease of flights in winter followed by a a further recovery led to a summer with a peak traffic month of 950 thousand flights (July 2022), roughly 87% of the same month in 2020 (1092 thousand flights).

The number of flights in China has recovered steadily since January, 2021. In February, China's civil aviation industry handled about 260 thousand flights, so did Europe. And

China's Lunar New Year holiday usually comes in February. So then the business passengers' TWI (Travel Willingness Index) was relatively low. But from March 2021, the number of business travelers increased to the same level as the end of 2020. Traffic in China from March to May 2021 surpassed that of Europe. In June, 2021, there appeared some new domestically transmitted COVID-19 cases in Guangzhou. Therefore, the targeted measures were implemented and the number of flights decreased significantly. Following 2021, a significant decrease of traffic due to COVID-19 restrictions is present around April 2022 with only approx 130 thousand flights occurring this month. This is followed by a quick recovery of traffic numbers in the upcoming months in Summer.

On average, traffic levels in Europe were lower than in China for the period November 2020 through May 2021. For the first half of 2021, the total amount of traffic serviced by China ranges about 10% higher than the total movements in Europe. In 2021 until the end of 2022, the traffic counts seem to be steadily recovering in Europe. In China, due to restrictions more fluctuation is present, intermittent periods with low traffic are followed up by a speedy recovery.

4.2 System-Level Comparison

4.2.1 Normalised Traffic Evolution

The previous section showed the overall traffic development in both regions. Obviously, government policies to restrict the further spread of COVID-19 were a key driver for the observed air traffic demand evolution. With a view to highlight the regional response to COVID-19 and its impact on air travel this section compares the evolution on a normalized basis.

Date	Context	Action
2020-01-23	EUR	EUR initial set of airlines stop direct flights to China
2020-03-11	EUR	US bans entry from EU/Schengen and later complete EU
2020-03-11	WHO	WHO assesses COVID19 as pandemic
2020-03-17	EUR	EUR entry ban for non-EU residents
2020-03-20	CHN	All international passenger flights bound for Beijing will be diverted to the designated first points of entry.
2020-03-29	CHN	All domestic airlines were allowed to operate only one flight to each country per week, while foreign aviation companies should keep only one air route to China and there should be no more than one flight every week for each of the air route to China.
2023-01-08	CHN	CAAC declared COVID-19 control measures will no longer be implemented on international passenger flights, and Chinese and foreign airlines will arrange to operate scheduled passenger flights in accordance with bilateral transport agreements.

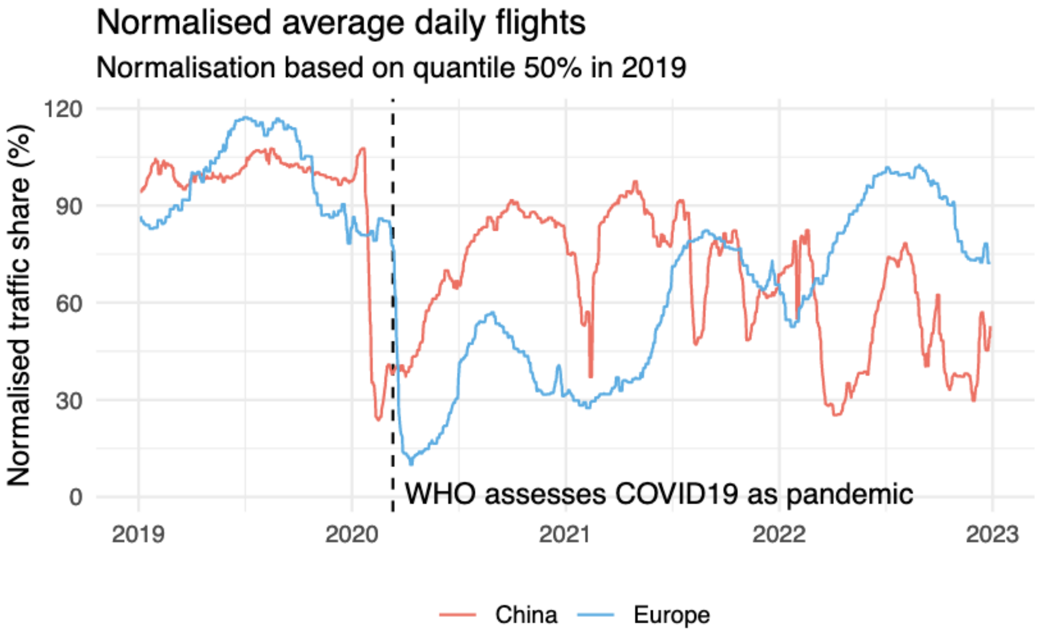

Figure 10: Normalised comparison of traffic development in China and Europe

Figure 9 showed the total of traffic in both regions. With this section Figure 10 highlights the different responses in both regions by showing the air traffic volume in a normalised fashion. The normalisation is based on 50th percentile, i.e., median, for the average of daily flights per month.

It is apparent that China responded earlier to COVID-19 than Europe (about 2 months). Home quarantines were applied already in January 2020 in China. In Europe, a set of airlines stopped operating flights to China as of end January 2020. This was broadly masked by the overall reduced traffic beginning of the year (seasonal winter traffic). The WHO assessed COVID-19 as a pandemic on 11 March 2020. On the same day, the US banned entry from EU/Schengen flights and non-US citizens. Equally, European states introduced inner-European travel restrictions. This lead to a traffic decline by about 85% in March 2020 for the average daily traffic.

Figure 10 highlights the temporal offset in terms of COVID related air traffic restrictions and the overall impact in both regions. The overall magnitude of the impact based on the average daily flights per month ranged about 5-10% lower in China than in Europe. Initial recovery in China started in early 2020. Europe showed a similar, but delayed behaviour with the aforementioned policy decision and related travel constraints kicking in as of mid March and with little change in April 2020. Traffic increased with April/May again in Europe.

The recovery rate - based on the monthly average of daily flights - in both regions is similar. However it continued for China into the autumn season, while Europe experienced a second wave in terms of COVID infection rates.

For the European region, this resulted in the re-introduction of increased social distancing measures and travel restrictions. Accordingly, air traffic declined as of August 2020 in Europe. The winter season November 2020 through March 2021 ranged about -65% of the traffic levels observed in 2019.

China showed a fairly stable traffic for the summer and autumn season in 2020 ranging about -15% under the 2019 traffic. The number of new domestically transmitted COVID-19 cases in China considerably increased in December, 2020, comparing with November. So in accordance with the requirements for joint prevention and control of COVID-19 cases, the government suggested people to reduce unnecessary movement beginning December 2020 to January 2021. During this period, the number of flights decreased.

Increased vaccination rates and reduced number of infections and critical hospital admissions resulted in more permissible travel requirements among European states. Traffic continuously increased for the second quarter of 2021 reaching a value of approximately -40% compared to the 2019 base level of average daily flights per month. As the conditions turned for the better in March, 2021, the number of flights in China continued to grow due to the expanded business travel market, and it recovered to a level similar to the end of 2020 from March to June.

While there is a temporal difference between both regions, policy reaction to curb the further spread of COVID19 resulted in a similar behaviour. Following the harsh decline of travel in the early stage, both regions evidenced an initial increase of air traffic based on the success of the travel constraints. Overall, the impact in terms of loss of average daily flights per month was milder for China (approx. 5-10%). The initial recovery phase is further pronounced for China leveling off for the summer autumn season at -10-15% compared to the base level in 2019. Europe faced a second wave of COVID-19 with the end of the summer vacation period resulting in a drop of air traffic to levels of -65% versus the 2019 base level. As of March 2021 a second recovery period started. Throughout 2022 traffic recovered in Europe, reaching up to 95% compared to earlier base levels in summer and displaying the normal seasonality.

Traffic in China for the period March to May 2021 surpassed that of Europe. However, in June, 2021, due to the local transmitted COVID-19 cases in Guangzhou, the number of flights decreased significantly. The swift reaction of the introduction of measures to curb the spread of COVID-19 cases decreased traffic counts momentarily, but recovered immediately when the restrictions were lifted. This pattern is observed in subsequent outbreaks in 2022, such as e.g., the Shanghai COVID-19 outbreak in March to May 2022 and outbreaks later in October in various cities (e.g., Shanghai, Guangzhou, Wuhan, Zhengzhou, Daton and Xining).

4.2.2 Market Segments

The overall traffic analysis revealed interesting trends in both regions. The following takes a closer look in how different market segments evolved throughout this period.

Figure 11 breaks down the annual traffic volumes for 2019 through to December 2022.

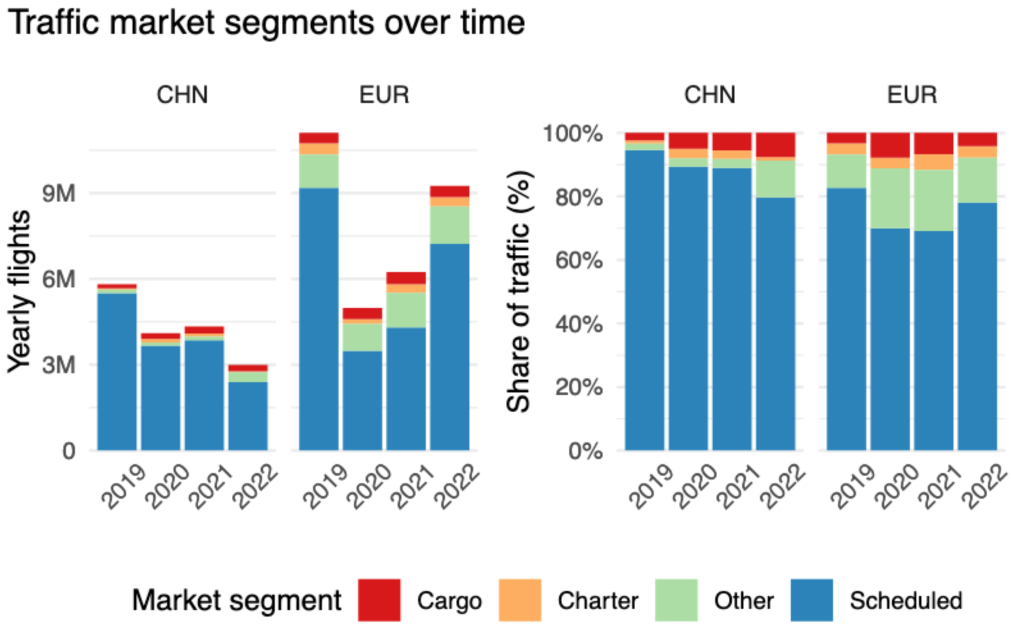

Figure 11: Comparison of market segments in China and Europe

The pre-dominant traffic category in both regions is scheduled passenger air traffic. Charter flights complement the passenger flights on a shallow level.

The share of scheduled passenger traffic within the Chinese region accounted for over 95% in 2019 and ranged at and above 90% in 2020 and in 2021. In 2022 a decrease of passenger traffic is noted to approx. 80%.

Europe showed a varied picture. Cargo flights in Europe account for a comparatively small share of the total flights. In 2019, the share of cargo flights was comparable with the share observed in China. The response to COVID increased the need for goods and equipment to fight the pandemic. This resulted in an increased number of cargo operations in 2020. An increased share of cargo flight operations is identifiable for 2021. In 2022, however, the share of cargo flights decreased significantly in comparison to the increasing number of passenger traffic. The total number of cargo flights in 2022 shrank slightly.

Scheduled passenger traffic accounted for the largest share of traffic in Europe (~80% in 2019). This segment was heavily affected by measures implemented by the countries to contain the pandemic and as a result the number of flights and its share decreased in 2020 and 2021. In 2022 the share is almost recovering to 2019 proportions. There is a discernible share of other operations in Europe, including business aviation. Although the total number of these operations declined in 2020 and 2021, its overall share increased. This suggests that this market segment is more flexible to account for the travel constraints and decreased by much less than the regular passenger traffic. The share of this segment decreased again in 2022 driven by the strong recovery of classical passenger operations.

The annual share of the different operations is more stable in China except for 2022. Typically scheduled passenger operations are the pre-dominant air traffic type in China. Passenger transportation accounts for the main part of market demand in China's civil aviation industry. And in China, water carriage, railway, highway and other modes are more used for cargo transportation. In 2021, China and Europe have serviced a similar total number of movements. In 2022, however, the share of passenger flights dropped in China and rose in Europe. The proportion of scheduled passenger flights in China is generally higher than that in Europe across all years. On the other side, there is a higher share of Cargo, Charter, and Other air traffic in Europe compared to China.

4.2.2.1 Passenger Traffic

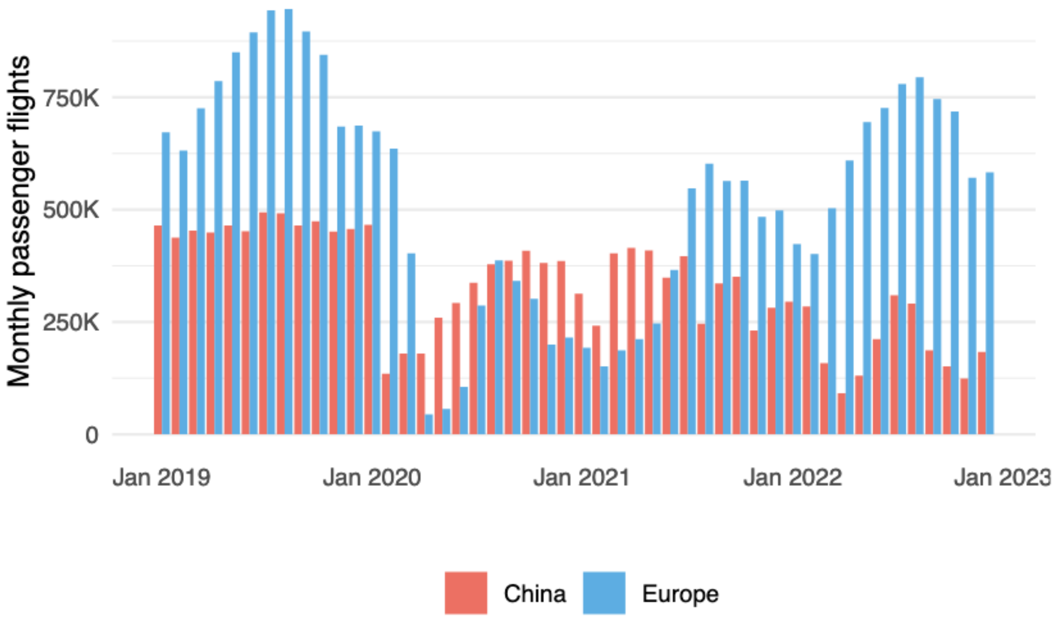

Figure 12: China/Europe - monthly traffic volume of passenger flights

As presented in Figure 11, passenger flights are the predominant traffic category in China and Europe. This reflects the relevance of air transportation in terms of regional (and international) connectivity and public mobility. Figure 12 depicts the monthly number of passenger flights in both regions. This also shows a characteristic difference between both regions. Traffic and connectivity in China was fairly stable across 2019. The passenger traffic pattern in Europe showed a strong seasonal pattern peaking during the summer months, i.e., July and August. On a monthly basis the difference between the lower winter season and the summer period accounted for a difference of approximately 25% in 2019. In China, the overall monthly difference in 2019 between ranged around 9%.

As mentioned before, COVID-19 related flight restrictions resulted in a decline in traffic in China about 2 month earlier than in Europe. Interestingly, the level of passenger traffic during the the summer and second half of 2020 ranged around the level of traffic observed in Europe during the peak month August 2020 (~ 360.000 flights). With June 2021, passenger traffic in Europe bounced back to this level. This recovery continued in 2022 with a typical seasonality pattern.

Passenger flights traffic levels continued to remain fairly stable in China in 2021. In China, a drop in passenger flights can be observed in spring and autumn of 2022 due to re-introduced travel restrictions to combat the spread of COVID-19.

4.2.2.2 Cargo Traffic

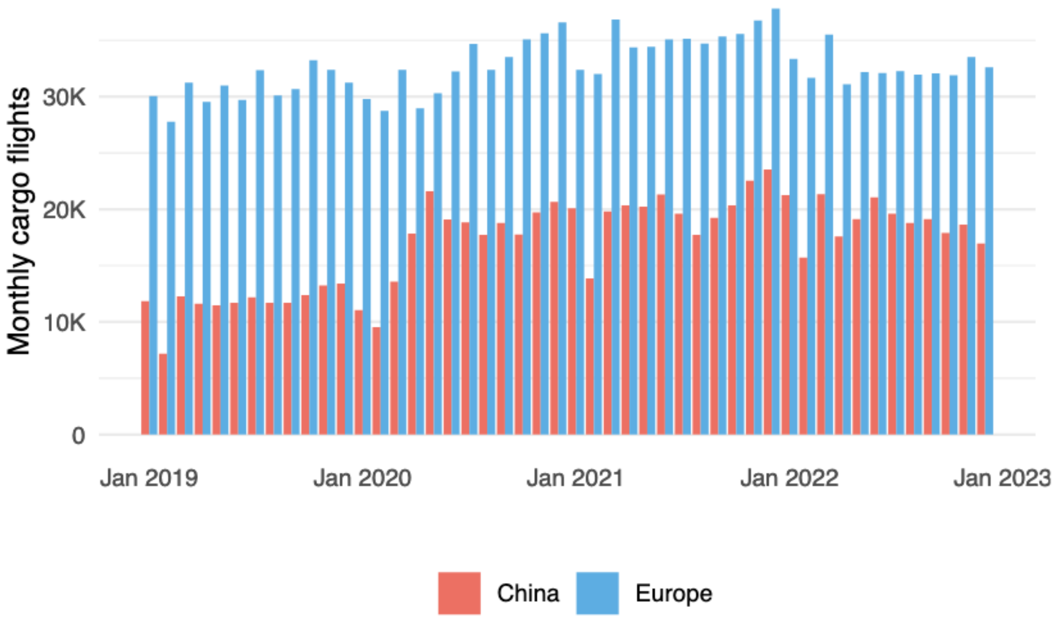

Figure 13: China/Europe - monthly traffic volume of cargo flights

Figure 13 shows the monthly totals of cargo flight operations. In 2019, the total number of cargo operations in Europe is about 55% higher than comparable traffic within China. This ratio changed considerably in 2020 and has remained this way until now in 2022. While there is a slight increase in total cargo flights in Europe, cargo operations increased significantly in China. On average, the monthly difference reduced by approximately 20%-points with the Chinese cargo traffic volume ranging around 34% of cargo traffic observed in Europe.

This pattern and spread continued in 2022. With the exemption of February 2021 during which China introduced renewed travel restrictions, a higher base level of cargo operations in observed in China comparable to the demand levels in 2020. Cargo operations showed the same reaction to higher constraints in 2021 and 2022. Over the whole period, cargo operations increased showing a mild seasonal behaviour.

The monthly aggregation of flight totals might mask changes of the logistical air network connectivity. This offers a candidate for expanding the analysis in future editions of this report.

4.3 Airport Level Comparison

This section compares the performance observed at the top 10 airports within the Chinese and European region. The overarching objective of air traffic services is the provision of safe, orderly, and efficient flow of air traffic. Accordingly, operational system performance is linked to the actual and serviced demand (i.e., air traffic). For operational comparisons, it is therefore important to have a good understanding of the level and composition of the air traffic at the study airports.

4.3.1 Traffic Development

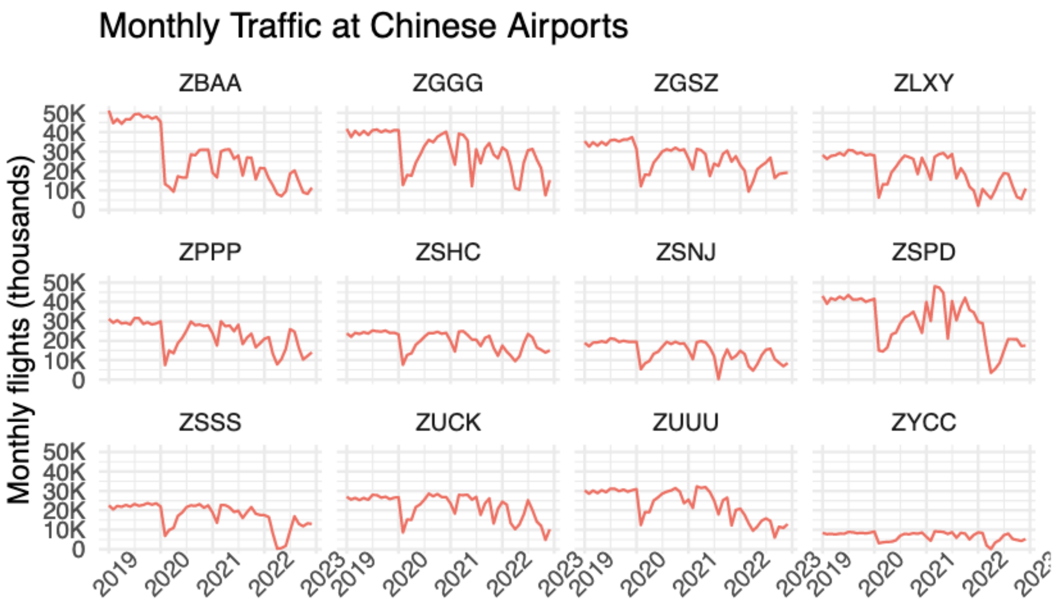

Figure 14: Monthly evolution of air traffic at Chinese airports

Figure 14 depicts the evolution of monthly traffic counts at Chinese airports. As shown, traffic across all airports followed a schedule characterised by little monthly variation. National travel constraints impacted mobility in January 2020. For the initial recovery in 2020 an interesting pattern emerged across the airports in China. With the exception of Beijing Capital (ZBAA), Shenzhen (ZGSZ) and Shanghai Pudong (ZSPD) traffic levels bounced back to pre-COVID levels. This suggests that outside the aforementioned airports, air traffic at the other 9 airports is pre-dominantly domestic (inner-China) air traffic. Thus, travel restriction for international traffic did not affect these airports.

On the other hand, the international hubs (ZBAA, ZGSZ and ZSPD) observed less traffic. As Beijing Daxing Airport (ZBAD) opened on September 25, 2019, and all international passenger flights bound for Beijing were redirected, the number of airplanes taking off and landing from Beijing Capital International Airport (ZBAA) reduced. Shanghai Pudong International Airport (ZSPD) mainly operates international passenger and cargo flights to/from Shanghai.

In 2019, international and regional passenger flights of Shanghai Pudong International Airport accounted for 42.75% of all flights. During secondary waves in the COVID-19 epidemic in 2021 and 2022, the number of international flights decreased sharply due to travel restrictions. This affected traffic in the major airport hubs such as Pudong Airport. Traffic in all airports is noted to be more variable in 2021 and 202. The decrease of internal traffic is related to lock down measures to curb the spread of COVID-19.

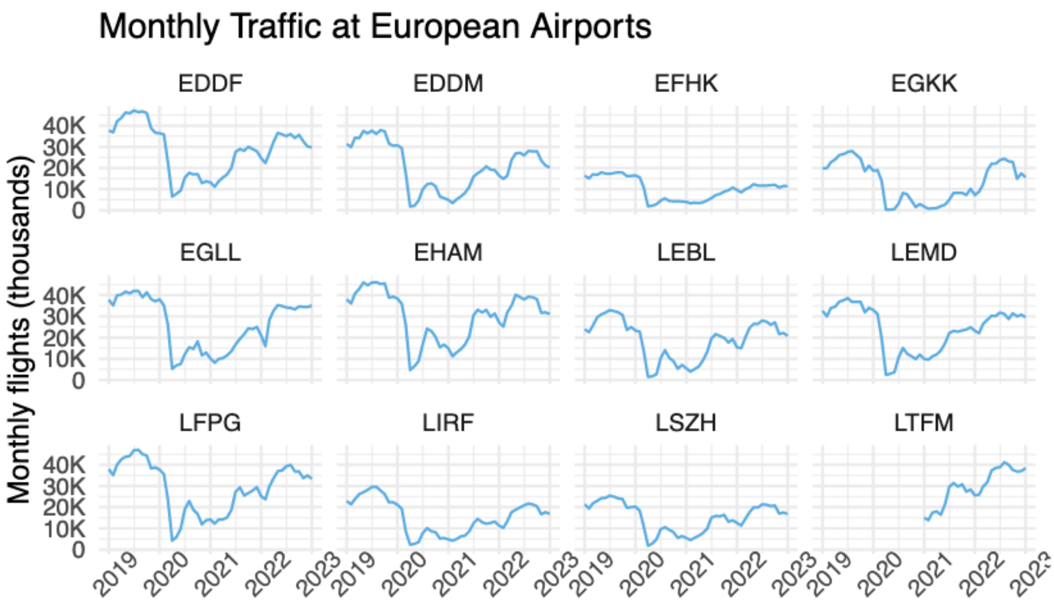

Figure 15: Monthly evolution of air traffic at European airports

Figure 15 shows the monthly traffic evolution at European airports. All airports showed a pronounced seasonality of the local air traffic in 2019. iGA Istanbul (LTFM), Amsterdam (EHAM), Paris Charles de Gaulle (LFPG), Frankfurt (EDDF), and London Heathrow (EGLL) ranked as the top 5 airports in Europe and monthly number of 40.000 or more fligths. While the overall pattern across the airports shows similar behaviour, there are differences in terms of local or national response to the COVID crisis.

The top-10 airports in Europe represent major national hubs with a strong share of pan-regional and international traffic. With the initial shutdown of flights to Asia of major airlines (e.g. KLM, British Airways, Air France, and Lufthansa), a shallow decrease of air traffic started already in January and February 2020. European states reacted to the pandemic declaration of WHO by introducing wide-ranging travel constraints. The introduction of national social distancing and travel restrictions on air travel lead then to a sharp decline of air traffic in March and April 2020 at all airports in Europe. The role of the airport within the domestic network and to what extent national carriers contracted operations to a sub-set of national airports was witnessed in the level of the initial recovery and the decrease gradient or plateauing in the autumn season of 2020.

The trend of recovery continues throughout 2021 and 2022 showing varying degrees of recovery levels for the different airports. The seasonal pattern with a high season in summer is present in most airports. Due to its recent opening, the timeseries for iGA Istanbul airport (LTFM) does not contain data before 2021.

4.3.2 Peak Day Operations

While the annual traffic provides insights in the total air traffic volume and associated demand served at an airport, it does not provide insights on the upper bound of achievable daily movement numbers. Next to the traffic levels (i.e., demand), the latter depends on operational procedures and constraints, and the use of the runway system infrastructure. The peak day traffic is determined as the 99th percentile of the total number of daily movements (arrivals and departures). This measure represents such an upper bound for comparison purposes.

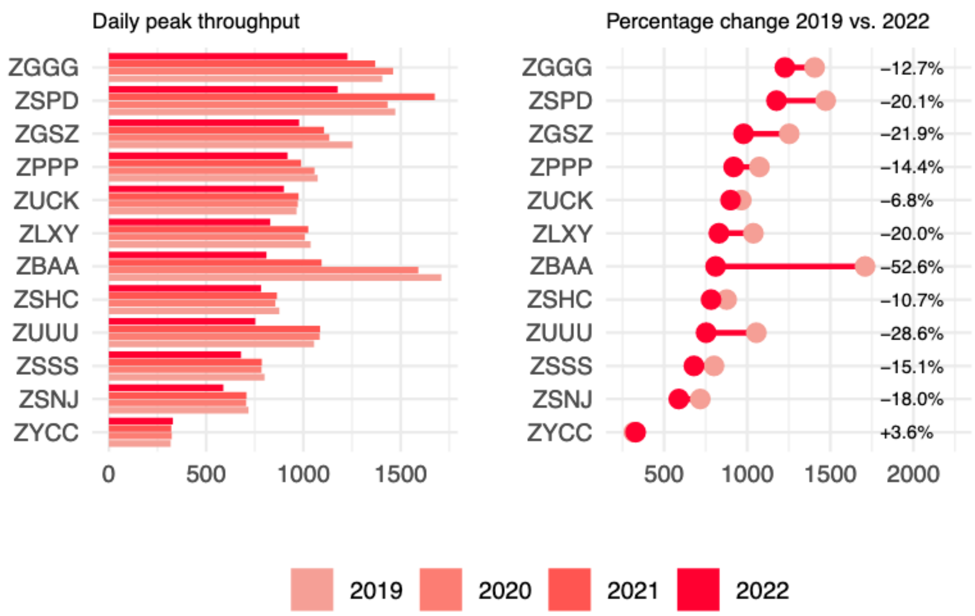

Figure 16: Peak day traffic observed at Chinese airports - annual evolution and recent change

For the majority of Chinese airports, the daily peak operations changed marginally for the years 2020, 2021 and 2022 as can be seen in Figure 16. This indicates that the overall pressure during peak hours did not substantially decline over time with a high stability of movements/connections. The major hubs, i.e., Beijing Capital (ZBAA), Shanghai Pudong (ZPSD) saw a strong decline in the peak behaviour due to the traffic reduction over the years. The traffic reduction is primarily linked to the loss of international connections. Remarkable is the increase of Shanghai Pudong (ZSPD) in 2021 in terms of daily peak throughput, followed by a significant decrease in 2022.

Comparing 2022 with 2019 shows an overall decrease in peak operations in all airports in China. The comparison shows a decrease ranging from 6.8% up to 52.6%. The exception to this trend is Changchun (ZYCC) with an overall increase of 3.6%.

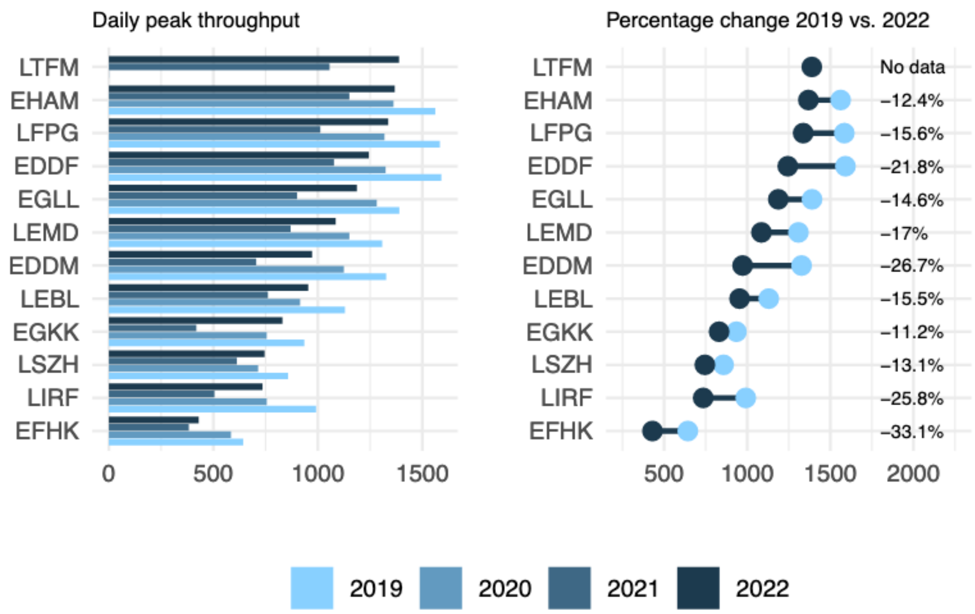

Figure 17: Peak day traffic observed at European airports - annual evolution and recent change

In Europe, the daily peak operations varied on a higher level than in China with a significant drop in 2020 and 2021 in light of the reduced air traffic. Peak day operations in 2022 increased with the returning traffic levels observed at European airports. However, on a general level the pre-pandemic peak throughput levels were not reached across all airports. This suggests an overall lower pressure on the system.

Comparing 2019 to 2022 levels, we see a varying percentage change decrease of -11.2% up to 33.1%. Due to its recent start of operations, there is no observation/data for iGA Istanbul (LTFM).

4.4 Domestic/ Regional Connectivity

Due to the international traffic constraints in response to the COVID pandemic, the domestic share of traffic at Chinese airports increased. For the majority of airport the regional

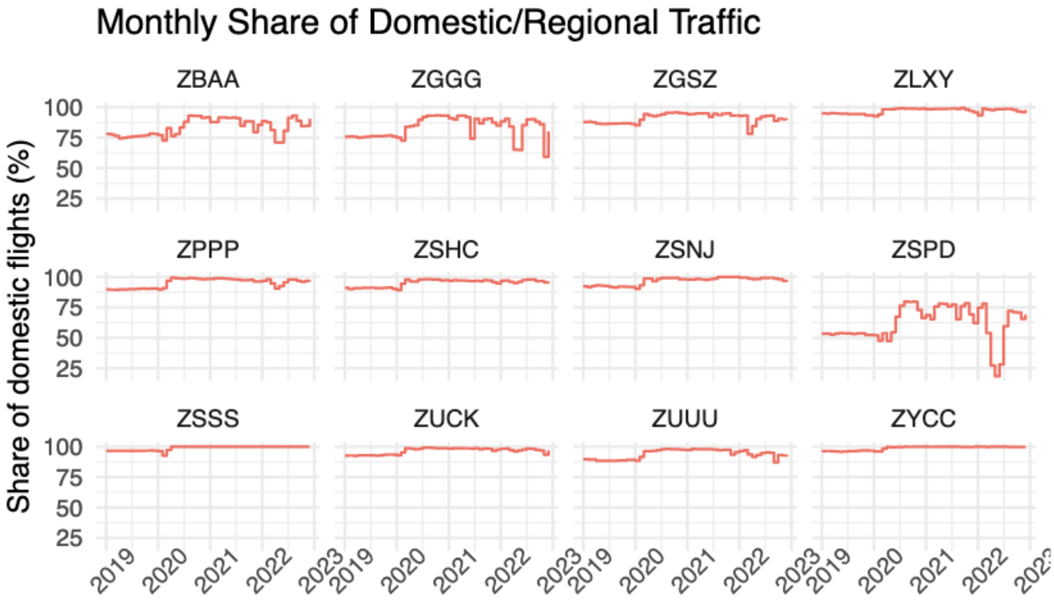

Figure 18: Domestic/Regional traffic observed at Chinese airports

traffic share accounted for 95% or more of air traffic (c.f. Figure 18) A distinct picture can be seen at ZSPD with a significant higher domestic traffic share of 20-35% over the past year. Shanghai Pudong International Airport (ZSPD) mainly carries out international passenger and cargo flights to/from Shanghai.

In 2019, international and regional passenger flights of Shanghai Pudong International Airport accounted for 42.75% of all flights. During the coronavirus epidemic, the number of international passenger flights decreased and the domestic market was comparatively stable, Pudong Airport increased the number of domestic flights, filling the spare operating hours. By doing this, it achieved a phased growth of the number of domestic flights in 2021.

In 2022, however, a significant decrease of domestic flights occurred in Shanghai Pudong (ZSPD) and Guangzhou (ZGGG) due to COVID-19 related travel restrictions to curb re-emerging outbreaks.

Figure 19 shows a higher variety of regarding the regional (intra-European) flights. Due to the nature of the European air navigation system with services typically organised on the national level, travel constraints among the different European countries affected also the operation of regional flights.

The level of regional traffic is lower at the major European hubs, i.e., Amsterdam (EHAM), Frankfurt (EDDF), iGA Istanbul (LTFM), Paris Charles de Gaulle (LFPG), and London Heathrow (EGLL). These airports saw in 2019 a share of about 20-25% of international traffic, and EGLL observed approx. 40% of such traffic. Interestingly, the share of regional connections at these hubs reached the same levels during the initial recovery in summer 2020. A second wave at the end of 2020, however, increased travel restrictions in various

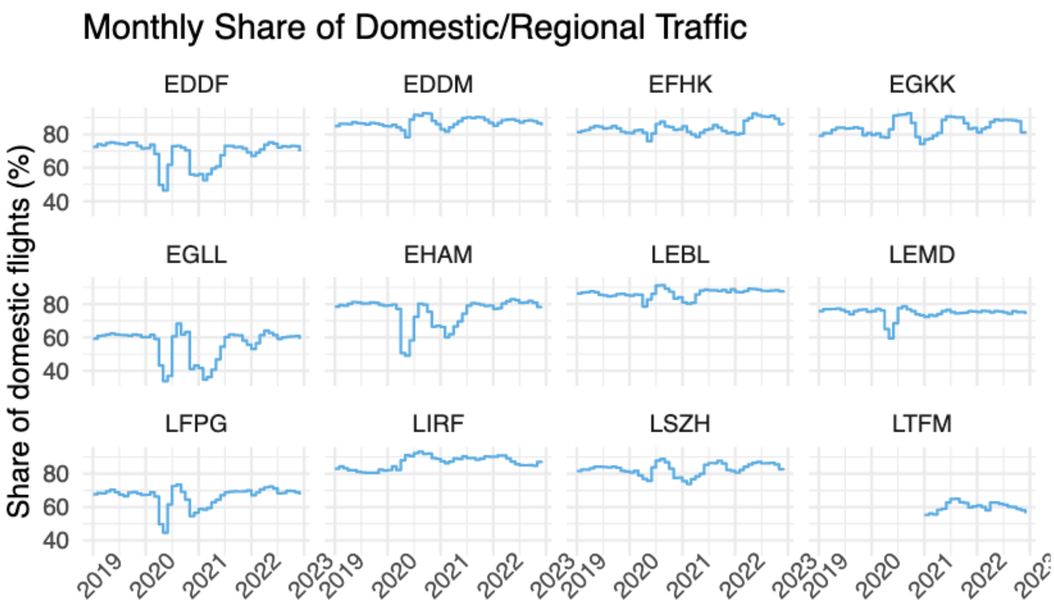

Figure 19: Domestic/Regional traffic observed at European airports

individual countries causing domestic flights to decrease in share. The decrease in domestic traffic is generally noted to be less significant than the decrease due to the first wave.

At the secondary hubs, the pattern shifted. These airports observed a higher share of domestic/regional traffic in during the initial recovery. While the number of intra-European flights decreased overall, there was an almost complete loss of international traffic amplifying the domestic and partial intra-European traffic. The overall share at these secondary hubs decreased during end 2020, 2021 and 2022. With traffic numbers still significantly below the 2019 values (c.f. above), the overall share of reemergence of international traffic pushed the ratio towards the pre-pandemic levels.

These pattern reveals that the European network is formed of some major hubs, secondary hubs, and a multitude of lower-tier airports. Given the national context, international air traffic typically operates to the major airport on a national level. The airports are also well connected. Secondary hubs and other airports serve primarily the local and regional level.

4.5 Fleetmix

Operational performance is also affected by the variation of the fleet composition as sequencing and traffic synchronisation impact the traffic flow. Traffic synchronisation influences therefore the capacity and observed (and realisable) throughput at airports. A highly varied mix including a larger portion of heavy aircraft may result in lower throughput due to the larger wake turbulence separation. The locally defined capacity values may therefore differ based on the predominant fleet mix and operational characteristics. This can ultimately result in different observed throughput numbers, higher sequencing times in the terminal airspace, or additional taxi times during surface movement.

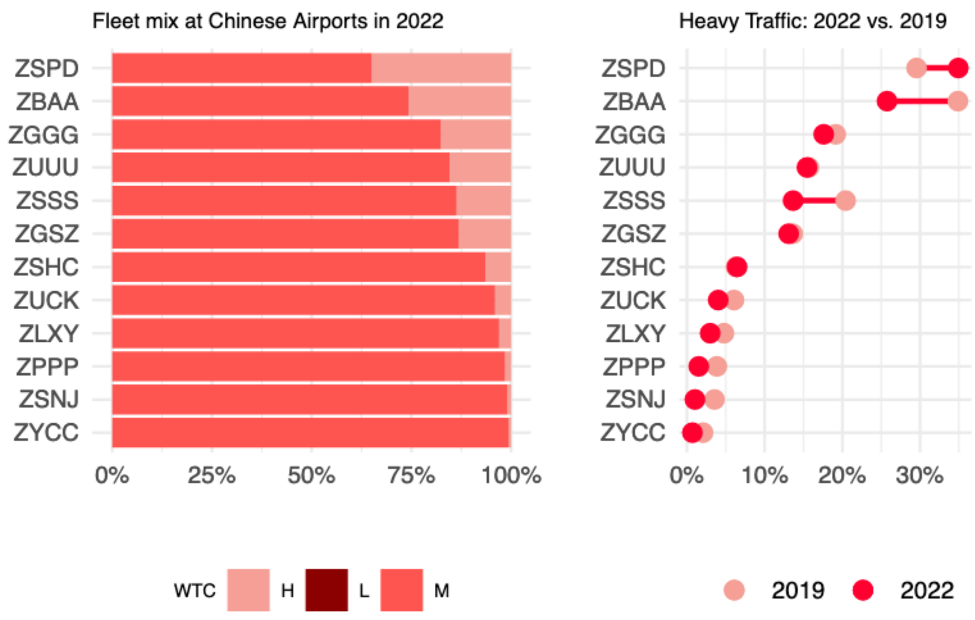

Figure 20: Fleet mix observed at Chinese airports in 2019 and 2022

Figure 20 shows the fleet mix at the Chinese study airports in 2022. Across Chinese airports the share of light types is negligible and Medium aircraft are the predominant fleet aircraft. In 2022, a share of Heavy aircraft of 25% or more was observed at ZBAA and ZSPD. However, there is also a considerable share of Heavy aircraft across the other airports. There was a varied picture for the reduction in Heavy aircraft comparing 2022 to 2019 levels. Beijing Capital (ZBAA) saw a drop by almost 10% which widely coincides with the drop of international long-range traffic. Contrary to the overall trend the share of heavies increased by approx. 5% for Shanghai Pudong (ZSPD). Simultaneously, the share of heavies in the Shanghai Hongqiao (ZSSS) airport decreased by approx. 7% from 2019 to 2022. International connections accounting for a significant share of Heavies appeared to be more centralised.

There is an interesting higher share of heavy wake turbulence category aircraft at ZGGG, ZUUU, ZSSS and ZGSZ. These four airports are China's major hub airports. Slots and flight schedules at these airports are more valuable to airspace users. Airlines are more willing to choose wide-body planes to carry out the flight plans. Airports located in the northwest of China, like e.g., ZUCK, ZLXY and ZPPP, cannot provide services to large aircraft and service only regional operations. Hangzhou airport (ZSHC) serves a high share of domestic cargo flights, whereas, Changchun (ZYCC) serves nearly none. In China, cargo airlines usually use middle-size airplanes to carry out domestic cargo flights. Notably, heavy flights decreased for ZUCK, ZLXY, ZPPP, ZSNJ and ZYCC from 2019 to 2022.

Figure 21 compares the fleet mix in Europe in 2019 and 2022. While at major hubs light

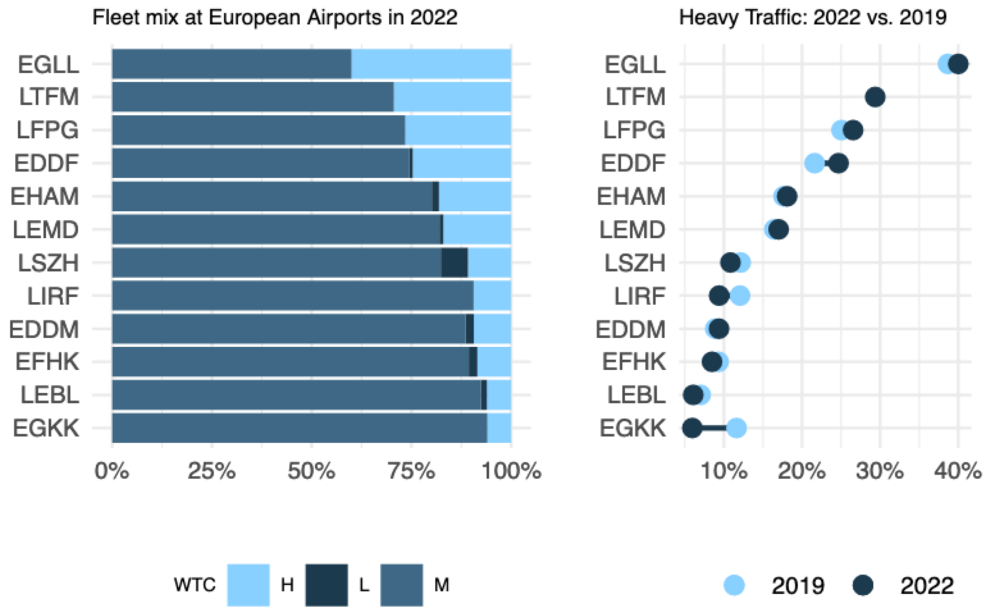

Figure 21: Fleet mix observed at European airports in 2019 and 2022

types are typically not operated, a small share of light types is observed at the secondary hubs. Zurich (LSZH) and Amsterdam (EHAM) showed the highest share of light type operations in 2019 and 2022. On average, traffic across the European region reached 85% of its pre-pandemic levels. The overall recovery is also reflected in the operated fleet mix. Across the European airports, the share of aircraft types in 2022 reflected the pattern observed in 2019 with the exception of London Gatwick (EGKK). This suggests that airspace users tend to offer the same services with a similar fleet in the post-pandemic environment.

Note again that LTFM data is missing since the airport became operational only recently.

5 Efficiency

Operational efficiency is a critical component in assessing the management and execution of operations during the arrival and departure phase of flight. Air navigation services play a vital role in enabling an efficient flow of air traffic, both on the ground and in the air, in particular by applying associated separation and synchronisation activities. Inefficiencies can have an impact on user operations in terms of experiencing delays or excessive fuel burn.

For this report, operational efficiency is assessed for the surface operations (i.e., taxi-in and taxi-out) and during the arrival phase. Conceptually, the measures reported in this study are based on the observed aircraft travel time. These travel times are compared with an associated reference time based on similar characteristic operations. The determined difference (i.e., additional times) measures the level of inefficiency during the operations. It must be noted that high performant operations will still yield a certain share of measured additional times. Operational efficiency is therefore aiming at the minimisation of these additional times across the population of flights.

5.1 Additional taxi-out time

The additional taxi-out time compares the actual taxi-out duration from the aircraft parking position to take-off with a reference time for the same type of operation. From an efficiency perspective, these reference times shall be comparable to traffic situations during which no congestion occurs (i.e., unimpeded time). Monitoring of the unimpeded times could support the identification of bottlenecks or seasonal specifics that can inform standard operating procedures.

For this report, taxi-operations at airports in China are grouped on the airport level. Standard taxi-out reference times are calculated using the 20th percentile of the actual taxi-out time of the airport. The reference taxi times are calculated on a per year basis.

For the European data the reference taxi-out times are determined for each parking position and runway combination. To account for operational variation, e.g., operations during peak vs low traffic periods, varying weather conditions, the respective reference times are set as the 20th percentile of all observed combinations for the period over which the reference is calculated. Note that for this report for Europe, the reference times are determined using the taxi times from 2019 until 2022. [5]

5.1.1 Unimpeded standard taxi-out time

Figure 22 depicts the calculated reference times on a monthly level in 2019 in China. For most airports, the standard taxi-out times represent a constant value over a series of months. For example, the standard taxi-out time is determined as 10 minutes at Xi'an Xianyang International Airport (ZLXY). To account for local specifics, the standard taxi-out time is modulated and varies across the year.

Shanghai Pudong (ZSPD) is the only airport with a highly varying standard taxi-out times on a month-by-month basis. The airport is situated near the sea shore, which makes it is easily affected by advection fog and low clouds in winter. Aircraft taxi times will be affected in seasons with these phenomena.

Figure 23 shows the calculated reference times on a monthly level for Europe. For the majority of the European airports, the 20th percentile approach provided a fairly constant monthly reference taxi-out time. Based on the algorithm, this suggests a fairly stable and regular schedule, and similar operating conditions. A higher level of variance is observed at Amsterdam (EHAM), iGA Istanbul Airport (LTFM), and London Gatwick (EGKK).

[5] This is to account for the significant change of traffic patterns at the different airports (pre-COVID and COVID constraints).

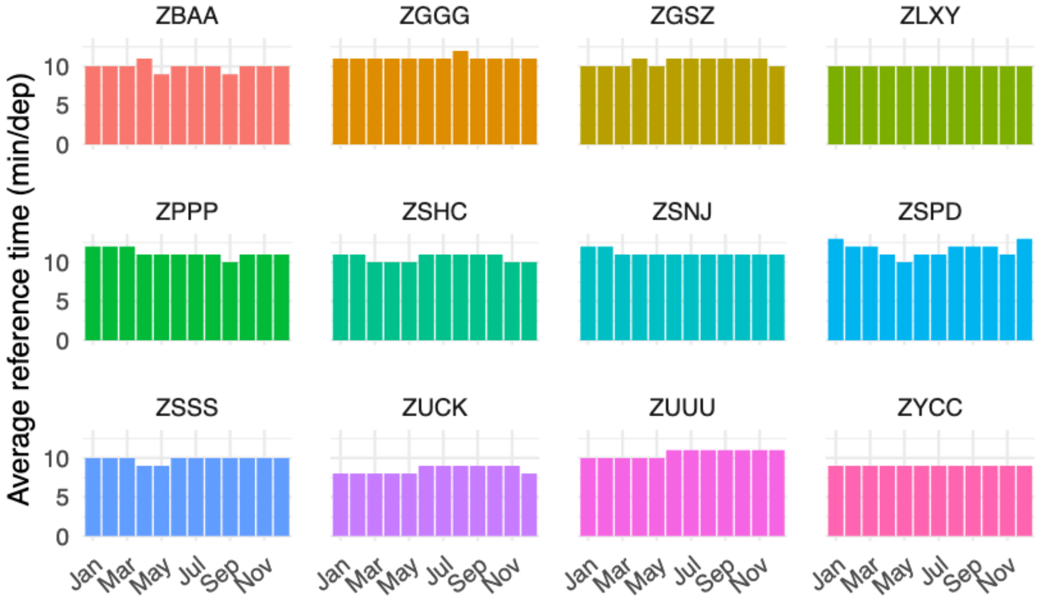

Figure 22: Reference taxi-out times observed at Chinese airports

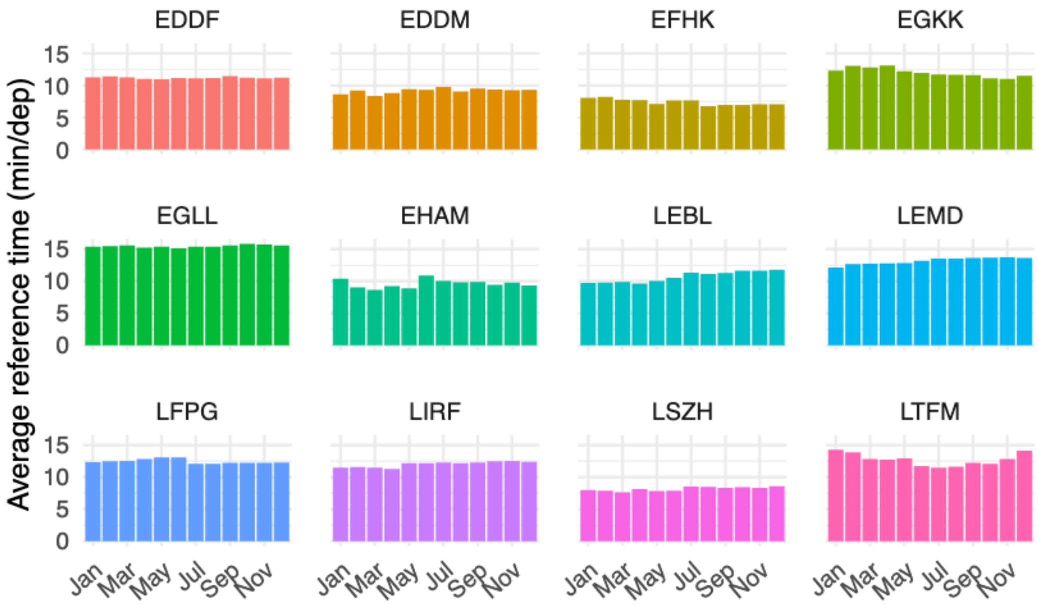

Figure 23: Reference taxi-out times observed at European airports

EHAM is the only European airport with 6 runways. Given Amsterdam's airport location (close to Dutch coast) and variable weather conditions, a multitude of runway system configurations are used on a month-to-month basis. The variation of combinations leads to the observed variability of the aggregated monthly reference times.

The iGA Istanbul airport is recently opened and has 5 runways. Proximity to the coast and an iterative approach to implement operational procedures results in differing operational conditions across the year. This ripples down into the monthly average of the observed 20th percentile of the taxi-out times.

Gatwick (EGKK) is renown as the busiest single runway airport in Europe. Throughout the recent years, there are strong seasonal winds impacting the arrival and departure sequence during the months of February through April. In a busy single runway context, variations of the arrival sequence have had an immediate effect on the departure sequencing and the associated taxi-out times.

5.2 Additional Taxi-out Time

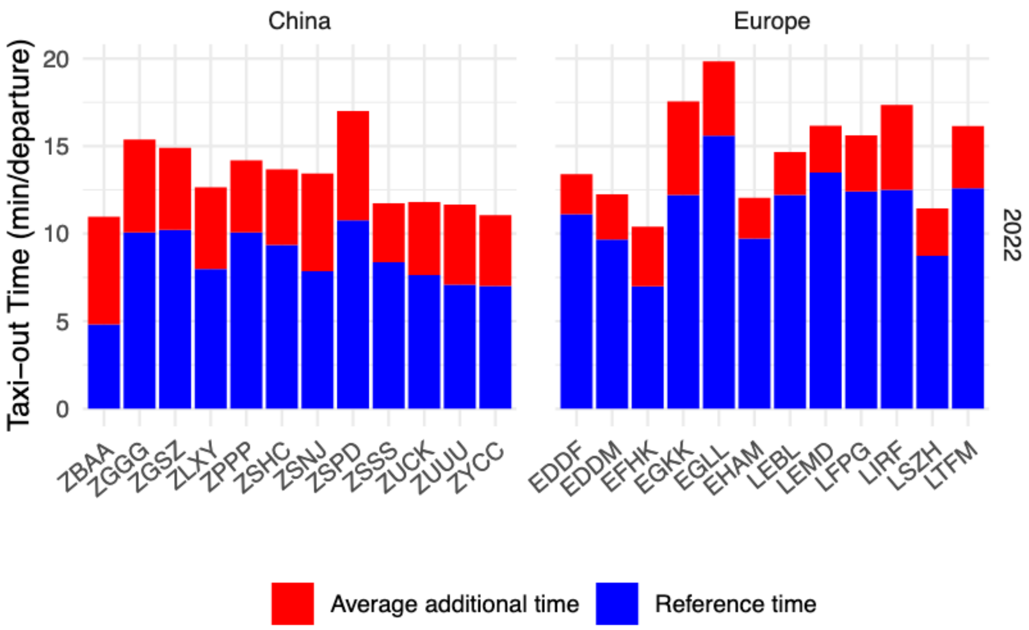

Figure 24: Taxi-out times observed in China and Europe in 2022

According to Figure 24, taxi-out times in 2022 vary across the airports in both regions. In general, the average additional taxi-out time is lower in Europe in comparison to China. With the exemption of Beijing Capital (ZBAA) and Chongqing (ZUCK), there exists a moderate linear relation with the overall traffic served by the Chinese airports. Europe shows a variable pattern. London Heathrow (EGLL) accrued the highest aggregated reference time of all airports. In comparison to the other European hubs, EGLL is a 2-runway airport

(EDDF/4, EHAM/6, LFPG/4 and LTFM/5). Accordingly, there is a significant pressure on the surface infrastructure in terms of taxi operations. This suggests that the 20th percentile approach applied for EGLL may contain already a discernible share of congested flights. Among the European airports, London Gatwick (EGKK), followed by Rome Fiumicino (LIRF), accrued the highest average additional taxi-out times.

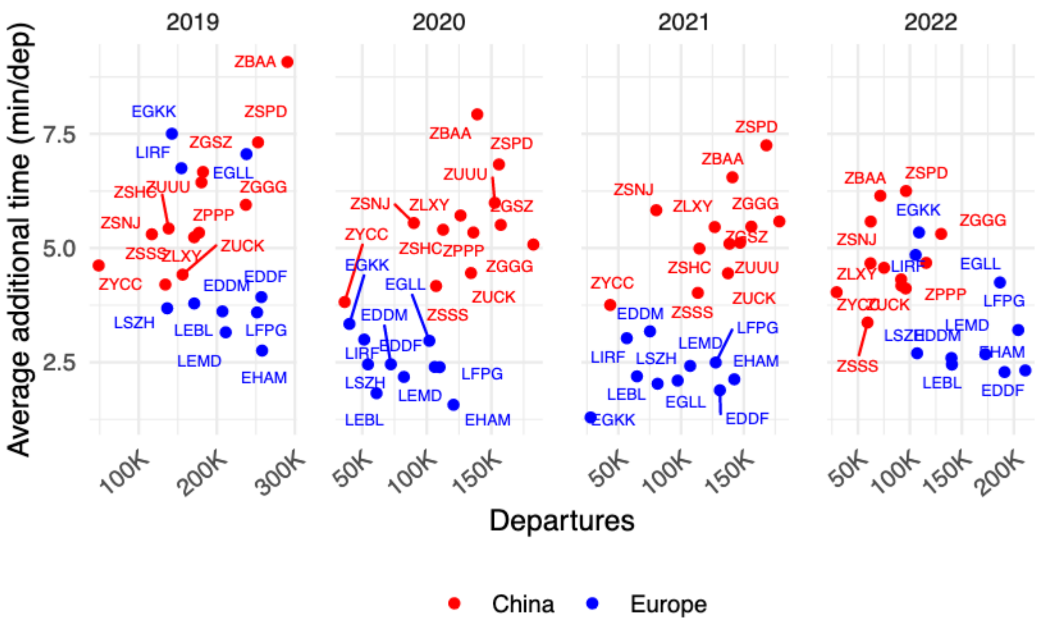

Figure 25: Comparison of additional taxi-out in China and Europe

The overall evolution of the departure traffic and associated average additional taxi- out time is shown in Figure 25. In 2019, departure traffic levels at ZBAA, ZSPD and ZGGG are comparable with the traffic observed at the major European hubs (EGLL, LFPG, EDDF, and EHAM).[6] Beijing Capital (ZBAA) was the busiest airport of all study airports in 2019. It also accrued the highest average additional taxi-out time of 8.94 minutes per departure. Interestingly, the average additional time has dropped significantly over time for ZBAA. This decrease is closely related to the decrease in the number of departure flights during the pandemic.

The average additional taxi-out time is positively associated with lower air traffic. A reduced number of movements (such as during COVID-19) relaxes the pressure on the surface movements and is reflected in a lower average additional taxi-out time for all airports.

Traffic levels in 2020 and 2021 are higher in terms of the number of departure flights in China compared to Europe. Over time a trend towards lower average additional times is present for both regions. Constraints on departing traffic in term of high additional taxi-out times at London Heathrow (EGLL), London Gatwick (EGKK) and Rome Fiumicino (LIRF) relaxed significantly during the pandemic (I.e. observed additional taxi-out times reduced

[6]Whilst the airport iGA Istanbul (LTFM) opened in April 2019, data is only available from 2021 onward.

by a factor of 2-3). In 2022, traffic numbers in Europe are recovering and the additional times are slowly increasing again in this region. In China, the observed additional times decreased further in 2022 because of COVID-19 constraints.

5.3 Additional Time in Terminal Airspace

The additional Arrival Sequencing and Metering Area (ASMA) time compares the time in the arrival terminal airspace with a reference time for the same type of operation. From the standpoint of operational efficiency, these benchmark reference times should be similar to the flying times observed when traffic flows without hindrance.

This report uses the ICAO GANP algorithm for the calculation of the additional ASMA time. After filtering out incomplete data (e.g., flights lacking an ASMA time), the unimpeded time is determined for each aircraft class, runway and entry point combination. Combinations registering no more than 20 flights per month are excluded to prevent any statistical outliers from skewing the results. The reference ASMA time is calculated using the average of the 5th and 15th percentiles of the ASMA time for the remaining combinations.

The additional ASMA time for each individual flight is the difference between the measured ASMA time and the associated reference time for this flight. The yearly average of the additional ASMA time thus provides insights into deviations from the standard operations in terms of quantifying a benefit pool for operational improvement.

The algorithm above is applied to both regions, however, the choice of entry points to calculate the reference times differs. The entry points used in the European analysis are based on identifying arrival flows based on bearing sectors at the constant distances (40 NM and 100 NM) from the airport. This is not the case for the analysis of the Chinese airports. Entry points for the Chinese airports are based on the existing entry fixes around the airport and thus vary in distance from the airport. The determined additional times are therefore not fully comparable. Different segment lengths may influence the level of operational flexibility in terms of sequencing and impact the observed additional ASMA time measured. This will be analysed in the future to harmonize the applied methods and further improve the comparability of the results.

Due to data availability limitations, a limited number of airports is shown for the last eight months of 2021 and full 2022 for China in Figure 26. The additional ASMA time for three airports in China is similar in the last eight months of 2021 with values ranging between 3.5 and 4 minutes. In 2022 a larger variation is present among the airports.

The deviations from 2021 are most notable for Guanzhou airport (ZGGG). Guanzhou airport experienced a significant operational change in 2022 causing the traffic to operate differently in the terminal airspace due to the construction of a fourth and fifth runway, a T3 terminal building and the relevant support facilities. This included changes to the operational concept and resulted in an adjustment from an independent parallel approach to segregated parallel operations. This change was introduced during the pandemic and associated COVID-19 travel restrictions lead to significantly disturbed traffic. Accordingly, strong changes in the additional ASMA time for ZGGG can be observed.

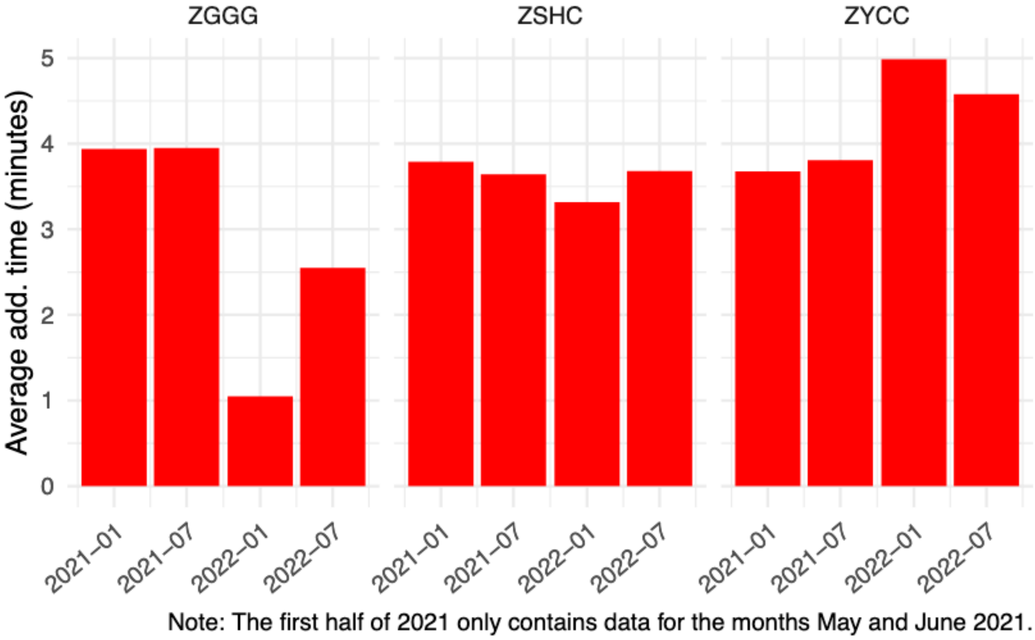

Figure 26: Average additional time in terminal airspace - China

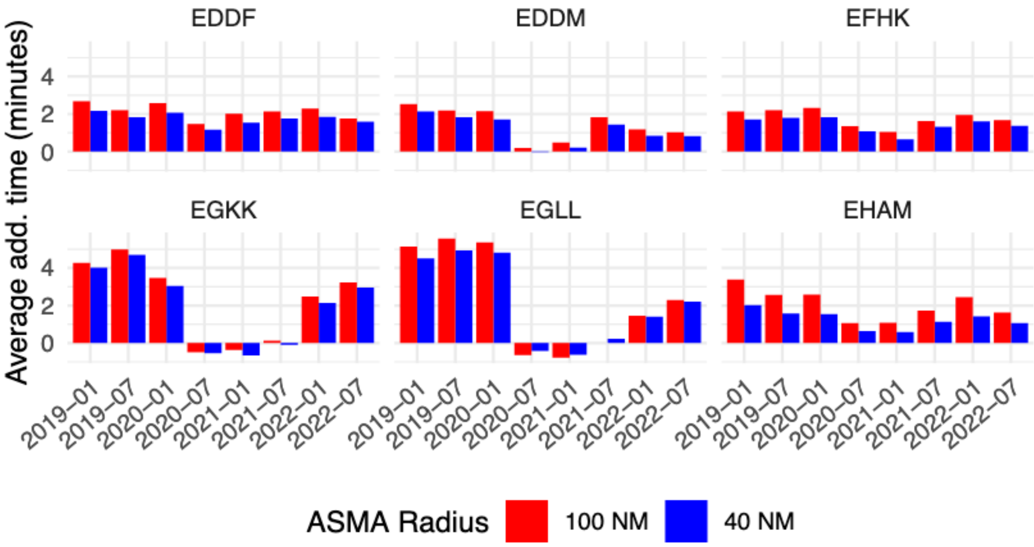

Figure 27: Average additional time in terminal airspace - Europe (Part 1)

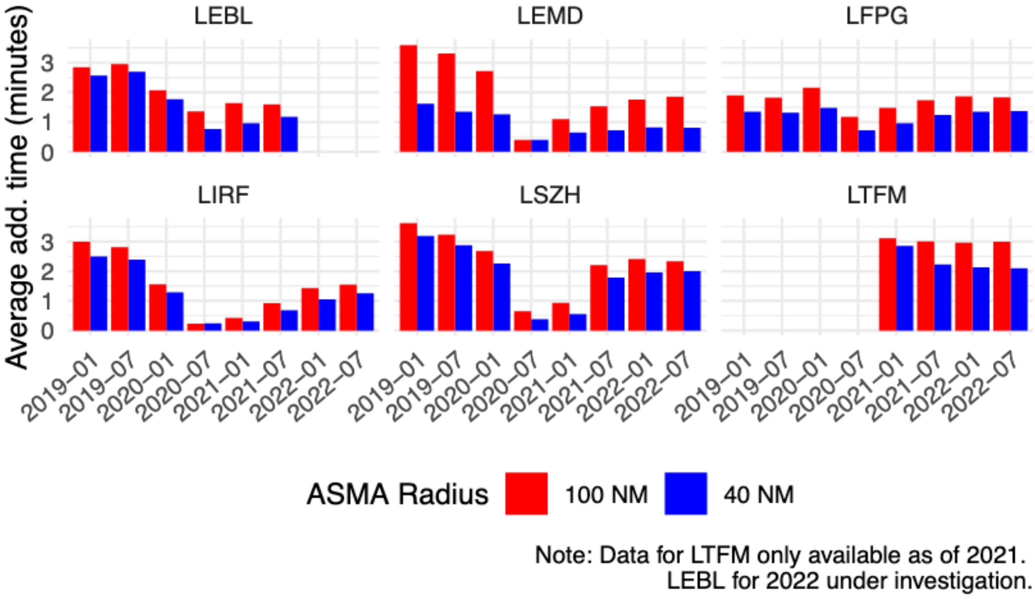

Figure 28: Average additional time in terminal airspace - Europe (Part 2)

The European figures can be seen in Figure 27 and Figure 28. Significant changes in additional time can be noted for nearly all airports for 2021 due to the severe COVID-19 travel restrictions. The sharp drop in air traffic at European airports resulted in a lower level of arrival sequencing the terminal airspace. The 'negative' additional times observed at EGLL and EGKK demonstrate that the determined reference times include a higher share of impeded arrival traffic and in consequence yield negative times when compared to highly efficient operations during the prevailing low traffic operations during the pandemic years. Across the European airports it appears that the band of 2-4 minutes of additional ASMA time can serve as a an upper and lower bound to characterise efficient operations. On average, the additional ASMA time observed for the 100NM radius ranges above the 40NM. This includes - inter alia - additional inefficiencies due to airspace structure and higher level of efficiency will require a closer collaboration between adjacent ANSPs.

In future revisions of the report, a new method to calculate reference values will be developed. Currently reference values are not adjusted to the effects of the pandemic on traffic, causing there to be the statistical anomaly of negative average additional time for London Heathrow (EGLL) and Gatwick (EGKK). This is caused because traffic is more efficiently navigating the terminal airspace compared to the used reference values which represent unimpeded traffic pre-pandemic.

6 Flight Punctuality

Predictability of movements affects operations in many ways. For example, during the strategic phase when airlines set their schedules and consider the stability of their schedule throughout the past seasons, or during the operating phase when air navigation service providers and stakeholders balance demand and capacity.

Within that context, on-time performance is a widely used measure for the aviation industry. It provides a measure for passenger satisfaction, helps airlines to check the achievability of the set schedule, and supports the further analysis of delay drivers or systematic delay causes.

Punctuality can be measured in multiple ways. This chapter builds on

- the on-time-performance (OTP) metric considering flights that departed/arrived less than or equal to 15 minutes past the published scheduled departure/arrival time; and
- a set of punctuality intervals based on the ICAO GANP performance indicator catalogue.

6.1 On-Time Flight Punctuality

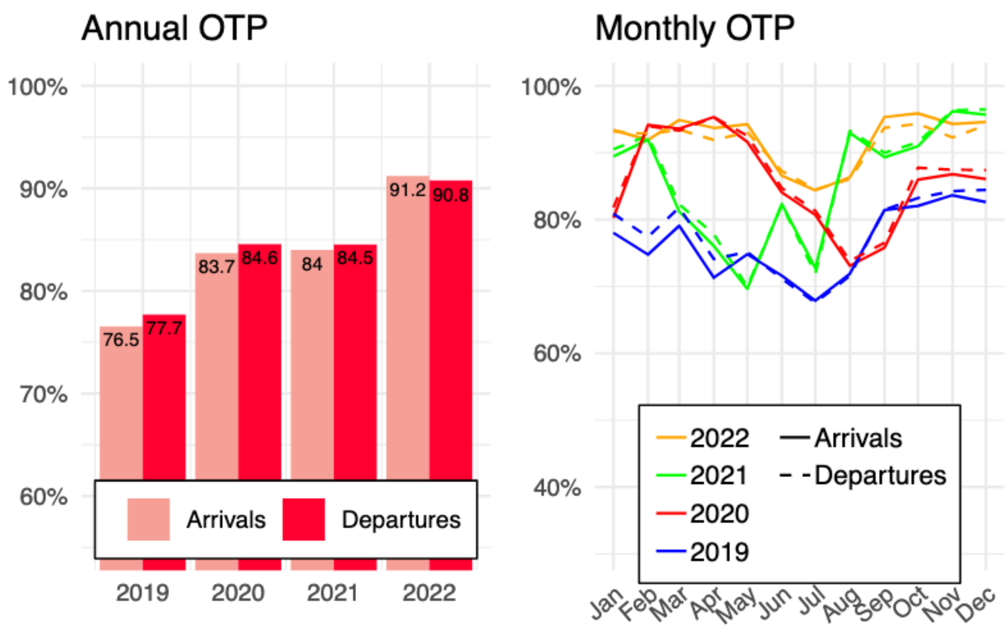

Figure 29: On-time performance in China (2019-2022)

Comparing 2019 to 2020, China's OTP measure improved by 7%. The OTP remained constant in 2021 followed by another increase in 2022 of approximately 7 percentage points to +90% on-time performance. There exists a negative correlation between the OTP measure and the flight volume in China. From 2019 to 2022, the COVID-19 pandemic led to a significant reduction of air traffic. Lower demand on the system resulted in an improved OTP value. In 2022, the number of flights in China decreased to about 51% of 2019 and subsequently the OTP value rose significantly as a result.

The peak of China's flight volume usually occurs during the summer month in July and August. However, the summer season also sees a high share of convective weather phenomena (with e.g., thunderstorms). Both factors (peak traffic, weather) contribute to corresponding lower OTP performance during the summer.

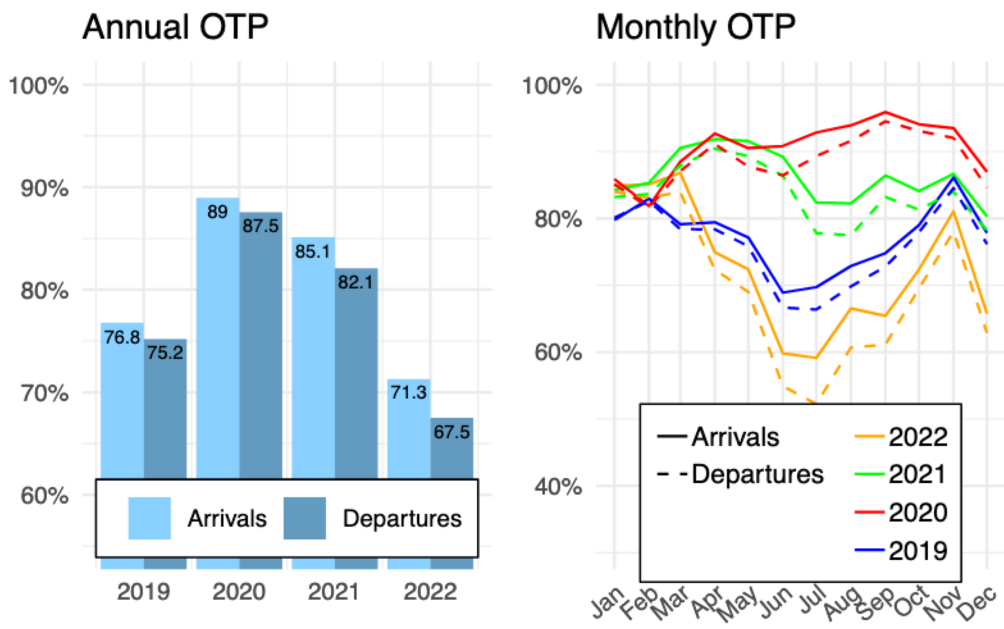

Figure 30: On-time performance in Europe

Within Europe, the OTP measure increased by more than 10 percentage points from 2019 to 2020. In 2018 and 2019 Europe experienced a high level of ATFM delay due to limited airspace capacity. In 2019, the increased level of ground holding negatively affected the overall OTP performance ranging around 75% for both arrivals and departures. The higher level of OTP performance in 2020 and 2021 was, similarly as in China, facilitated by significantly lower traffic levels due to the COVID related travel restrictions. In 2022, traffic recovered to 82% of 2019 traffic levels with a substantial decrease in on-time performance which droped to approximately 70%.

The poor delay performance in 2022 was strongly influenced by the European aviation industry struggling to accommodate the returning high numbers of passengers and flights following the COVID-19 pandemic. Due to this strong increase in demand, the delays within airline and airport operations increased. In addition, ripple effects of the Russian invasion of Ukraine generated a significant number of ATFM delays from 22 February 2022 onwards as traffic flows shifted following the closure of the Ukrainian FIR. Karlsruhe UAC also saw delays from a combination of ATC capacity, weather and increased complexity due to military traffic. Industrial action returned to the network, with French ATC and Italian ATC both striking during the year. There were also ATM system implementations in Reims, Praha and Lisbon ACCs.

The traffic numbers in Europe show a seasonal pattern peaking during the summer season. This combined with the observed capacity shortfalls lead to a lower monthly OTP performance for the months from May to September in 2019. The OTP value was below 75% and fell even shortly below 60% in the summer of 2022.

Traffic during the year 2020 and 2021 decreased and a higher OTP performance was observed on the network level. Following the recovery of traffic in Europe in 2022, significant drops in the OTP indicator for the network were noted. In China, the travel restrictions due to the COVID-19 health crisis continued in 2022, causing a significant increase of on-time performance for the network. The following analysis shows the OTP measure for each of the 12 study airports in both region.

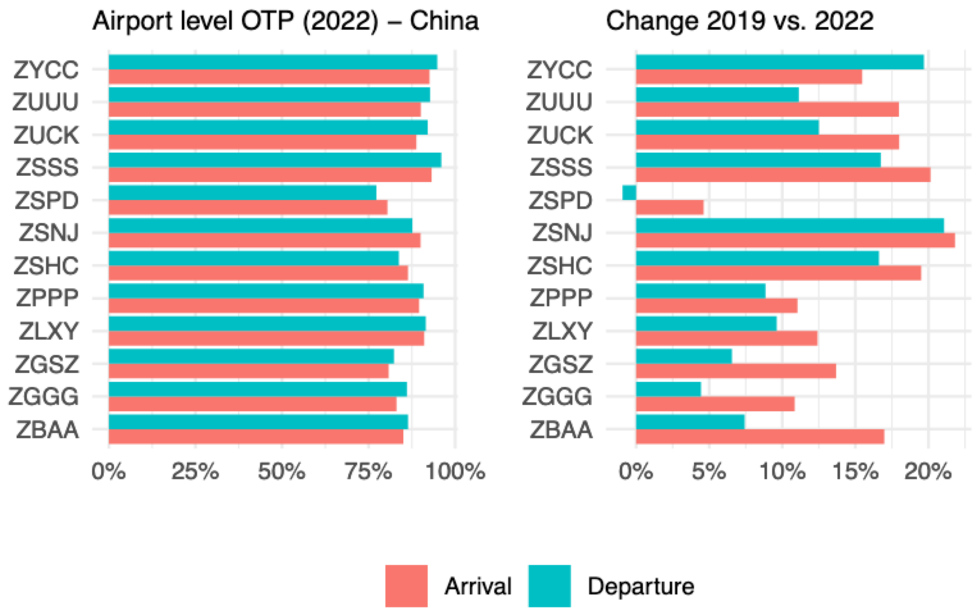

Figure 31: On-time performance at Chinese airports

Compared with 2019, the OTP performance of China's 12 study airports in Figure 31 increased significantly in 2022. This is due to a reduction in travel demand during the COVID- 19 pandemic period. The flight volume dropped sharply, and the pressure of airport's operation lightened with an improvement in operational quality. Nearly all study airports has an OTP increase for inbound traffic over 10%. As an example, the OTP value of inbound flights of Beijing Capital International Airport (ZBAA) has increased by more than 15% since 2019. The opening of Beijing Daxing International Airport (ZBAD) and the significant reduction of international passenger flights have effectively alleviated the operation pressure of Beijing Capital Airport.

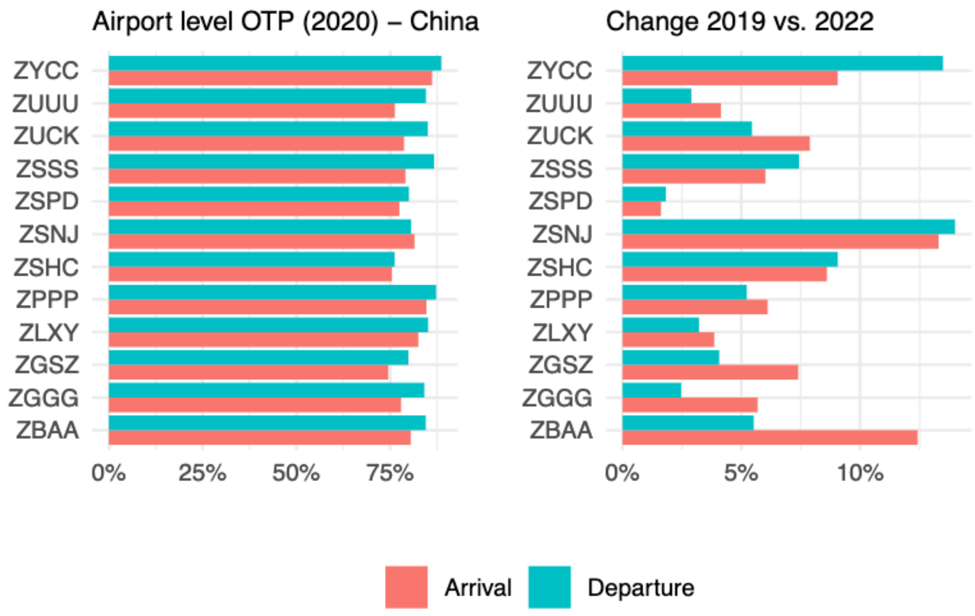

Figure 32: On-time performance at Chinese airports

Since the OTP measure is strongly depended on the scheduled times these changes and absolute values need to be understood within the on-going context of the COVID-19 pandemic and subsequent recovery thereof. Travel and turnaround times may benefit from the lower traffic levels, and ultimately result in a higher share of OTP arrivals/departures. An outlier of this trend, however, is Shanghai Pudong airport (ZSPD) with a relatively speaking small 5% improvement over these 3 years for inbound flights, and a minor decrease in on-time performance for outbound flights.

The airport level OTP performance follows the network level behaviour for the European airports as indicated in Figure 33. For most of the European airports, the OTP performance decreased in 2022 compared to 2019. There is a strong variation across the European airports. The percentage point changes range between -10% to +2.5%.

A noticeable decrease of on-time performance is visible for Paris Charles de Gaulle airport (LFPG) and Frankfurt airport (EDDF) operations as these airports were specifically impacted by delays with different drivers including industrial actions in French ATC, strong capacity constraints at Karlsruhe UAC, weather and increased complexity due to military air traffic mission requirements.

6.2 Arrival Punctuality

The on-time performance measure accounts also for early arrival and departures. The level of flights outside the expected arrival or departure window can pose challenges to air navigation as traffic patterns shift and may exceed the available capacity or require

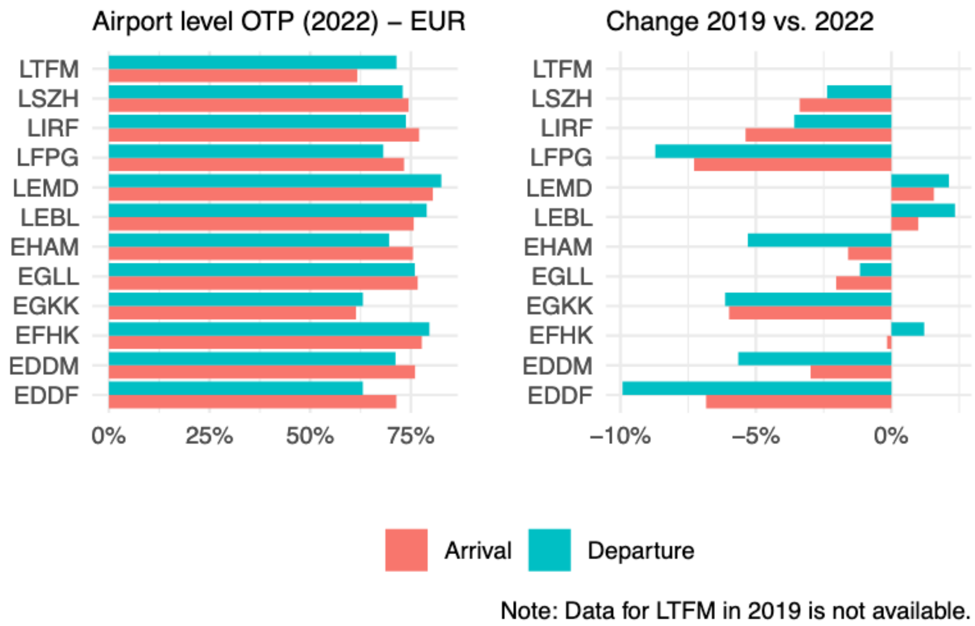

Figure 33: On-time performance at European airports

additional sequencing within the arrival and departure airspace or during the taxi-phase of flight.

Figure 34 shows the change of arrival punctuality of China's study airports from January 2019 to December 2022. From 2019 to 2022, arrival punctuality gradually increased at the Chinese airports. A particular level of improvement was observed at Beijing Capital International Airport (ZBAA, the reasons have been mentioned above). In addition, the proportion of flights arriving more than 15 minutes earlier than the scheduled arrival time increased, which may be due to the reduction of flight demand, smoother air traffic and shorter flying time.

Figure 35 shows the change of the arrival punctuality rate at European airports for the period from January 2019 to December 2022. On average, arrival punctuality at the European airports increased in 2020 and 2021. Across all airports, the proportion of flights arriving earlier than 15 minutes before the scheduled arrival time increased. This suggests that less air traffic made the overall travel time shorter. Therefore, air transport operators intended to use operating slots or apply conservative scheduling arrangement. In 2022, the arrival punctuality dropped due to the post pandemic traffic recovery.

6.3 Departure Punctuality

Figure 36 shows the change of departure punctuality of China's study airports from January 2019 to December 2022. From 2020 forward there is a year-to-year steady increase in

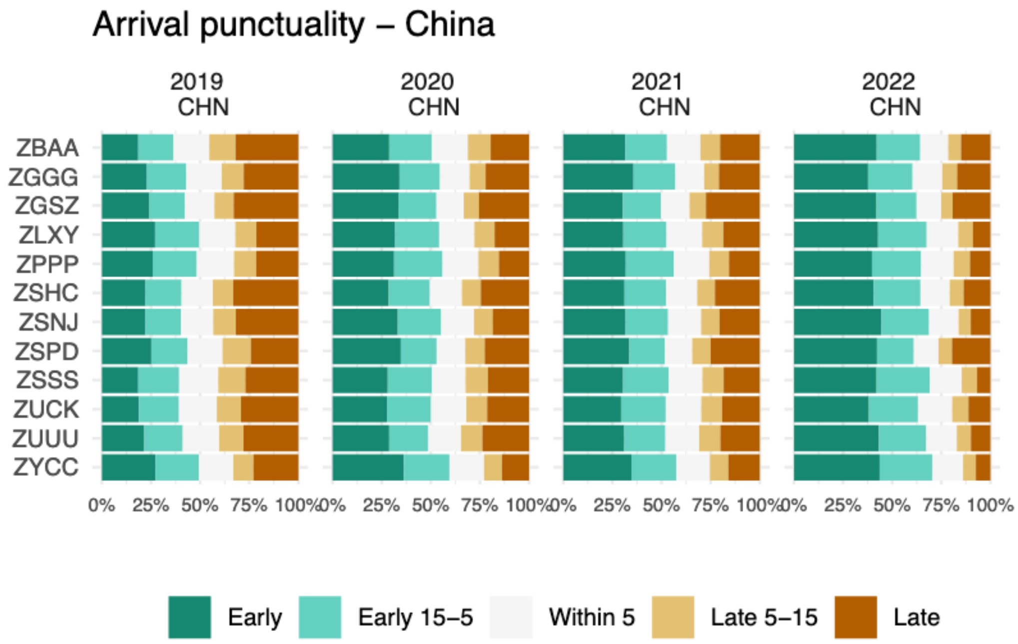

Figure 34: Evolution of arrival punctuality at Chinese airports

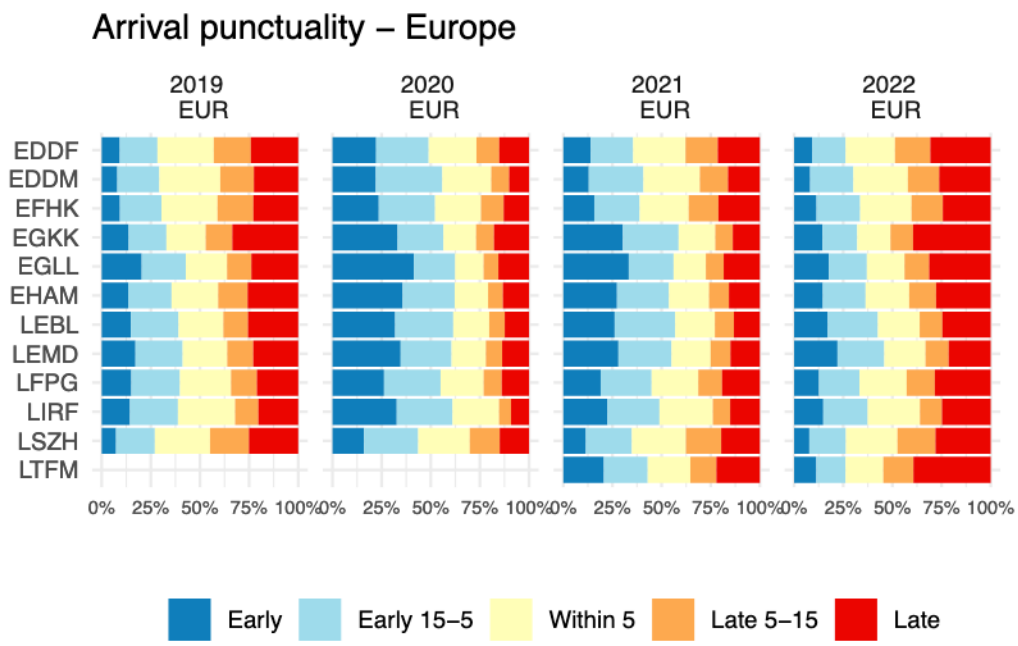

Figure 35: Evolution of arrival punctuality at European airports

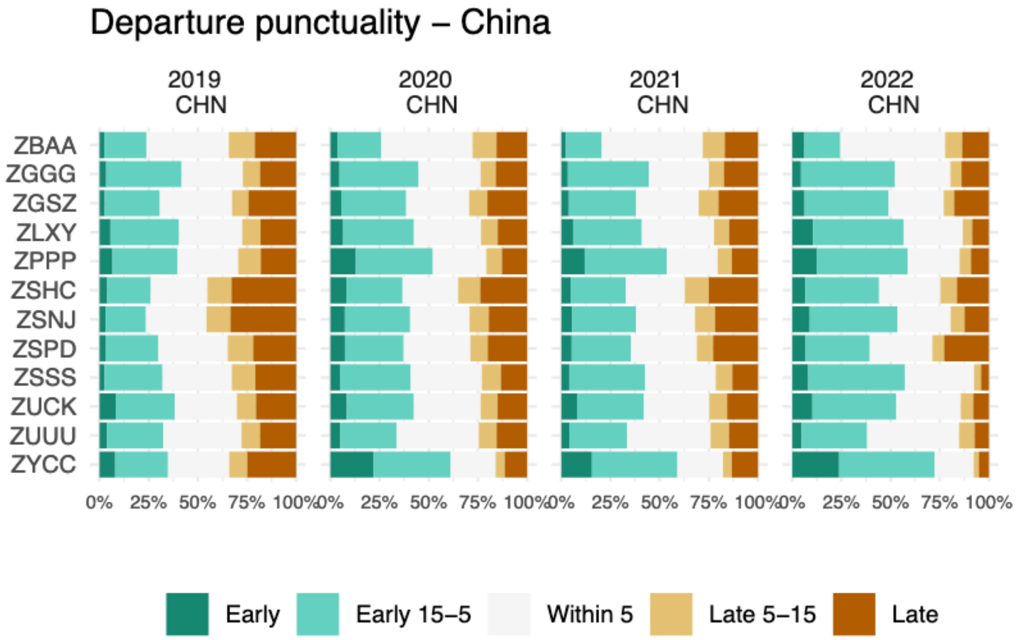

Figure 36: Evolution of departure punctuality at Chinese airports

departure punctuality. Comparing Figure 36 and Figure 34, it is noticed that the proportion of departing flights more than 15 minutes in advance is lower, but the proportion of arriving more than 15 minutes in advance is higher. It may be because the airlines are more conservative in formulating flight plans and the operation time in planned flight segments is longer.

Figure 37 depicts the annual aggregation of the departure punctuality at European airports. On average, departure punctuality during 2020 and 2021 increased. Across all airports, the share of flights departing within -/+ 5 minute of their scheduled time increased. Interestingly, Paris Charles de Gaulle (LFPG) and Frankfurt (EDDF) showed a lower reduction in delayed departures (i.e., 15 minutes of more after the scheduled departure time) in comparison to other airports. London Heathrow (EGLL) showed in 2020 and 2021 a higher share of early departures. In 2022, the overall share of late departures significantly increases to about 25% or more for all airports. Particularly, for flights departing 15 or minutes ahead of their schedule it is assumed that the schedule times and associated airport slots are not fully aligned with the operated schedule.

6.4 Main Causes of Delay

Delays of several types can be causing sub-optimal performance of operations. This section analyses the main categories of delays and their relative frequency of occurrence. Table 3 shows the delay code conventions applied in China.

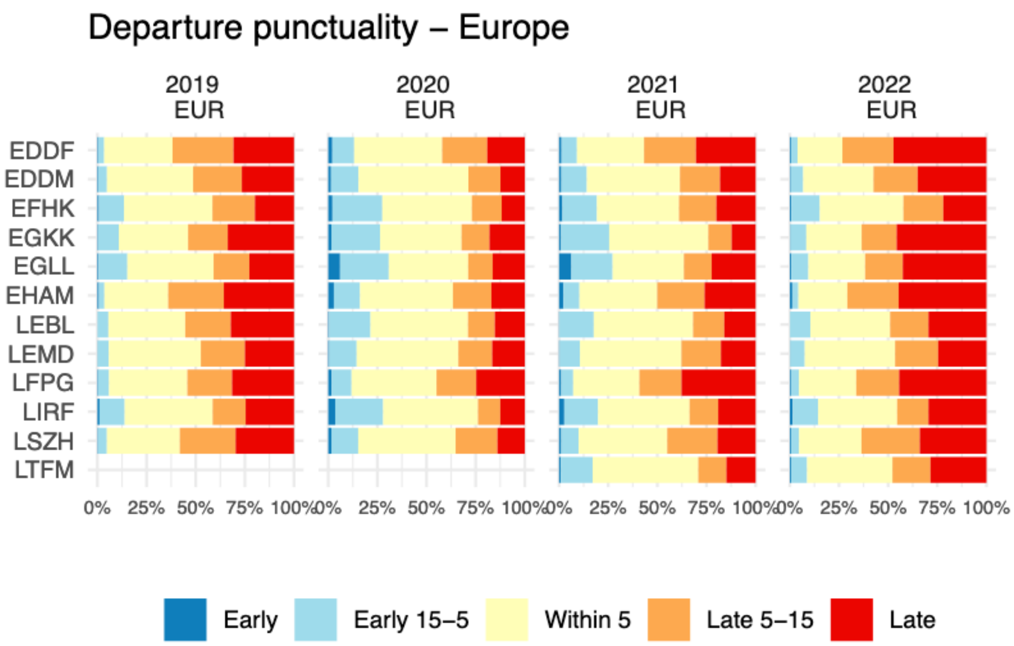

Figure 37: Evolution of departure punctuality at European airports

Table 3: Delay categories in China.

Categories China	Explanation
Weather	Delays related to weather conditions such as below PIC's minimum take-off criteria, airport's minimum operating criteria, rerouting due to weather conditions, etc.
Airlines	Delays within the control of the airline including flight plans, air crew, ground service, food supply, etc.
Traffic	Delays related to exceeding handling capability of regional control sectors, terminal control sectors, airport runways, etc.
Flight Schedule	Delays caused by flight scheduling beyond the capabilities of air traffic control or airport support.
Military Activities	Delays caused by military flight training, aircraft relocation, military exercises, or other military-related activities.
Air Traffic Control	Delays related to human factors, equipment faults, untimely provision of services, etc. within the air traffic control.
Airports	Delays caused by runway damages, foreign objects, incursion of people, animals or vehicles, bird strikes, etc. at the airport.
Joint Inspection	Delays due to untimely completion of passenger check-in procedures caused by joint inspections such as frontiers, customs, etc.
Fuel	Delays related to the provision of fuel, unqualified fuel, faulty refueling facilities, etc.

(continued)

Categories China	Explanation
Departure Control System	Delays due to faults in the departure control system or other related causes.
Passengers	Delays caused by waiting for passengers, noncompliance with boarding procedures, sudden illness, etc.
Public Security	Delays due to large-scale public activities, emergencies, flight hijacks, public health incidents, etc.

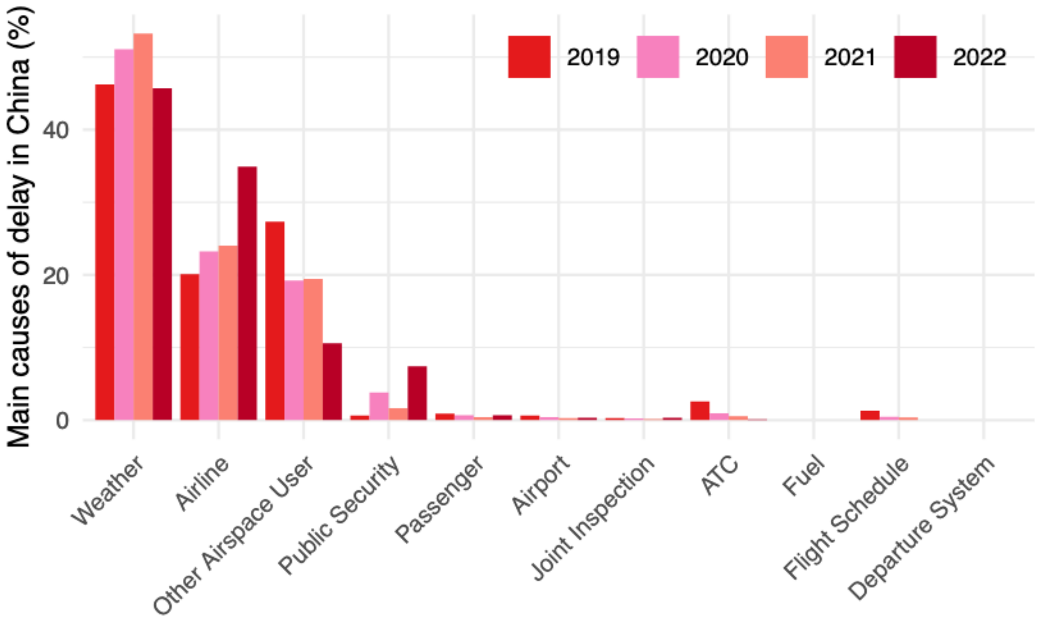

Figure 38: Main Causes of Delay in China

In China, the delay of each flight is ultimately attributed to one main reason. Therefore, the percentage in Figure 38 refers to the percentage of delayed flights. From 2019 to 2020, the main reasons for flight delays in China are coded as Weather, Airlines and Other Airspace Users. On average, Airline reasons account for about 25% delayed flights while Air Traffic Control (ATC) accounts for a relatively small proportion. In 2020 and 2022, due to the impact of the pandemic, delays to to public safety and health measures (Public Security) considerations increased significantly. Flights were cancelled or delayed due to some public health events. Notable is the increase of Airline delay share in 2022.

Table 4: Delay categories in Europe.

Categories Europe	Explanation
Airline	Delays within the control of the airline including aircraft maintenance, crew scheduling issues, and baggage handling.
ATFM En-route	Delays due to air traffic flow management issues while the aircraft is in flight, like air traffic congestion or changes to planned flight path.
ATFM Airport	Delays caused by air traffic flow management issues at the airports, due to congestion, runway availability, or other operational issues at the airport.
Other Airport	Delays caused by infrastructure issues like runway maintenance, terminal issues, and other logistical issues not caused by air traffic management.
Miscellaneous	Other causes of delay which do not fall under the above categories.
Government	Delays caused by policy or regulatory issues, security checks, or other procedures imposed by governmental authorities.
Other Weather	Weather-related delays that do not fall under ATFM-related weather issues, like severe weather at departure or destination airport, or unexpected weather changes.
ATFM Weather	Delays specifically due to weather-related air traffic flow management issues, where predicted severe weather might require changes to planned flight paths.

The classification and statistical methods of flight delay causes in Europe are different from those in China. They are determined by CODA, the Central Office for Delay Analysis.

The time proportion of each flight delay can be associated with different reasons. Therefore, the delay percentage in the figure refers to the percentage of each cause of delay in the overall total of all delay times. From 2019 to 2022, there are three main delay causes in Europe: the first is the late arrival of previous flights and late delivery of passengers'/cabin crews' baggage, the second is the airlines' factors, and the third is the volume of air traffic route controlled by ATC .

One similarity between both regions is that airline related delays are among the major contributors in the overall delay of a flight. The large differences between both delay classification systems cause further comparisons to be hard. Further research is needed to establish a better mapping between both delay code systems and compare the observed delay in both systems.

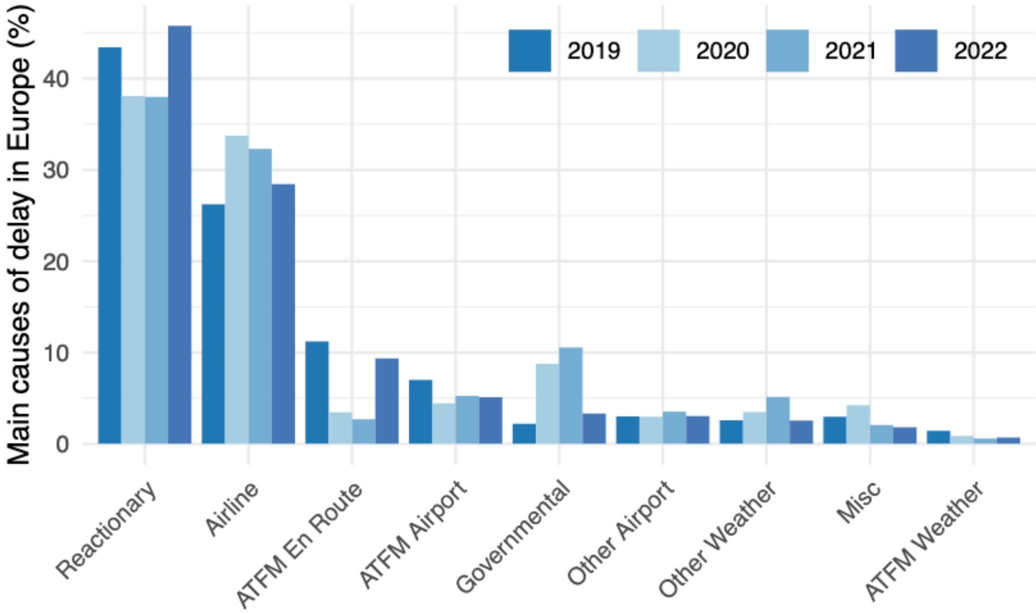

Figure 39: Main Causes of Delay in Europe

6.5 Turnaround - DDI Analysis

For this study, the groups agreed to investigate the delay absorption at the selected airports. The Delay Difference Indicator (DDI) measures the magnitude of the deviation of the scheduled turnaround time and the actual observed turnaround time for each flight arriving at an airport and its successive departure.

Figure 40 shows the average daily DDI per month for each of the airports.

The study airports in China show a certain delay absorption capacity, that is, they can absorb a certain amount of delay during the turnaround process of the airport, to reduce the delay chance of the next flight leg. This index reflects the transit support capacity of the airport. However, it is obvious that the delay absorption rate of each airport has increased significantly from February to June 2020 and from January to March 2021, that is, the delay of subsequent flights has increased by 10-15 minutes compared with the delay of previous flights, which is due to the longer transit time caused by more stringent pandemic prevention and control measures at these airports. This variable trend continuous in 2022 whenever health restrictions are present. Shanghai Pudong (ZSPD) observed a strong increase in its DDI in 2022.

For the European airports, the average daily DDI was generally positive throughout the study period and ranged between 5 to 15 minutes per turnaround. On average, flights arriving late will not be able to absorb the experienced arrival delay and depart slightly late. The general trend is broken for March and April 2020. In March 2020 the European traffic declined due to the imposed travel restrictions and was floored throughout April.

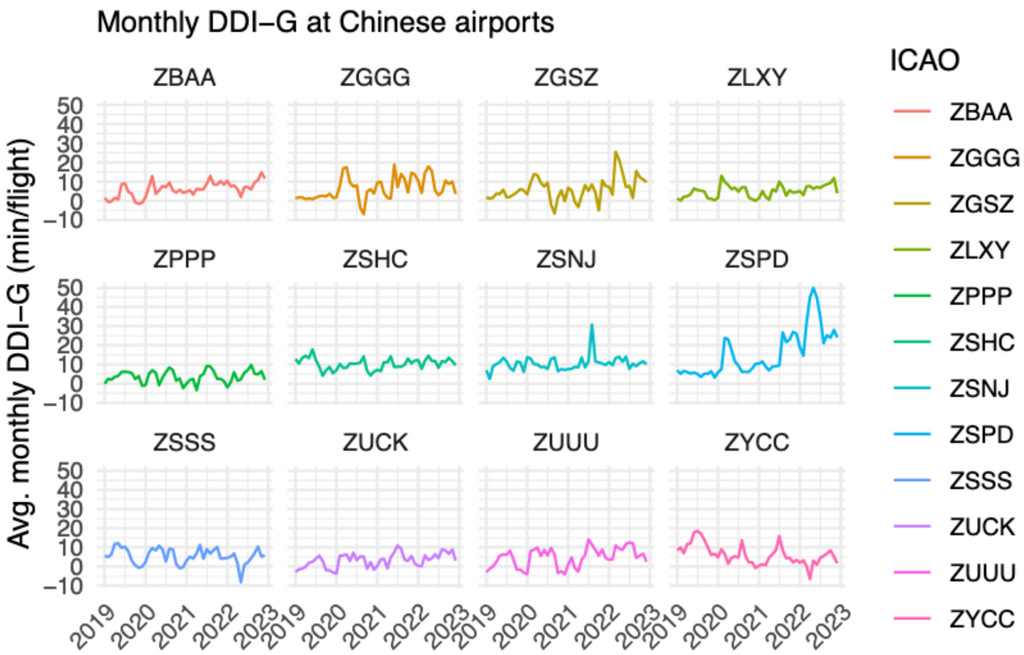

Figure 40: Evolution of Delay Difference Indicator (DDI) at Chinese airports

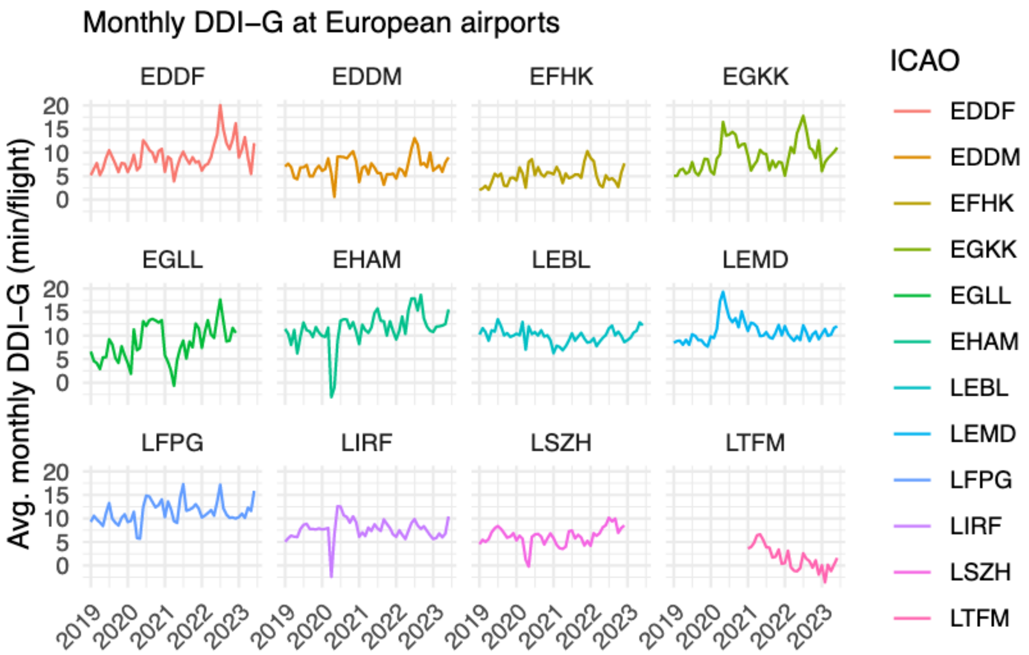

Figure 41: Evolution of Delay Difference Indicator (DDI) at European airports

As of May 2020, an initial rebound was observed (c.f. above). The distortion in these 2 months resulted in a reduction of the average daily DDI, and in some cases a negative DDI (i.e., off-block delay smaller than arrival delay) was observed at some airports (e.g. EDDM, EHAM, LIRF). A positive trend is observable at Istanbul airport iGA (LTFM). Here the DDI showed a decrease since the starting of reporting in 2021.

7 Weather Impact

Each geography has its' own climate and weather conditions. The level of intensity and frequency of weather events will thus impact the operational air traffic conditions and air navigation system performance differently at the various Chinese and European airports. For this report a comparison of the weather conditions at airports was made (see the annex in Section 10) and the relative impact of weather events in both geographic regions is outlined in this chapter.

In this analysis, the local weather is inferred from historically published Meteorological Aerodrome Reports (METARs)[7]. METARs are predominantly used by aircraft pilots and by meteorologists who use aggregated METAR information to assist in weather forecasting.

METARs contain information on temperature, visibility, gusts, winds, etc. In addition, each message contains a weather code which highlights the presence and intensity of weather events such as liquid or solid precipitation, obscuration, thunderstorms, or other weather phenomena. These categories are compiled from the weather codes according to Table 5 As per example: If a weather code mentions rain (RA) or drizzle (DZ), it is indicated that liquid precipitation is present.

Table 5: METAR weather codes classification

Weather phenomena category	Weather code elements
Liquid precipitation	Rain (RA) and drizzle (DZ)
Solid precipitation	Snow flakes (SN), snow grains (SG), snow pellets and small hail (GS), hail (GR) ice pellets (PL) and ice crystals (IC)
Unknown precipitation	Unknown precipitation (PU)
Obscuration	Obscuration Fog (FG), mist (BR), haze (HZ), volcanic ash (VA), widespread dust (DU), smoke (FU), sand (SA) and spray (PY)
Thunderstorms	Thunderstorms (TS)
Other phenomena	Squalls (SQ), dust or sand whirls (PO), duststorms (DS), sandstorms (SS) and funnel clouds (FC)

[7]Meteorological Aerodrome Report. METAR is a format for reporting weather information. Raw METAR is the most common format in the world for the transmission of observational weather data. It is highly standardized through the International Civil Aviation Organization (ICAO), which allows it to be understood throughout most of the world. The origin of the historical METAR weather reports used throughout this section is the Iowa Environment Mesonet. The data is retrieved through the `riem` package published by `ropensci`.

The weather phenomena classification used in this study is based on the established classifications in the Air traffic management airport performance (ATMAP) framework[8] developed by the ATMAP Working Group (EUROCONTROL).

The weather analysis based on the available METAR information is used to compare key performance indicators under different weather circumstances. More information on METAR messages and how to read them can be found in Meteorological Service for International Air Navigation by ICAO (Annex 3)[9].

7.0.1 Influence of Weather on Departure Punctuality

Strong and adverse weather conditions are capable of disrupting air traffic and may in turn impact operational performance. One of the areas where the effects might be visible is in the departure punctuality. Figure 42 compares the departure punctuality for three airports in Europe and China on a peer-basis (i.e. EGLL - ZGGG, LSZH - ZSHC and EFHK – ZYCC) for different weather phenomena and intensities. These airports were selected to cover operations at a major hub (EGLL, ZGGG) and similar seasonal weather conditions (LSZH, ZSHC, EFHK, ZYCC).

A flight is indicated as departing on time if the actual departure is before or equal to 15 minutes after the scheduled department, similar as done earlier in Section 6.1. Each departure is labelled with the various weather phenomena intensities (as extracted from the METAR data) at the time of departure allowing for various aggregations based on intensity. To avoid statistical outliers, for each weather phenomena only aggregates for which more than 100 observations are present within the study time period are visualized.

The influences of various weather phenomena on on-time performance of departures are visualized in Figure 42 and Figure 43. From Figure 42 it is noticeable that any precipitation (solid or liquid) negatively affects the on-time performance of departures of European airports to a greater extent than the Chinese airports.

The on-time punctuality at the three European airports (EGLL, LSZH and EFHK) is affected to a larger extent by liquid precipitation compared to two Chinese study airports ZGGG and ZSHC. Changchun airport (ZYCC), however, is similarly affected. From studying the weather phenomena it is clear that Changchun has an intense monsoon season during summer months and a dry winter. This change from a dry winter to a rainy summer may cause- operational circumstance differences influencing the observed OTP behaviour at ZYCC.

Solid precipitation similarly leads to a lower on-time punctuality in Europe. Comparing Europe and China, solid precipitation affects European airports more heavily than Chinese airports. In addition, in Guangzhou airport (ZGGG) solid precipitation did not occur as the climate in Guangzhou is subtropical with temperatures in the coldest months dropping only to 13 degrees Celsius on average.

[8] https://www.eurocontrol.int/publication/air-traffic-management-airport-performance-atmap-framework
[9] https://www.icao.int/airnavigation/IMP/Documents/Annex%203%20-%2075.pdf

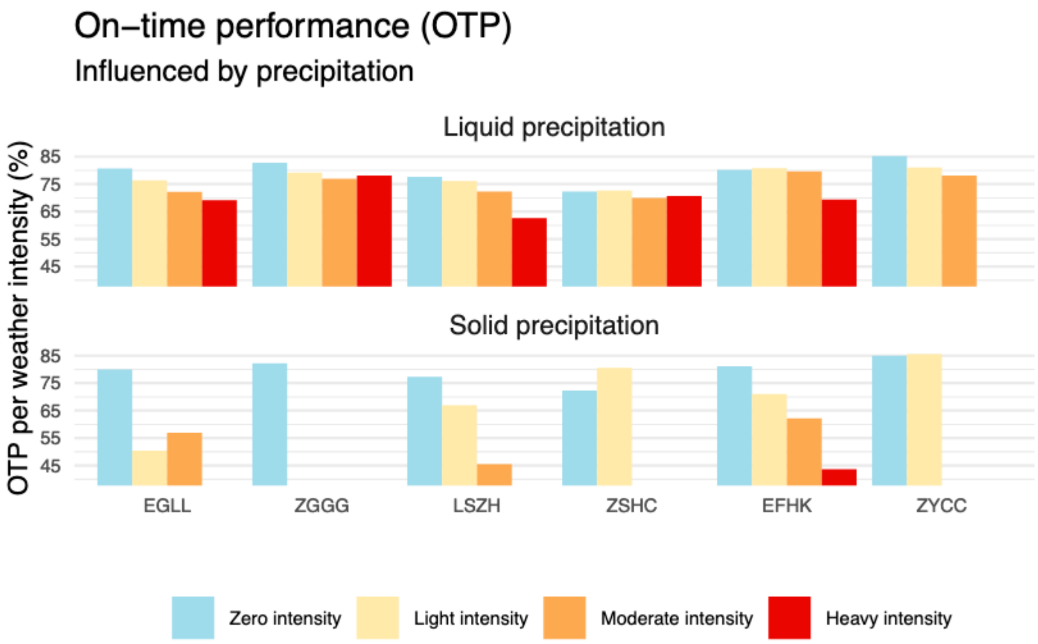

Figure 42: The effect of precipitation phenomena on the percentage of flights departing from the gate on-time.

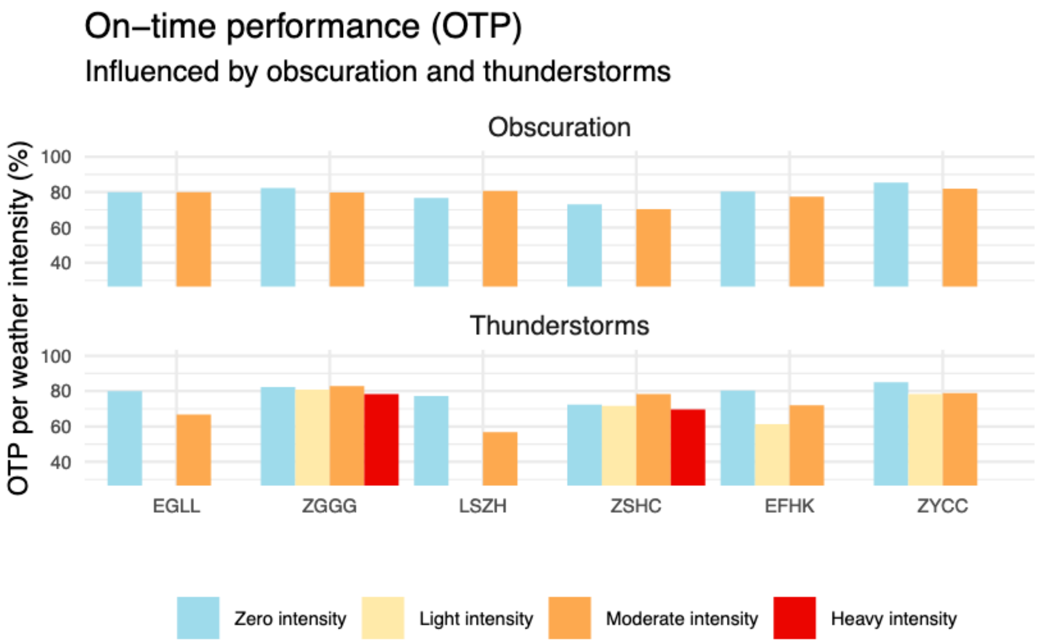

Figure 43: The effect of obscuration and thunderstorms on the percentage of flights departing from the gate on-time.

Additional to precipitation, other phenomena like obscuration or thunderstorms can cause sub-optimal operational circumstances. The visualization in Figure 43 indicates obscuration has a minor negative effect on OTP, with the exception of Zurich airport (LSZH) where obscuration is more frequently present compared to the other European airports.

The presence of thunderstorms affects most airports departure OTP negatively, especially impacted is Zurich airport (LSZH). From the weather study airports (see annex Section 10)) it is clear Guangzhou (ZGGG) and Zurich (LSZH) airport are the most frequently impacted by thunderstorms. Guangzhou airport, however, experiences more frequently heavy intensity thunderstorms compared to Zurich and from the stable results one can see in Figure 43 it seems Guangzhou is thus more prepared to maintain on-time performance.

From an OTP perspective, European airports suffer more under adverse weather effects compared to its' Chinese counterpart.

7.0.2 Influence of Weather on Taxi-out Additional Time

Also ground operations during the taxi-phase are affected by weather phenomena. This can be shown by observing the taxi-out additional time at airports for different weather intensity. The taxi-out additional time is calculated using the same reference percentile used previously in Section 5.1, however, runway and stand are not considered here in the calculation of the reference.[10]

The effects of solid and liquid precipitation on the additional taxi-out time for each airport is visualised in Figure 44 and Figure 45. The presence of solid precipitation causes the average additional taxi-out time to increase as expected. This increase due to solid precipitation is more dominantly present in European airports and is often linked to de-icing.

The effect of liquid precipitation is less pronounced compared to its' solid equivalent for both regions. An increasing additional time can be observed for EGLL, ZGGG, ZSHC for all intensities. For LSZH and EFHK and ZYCC there's not a clear trend. Different operational procedures for different weather conditions might cause a decrease in pressure on the system, causing temporarily increases in operational performance under adverse weather effects. However, as can be seen in LSZH and ZSHC - under heavy intensity the additional taxi-out time seems to increase, nonetheless.

In Figure 45 obscuration shows a mild increasing effect on additional taxi-out times on some airports. Most specifically LSZH, EFHK and ZYCC.

Thunderstorm intensity has significant effects on the additional taxi-out time in EGLL and LSZH. The effects of thunderstorms are less clear on Chinese airports. Due to light to heavy intensity weather phenomena such as thunderstorms, flights might be cancelled or delayed.

[10]The 20th percentile of the actual taxi-out time of the airport is the unimpeded taxi-out time of the airport and each airport has a reference taxi time per month. The observed taxi-phase is labelled with the weather phenomena intensities present (as extracted from the METAR data), allowing for follow up aggregations. To avoid drawing erroneous conclusions from statistical outliers, only aggregates for which more than 100 observations are present within the study's time period are visualized.

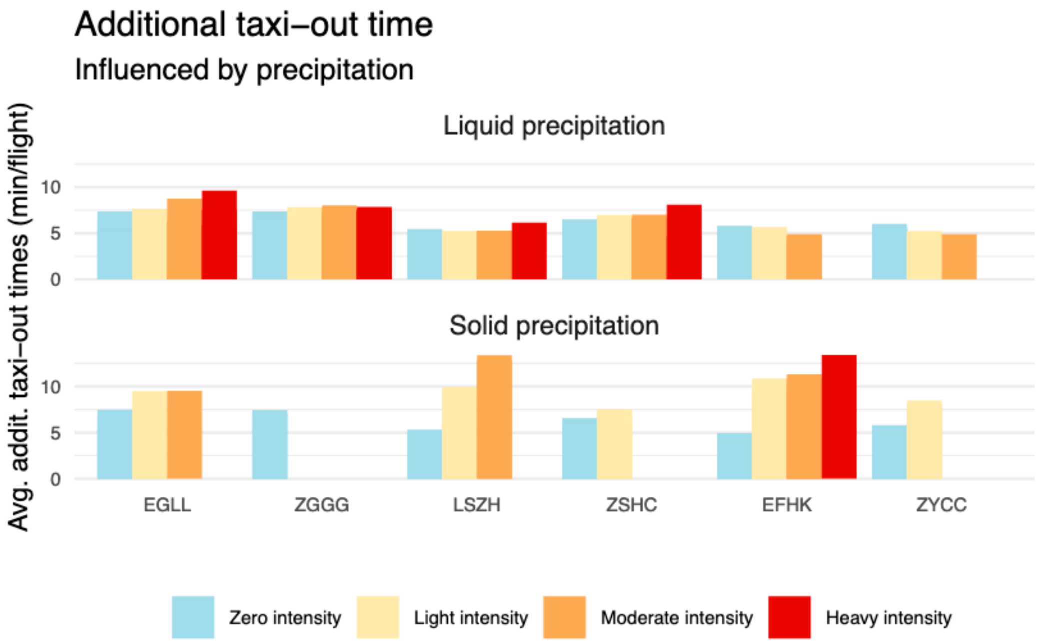

Figure 44: The effect of precipitation phenomena on the additional taxi-out time.

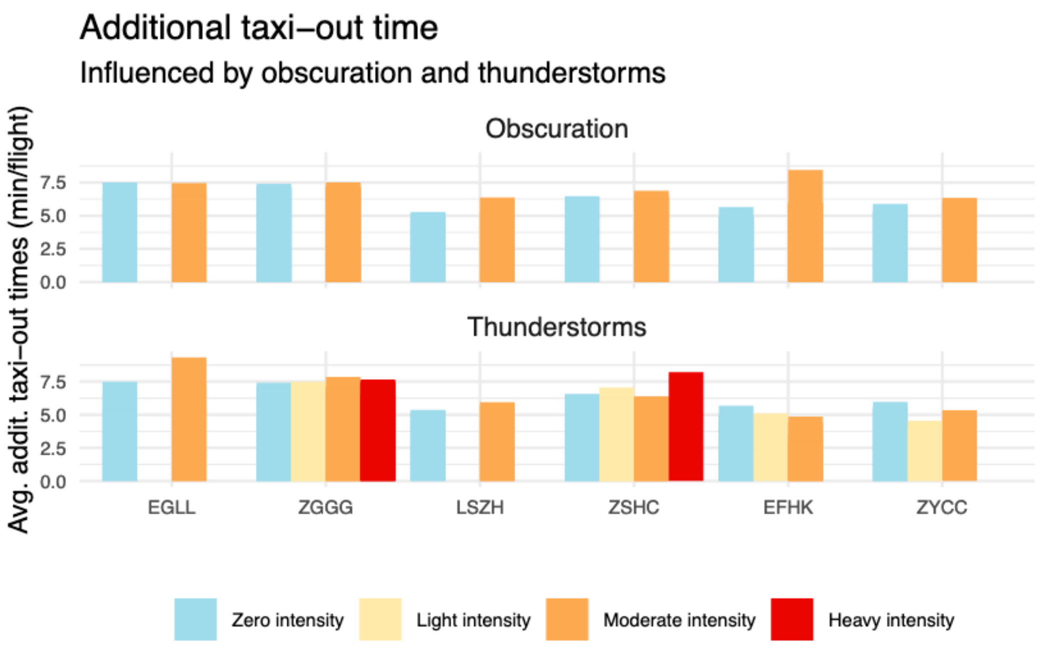

Figure 45: The effect of obscuration and thunderstorms on the additional taxi-out time.

This opens capacity in the runway system which decreases the observed additional taxi-out time.

This initial analysis of the impact of weather on operational performance showed several patterns that requires further research in future editions of the comparison report. It appears that – while there is a difference in intensity – the frequency of exposure to such weather conditions may play a role in how local operations are affected.

8 Major Improvement Projects

Both regions are continually working on new improvements to their air traffic systems. As an example, hereof, two major projects will be outlined.

8.1 New establish ZBAA-ZGGG air route channel

In the Chinese region a project to improve the Beijing-Guangzhou corridor airspace capacity has been completed.

The southern section of the Beijing-Guangzhou corridor consists of two groups which have four routes. The goal is transforming the former Beijing-Guangzhou route (A461) in the south of the Hubei region, a "parallel one-way transformation", while opening the Beijing-Guangzhou diversion route (W45) to the Guangdong-Hong Kong-Macao Bay Area, and then combining them with the western side of the W102 route, in order to achieve the "Two up and two down, one-way circulation" pattern which is a large channel. This effectively links the two Beijing airports, Tianjin, Zhengzhou, Wuhan, Changsha, Guangzhou, Shenzhen, Hong Kong, Macau and other important regional airports.

According to the statistics, the southern section of the Beijing-Guangzhou corridor plan has opened and adjusted a total number of 19 new routes. This new route mileage is 2,313 kilometers, adjusted and optimized 13 airports which are related to the approach and departure flight procedures and adjusted about 5,000 flight routes.

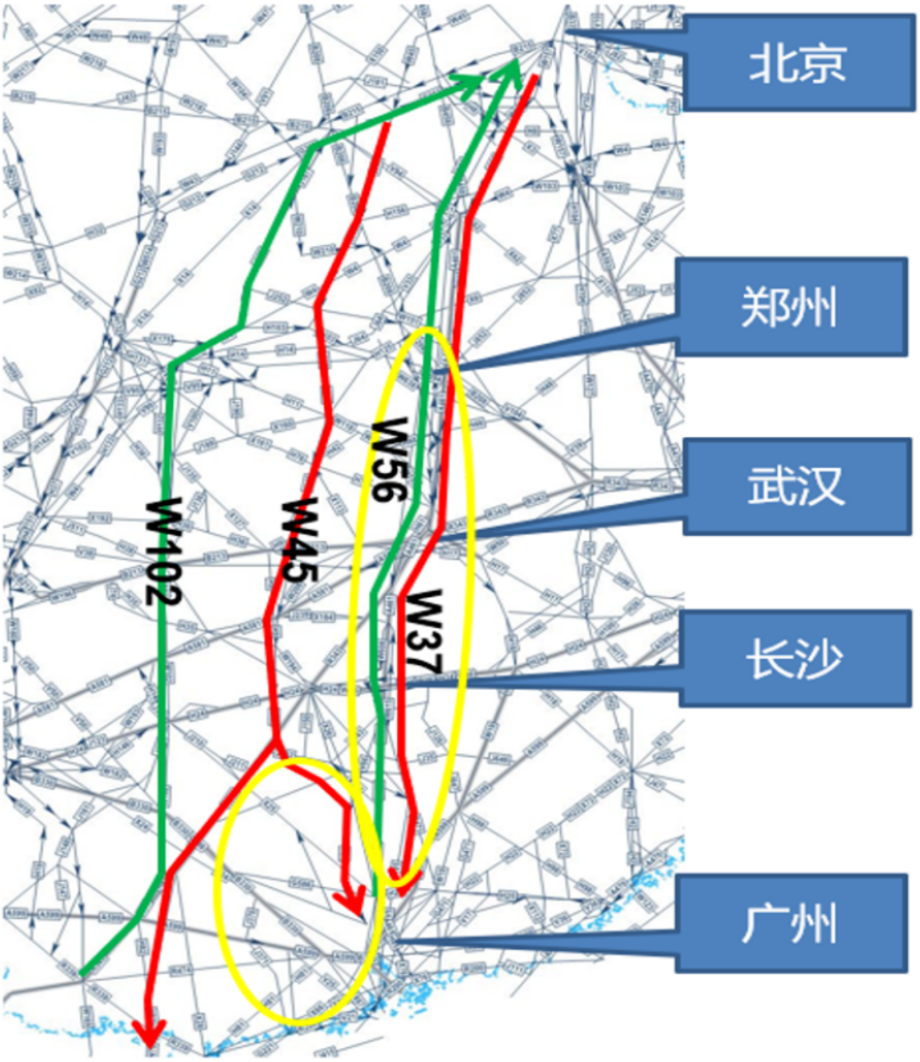

Figure 46: New air route channel ZBAA-ZGGG

After the adjustment, the north-south artery has been transformed from the past “single on single off” two lanes to “double on double off” four lanes. This can enhance the level of operational safety and flight efficiency. In terms of operational safety, the Beijing-Guangzhou A461 route has 6 busy route points with a daily average of about 1,000 flights, and 10 busy flight segments with a daily average of more than 600 flights. The combination of high traffic numbers serving several large hub airports, route organisation and airspace structure results in highly complex operations that causes route congestion problems. After the adjustment, the number of daily route crossings and other deployments will be reduced by about 572 times along the Beijing-Guangzhou corridor.

In terms of energy saving and emission reduction, flights from Beijing to Hong Kong, Shenzhen, Zhuhai and Macao can reduce flight distances by about 125 kilometres each way. This can save about 3.18 million kilometers of distance travelled in one year, which equals to about 17,000 tons of fuel and associated $CO2$ emissions of about 54,000 tons.

In terms of air traffic flow, the implementation of the Beijing-Guangzhou corridor airspace program can reduce the flow management of major congested route points which are along the Beijing-Guangzhou route, up to 67.1% of the pre-implementation. This will significantly reduce the congestion, enhance the Beijing-Tianjin-Hebei region and the Guangdong-Hong Kong-Macao-Great Bay Area between the route capacity effectively. It can simultaneously promote the Beijing-Tianjin-Hebei region, Guangdong-Hong Kong-Macao-Great Bay Area and the economic construction of the region along the route, smooth the domestic circulation, promote domestic and international circulation.

8.2 European Free-Route Airspace

Airspace capacity enhancements are also a primary driver in Europe. Free-route airspace is a specified airspace within which users may freely plan a route between a defined entry point and a defined exit point, with the possibility to route via intermediate (published or unpublished) points, without reference to the ATS route network.

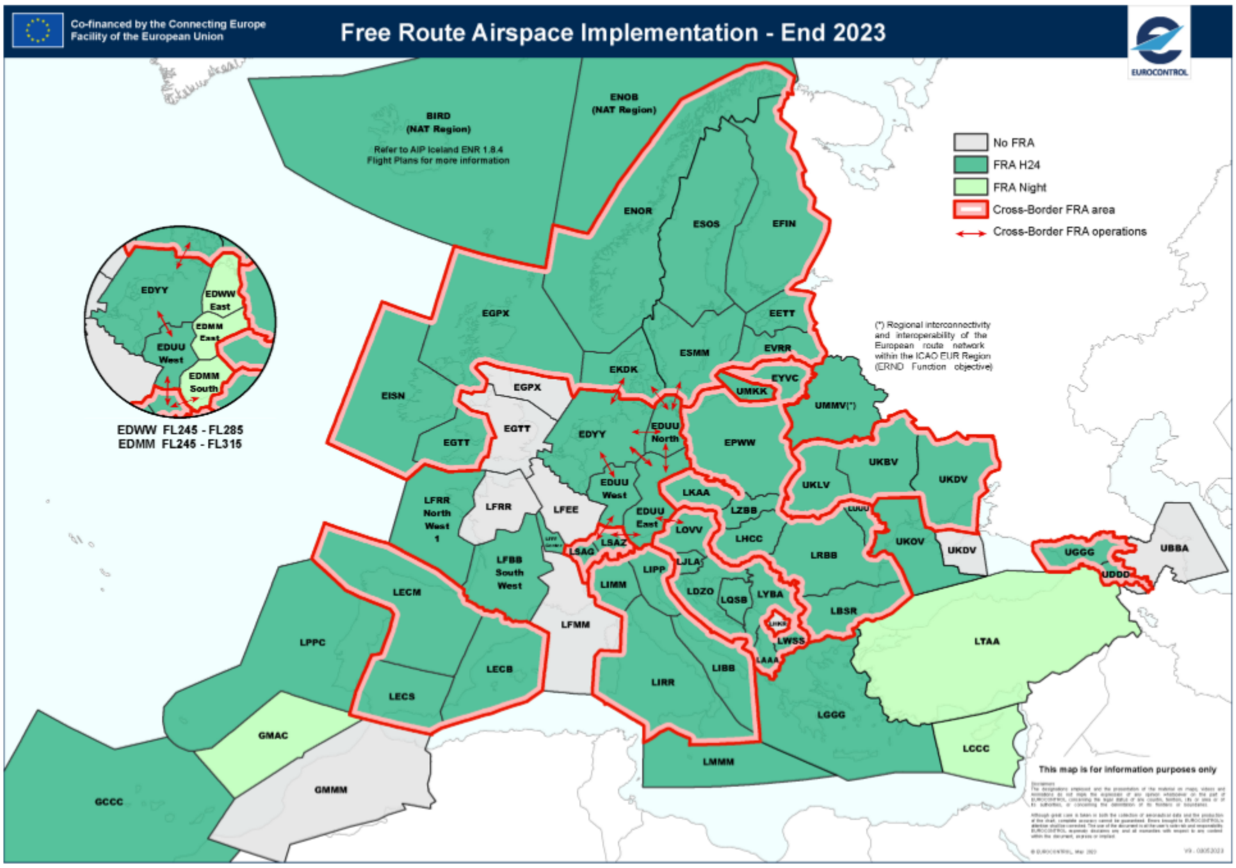

Figure 47: European Free-Route Airspace Implementation Overview

Figure 47 shows the level of free-route implementation in Europe. The move from routes to free route airspace offers significant opportunities to airspace users. Once fully implemented at European level, these improvements should allow the following savings, compared with the current situation:

- reduced routing: 1 billon Nautical Miles
- fuel savings: 6 million tonnes, and associated savings in fuel cost 5 billion EURO
- emission reduction: 20 million CO_2

The implementation of the free-route concept supports increased air traffic predictability and may positively impact traffic complexity as flows are more spread across the airspace in comparison to the concentration on fixed air traffic service routes. The implementation programme is on-going and a full implementation of the free-route concept across all Europe is planned for December 2025.

9 Conclusions

This report represents the second edition of a bi-regional comparison between China and Europe in terms of operational air navigation system performance. It has been jointly developed by CAAC/CAUC/ADCC and PRU on the basis of a harmonised set of comparable data prepared by both groups. The collaboration builds on existing performance measures in both regions and the indicators proposed by the ICAO Global Air Navigation Plan (GANP).

This comparison shows similarities and differences in the observed system performance in both regions. This opens the door for future research and further use-case analyses to study the underlying causes in future editions. Based on the observations from the first edition, this report includes an initial use-case analysis on the impact of weather conditions on the operational performance of some selected airports.

This report focuses on time period January 2019 through December 2022. The year 2019 serves as a pre-pandemic baseline to study air traffic developments and air navigation system performance in both regions. As shown throughout this report, constraints on air transportation were closely linked to the major waves of COVID-19 incidents and the regional responses to address the pandemic. The report supports therefore to also study the influence of the unprecedented constraints on air transportation on operational performance measures during the COVID-19 pandemic and to what extent air traffic and system performance recovered. Future updates of this report will support to understand the different dynamics in both regions as part of a continual performance monitoring. In general, the observed performance in 2022 is still characterised by the on-going recovery from the pandemic. While there are nuanced patterns in the connectivity across Europe overall network traffic reached 80-85% of pre-pandemic levels compared to the traffic in China ranging around 50-55%.

The first part of this report examined commonalities and differences in terms of the organisation of air navigation and factors influencing operational performance, such as air traffic demand and fleet composition. These factors can have a large influence on the observed performance. Overall, the continental airpace of China covers an area of about 84% of the

European area. Air navigation service provision is more fragmented in Europe with a high number of local/national ANSPs and their respective control units. Air traffic in China is serviced by one provider. Both regions share a similar number of air traffic service units (ACCs and APPs) and number of air traffic controllers in operations (~ China: 16.980, Europe: 16.785) The controlled flight hours in China are about a third of the 9.2 mission hours in Europe. Traffic levels in Europe reached 80-85% of pre-pandemic levels while in China the recovery accounted for about 50% compared to 2019 in 2022. The traffic recovery shows distinct patterns in Europe and China.

Among the 12 Chinese airports Beijing Capital (ZBAA) and Shanghai Pudong (ZSPD) "bundle" international air traffic. The other airports recovered after impact to pre-pandemic levels. This pattern is different in Europe with all airports seeing larger variations of the traffic levels and distinct traffic waves in line with the varied approaches to COVID-19 across the different Member States.

Across all European airports the peak day traffic fell significantly in 2020 and 2021 when compared to 2019. In 2022, an increase across all airports is present, however, the observed peek day traffic remain below 2019 levels. In China, ZBAA observed a significant drop in peak day throughput in 2020 and 2021 compared to 2019 levels. However, the initial decline (2020, 2021) is milder than the peak throughput variation observed across Europe. A further decrease of peak day traffic is noted in 2022. On average the share of domestic (or regional) traffic is higher at Chinese airports with Beijing, Shanghai Pudon, and Guangzhou showing a higher share of international traffic pre-pandemic and higher variation throughout 2020 to 2022 with an increasing ratio for domestic traffic. For the European region a reduction of the share of domestic traffic during the pandemic is noted for Frankfurt, Amsterdam, Heathrow and Paris Charles de Gaulle airports.

In terms of taxi-out performance, the European airports show a more prominent reduction of the additional taxi-out time during the pandemic years. With increasing traffic, 2022 saw a general increase of the additional taxi-out times commensurate with the traffic levels. Contrary, the reduction in taxi-out times at Chinese airports is milder and appears to be lesser affected by the overall traffic level.

A newly available data flow allowed for the analysis of the additional time in terminal airspace for a subset of the airports in China. The observed performance showed characteristics pattern. For example, the average additional ASMA time at ZGGG follows the observed wave pattern in terms of traffic demand, while the additional time in terminal airspace ranged fairly constant between 3 to 4 minutes per arrival at ZSHC despite the traffic variations. With the expanding timeline in future editions, it will be interesting to study the driver for these initial trends. In general, the observed performance at the Chinese airports is comparable to European airports that are constraint in terms of high number of (arrival) traffic, airspace, and associated operational procedures. Arrival performance at European airports between 2019 and 2022 is characterised by the lower pressure due to pandemic period with the average additional times in the respective arrival airspaces increasing in 2022.

The punctuality behaviour in both regions differs greatly. Comparing punctuality levels in 2019 vs 2022, performance increased at all Chinese airports by 5-10 percentage points, while Europe observed a significant drop in 2022. While the actual decrease varies widely per airport, the overall punctuality performance reflects the disrupted nature of European traffic in 2022. Local airport constraints were amplified by en route capacity constraints.

Agility of airport operators and service providers to account for the recovering traffic was limited and resulted in unsatisfactory levels of punctuality and turn-around performance.

The approach to delay reporting differs slightly in both regions. Based on the analysis of this report, an initial pattern emerges. The predominant reasons for the share of delayed flights in China can be attributed to weather, airline or other airspace user operations. In Europe, delay reasons can be split over multiple reasons. Accordingly, reactionary delay (i.e. ripple effects from previous flights/connections) and airline causes account for most of the delay observed by delayed flights. Weather impacts exists, however, their share is of lesser magnitude compared to the share of delayed flights in China. In terms of the turn-around and delay absorption, the delay difference indicator, shows varying behaviour in both regions. Part of the variation can be linked to the diverse traffic level changes. However, further research is required to identify the driver behind the observed trends

This iteration of the comparison report provided an initial approach to qualify the impact of the predominant regional weather phenomena on the observed performance. It appears that – while there is a difference in intensity – the frequency of exposure to weather conditions may play a role in how local operations are affected. This offers an entry to expand the analysis in future editions.

This second iteration of the China/Europe comparison of operational ANS performance showed interesting trends in terms of similarities and differences in both regions. With the growing scope and timeline for 2022, a baseline for most of the performance indicators develops that allows to report on the reaction and recovery from the pandemic impact and how increasing air traffic demand is handled and serviced in China and Europe. It will be interesting to study the further developments and identify the drivers behind the observed trends in both regions.

The outlook for the next report is promising as Chinese traffic showed a strong recovery.

This report identified areas for future work and further joint research. Both groups agreed to update this report and establish longer timelines, but also to expand on the set of indicators and initial approaches presented in this report. The lessons learnt and observations will also help to inform other interested parties about the benefits of regional performance benchmarking exercises.

Based on the close collaboration of both groups, a more regular update of the underlying performance related data is envisaged. This may form the basis for a bi-regional or multi-regional online repository

10 Annex 1: Climate Descriptions at Different Airports

A background on the weather for six airports will be provided in this section as a brief climate summary[11]. The goal of the weather impact analysis was to identify and map weather influences for a subset of study airports. For this purpose, two comparable airports in Europe and China were selected, i.e. London Heathrow (EGLL) and Guangzhou (ZGGG). To provide a further departure point for understanding seasonality, airports subject to winter weather conditions in Europe and Chinawith a colder climate were added:

- Heathrow Airport (EGLL, Londen, United Kingdom) and Guangzhou Airport (ZGGG, Guangzhou, China)
- Zürich Airport (LSZH, Zurich, Switzerland) and Hangzhou Airport (ZSHC, Hangzhou, China)
- Helsinki Airport (EFHK, Helsinki, Finland) and Changchun Airport (ZYCC, Changchun, China).

These airport pairs are indicated in Figure 48.

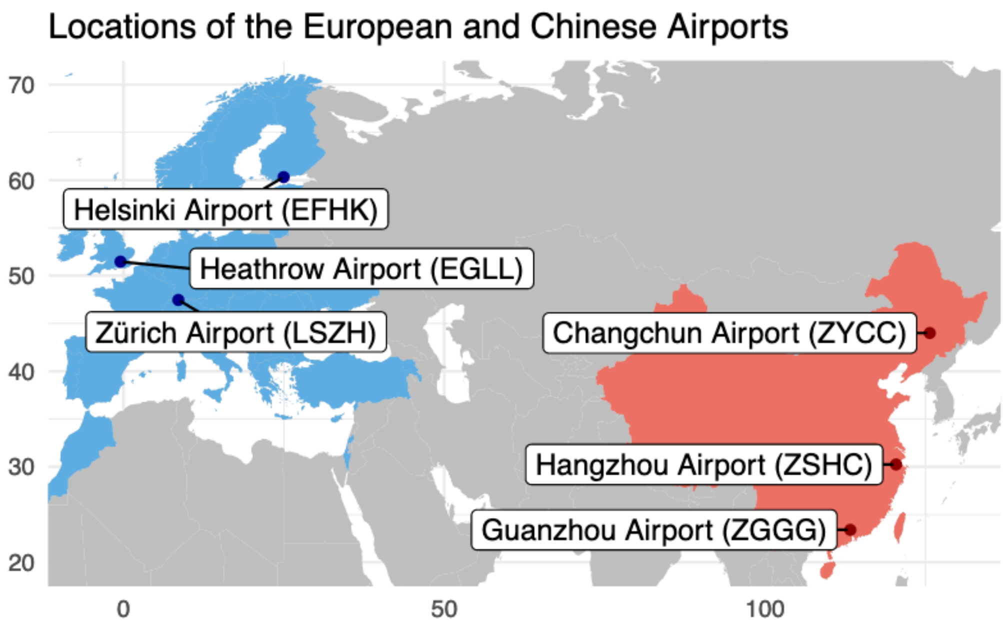

Figure 48: The airports of interest in the weather study.

Heathrow Airport (EGLL, EUR)

Heathrow Airport is located in the south of the United Kingdom of Great Britain and Northern Ireland (UK) near London, the capital of England. Given this location it features a humid temperate oceanic climate. More specifically, according to the Köppen-Geiger

[11]The data is extracted from https://en.climate-data.org/.

climate classification, it is considered to be temperate without a dry season and warm summers.

The region has four distinct seasons and experiences cool winters with an average temperature of 4.8 ° C and warm to hot summers with temperatures averaging around 17.8° C. The precipitation is distributed evenly throughout the year. Occasional extreme weather can occur, more specifically heavy snowfall in winter or thunderstorms in spring and/or summer.

Guangzhou Airport (ZGGG, CHN)

The Guangzhou Airport is situated in the south-east of China and located in the south subtropical monsoon climate zone. In winter there are often low clouds and low visibility conditions present. In late spring until the end of summer there is a high frequency of thunderstorms, strong winds, low-level wind shear, hail and typhoon (tropical cyclones). These are the main causes of reduced efficiency of flights operations. Autumn typically has optimal flight conditions.

The city of Guangzhou is called the "flower city". The annual average temperature is 23.0°C with the hottest month being in July with 30°C. Although January is the coldest month in Guangzhou, the monthly average temperature is still above 13°C.

Zürich Airport (LSZH, EUR)

The airport of Zürich, located North of Switzerland, is located in a climate which is considered to be temperate without a dry season and warm summers according to the Köppen-Geiger climate classification (identical to the Heathrow airport climate).

There are four distinct seasons. In winter, temperatures occasionally drop subzero with an average of 0.9° C in January, while hot summer days temperatures average around 18.8° C in July. Mild to heavy snowfall is expected in winter months and precipitation is most heavily falling in July with an average of 152 mm. In summer heavy thunderstorms can occur.

Hangzhou Airport (ZSHC, CHN)

The Hangzhou Airport is located in the Zhejiang province in the East of China near the East-Chinese Sea. It is located in the subtropical zone and subsequently has a subtropical monsoon climate with four distinctive seasons. In Summer, there are many thunderstorms.

The peak thunderstorm frequency takes place around July/August. It comes with strong winds, which are characterized by short duration, high velocities, and a large operational impact. For is present from October to February every year. In winter, when cold fronts transit Hangzhou, the gust wind speed can be up to 20m/s and above. The temperature ranges from 4.7 °C on average in winter to 29.0 °C in summer (with the hottest month being July).

Helsinki Airport (EFHK)

The Helsinki Airport is located in the south of Finland near the Baltic sea. The climate conditions are considered to be continental without a dry season and warm summers according to the climate classification.

Helsinki has cold winters with an average temperature below zero (around -4.9 °C) and mild to pleasantly warm summers around 18.3° C. There is a significant amount of rainfall throughout the year, especially during the summer months.

Changchun Airport (ZYCC)

The Changchun Airport is located in the northeast of China and lies in a climate transition zone, from a humid eastern mountainous region to a semi-arid western plain. The climate has a continental monsoon climate with four distinct seasons. Spring is dry and windy, summer is damp and hot with much rainfall, autumn is clean and clear and winter is cold and long.

The average annual temperature is 4.6° C, the highest temperature in history has been as high as 40° C and the lowest temperature as low as -36.5° C.

10.0.1 Numerical Weather Comparison

Extreme temperatures, bad visibility, winds or gusts and various forms of precipitation or other weather phenomena might adversely affect air traffic operations and performance.

10.0.1.1 Temperature and Precipitation

During periods with extreme cold or precipitation the traffic performance can be adversely affected. From the available METAR data it is noted that the Chinese study airports tend to exhibit higher temperatures during the summer months. In the winter months it is, however, colder in the European airports (except for the northern Changchun Airport (ZYCC) where extreme winter conditions are present). An overview hereof can be seen in Figure 49.

In addition, it is noticeable that whereas the European airports follow a rather similar temperature profile with minimal differences, the Chinese airports exhibit large differences in temperature profiles. The temperature variation in China is thus more extreme than in Europe.

Figure 50 displays the maximum temperature difference observed within the year (i.e., the temperature of the hottest month minus the temperature of the coldest month). Temperature fluctuations throughout the year are larger in China than in their European counterparts. E.g., the maximum difference between average temperature in the coldest month compared to the hottest is almost 40 degrees in Changchun airport (ZYCC) whereas in Helsinki airport (EFHK) it is only a difference of 20 degrees.

The occurrence of precipitation (liquid or solid) can be observed from the METAR messages. An overview of precipitation frequency can be observed in Figure 51.

As mentioned earlier, the European airports do not have a dry season. It is noticeable that during the winter season there is a slight increase in liquid precipitation. Both Helsinki

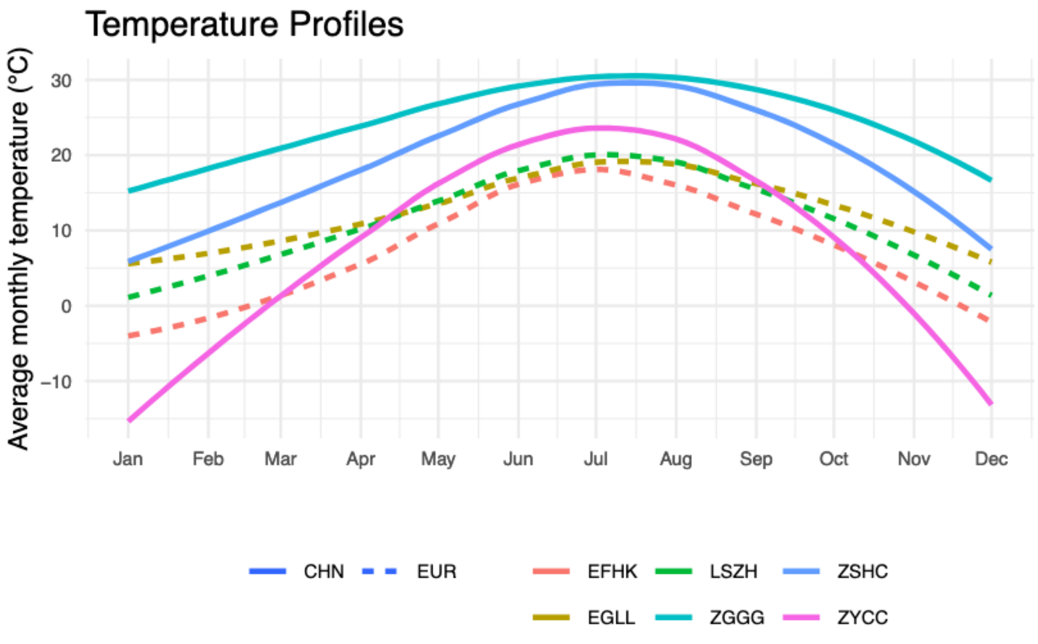

Figure 49: The temperature profiles of the study airports.

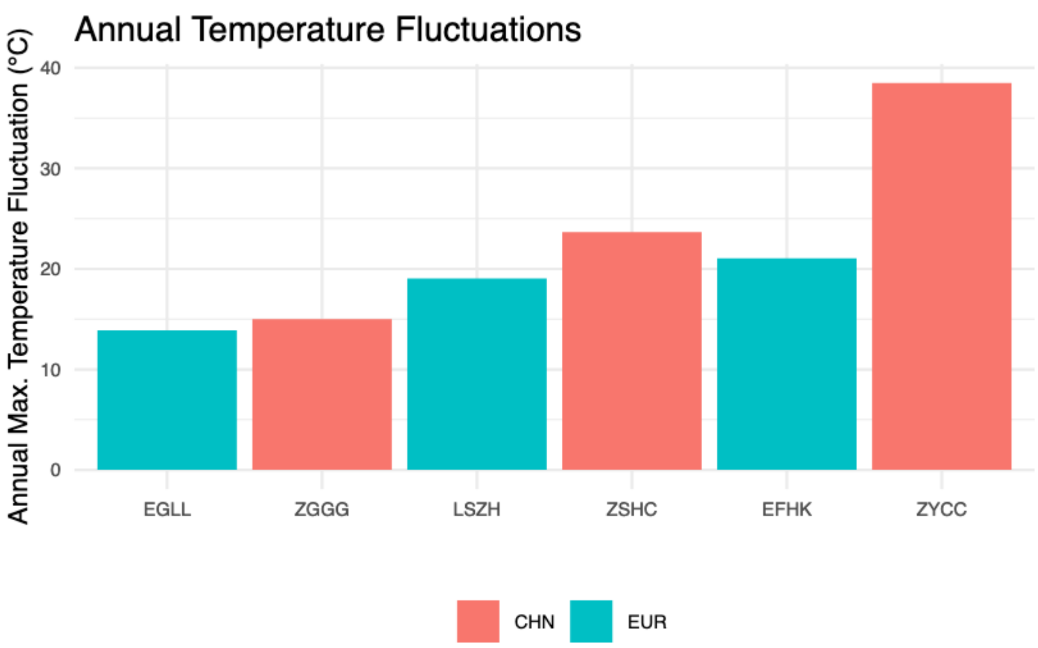

Figure 50: The temperature fluctuations of the study airports.

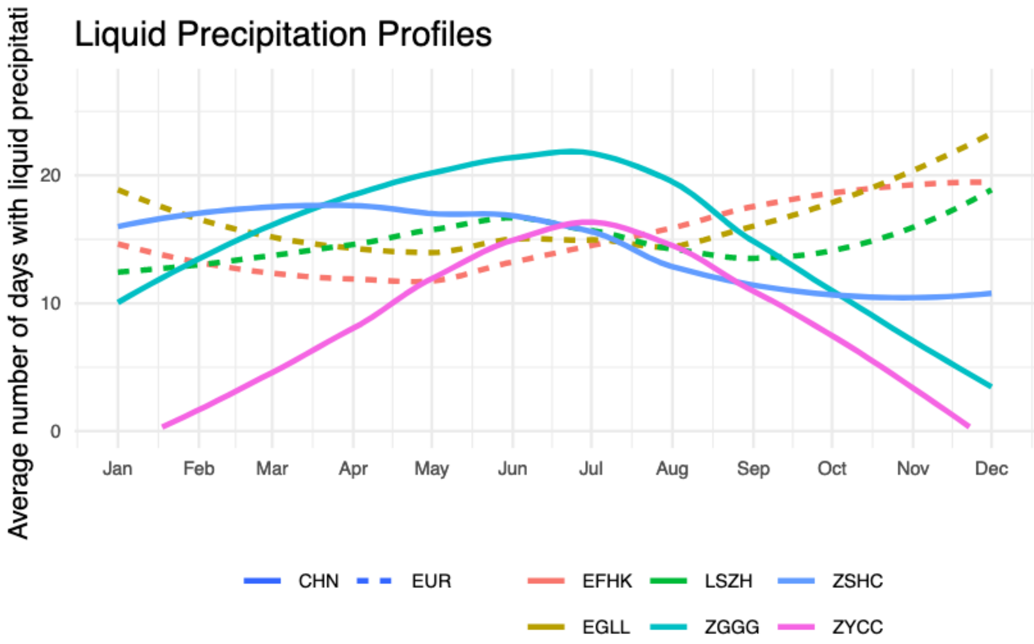

Figure 51: The liquid precipitation fluctuations of the study airports.

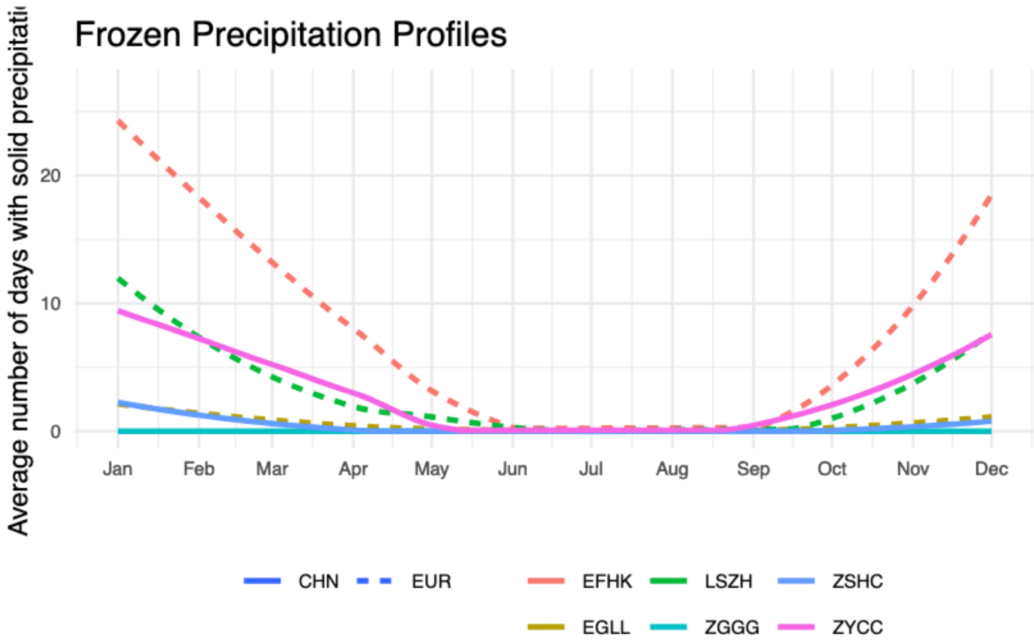

Figure 52: The solid precipitation fluctuations of the study airports.

airport (EFHK) and Zurich airport (LSZH) display a significant number of days with solid or solid precipitation during the winter and little to none during the summer. Heathrow airport (EGLL), likely due to its relatively high temperatures even in winter, does not have much solid precipitation during the winter months.

Guangzhou airport (ZGGG) and Changchun airport (ZYCC) experience a significant increase in days with rain during the monsoon season (between May and September). An example of this monsoon season can be seen in the heatmap in Figure 53. Hangzhou airport (ZSHC) has a more continuous rainfall spread equally over the year. It does not seem to exhibit the same monsoon season. The most northern Changchun airport (ZYCC) experiences significant solid precipitation during the winter months compared to the other Chinese airports.

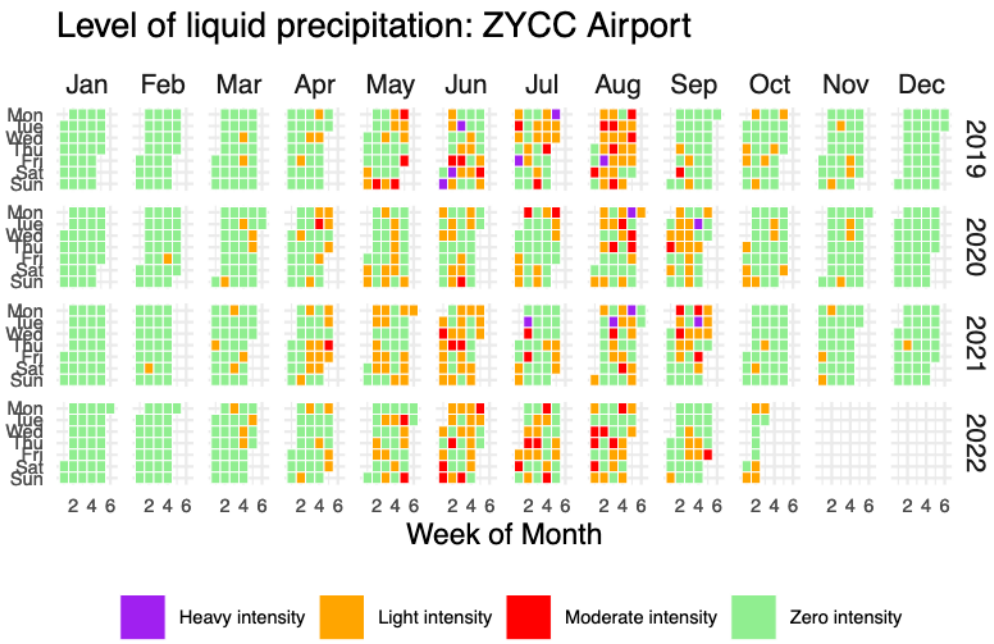

Figure 53: Level of liquid precipitation for ZYCC Airport.

In summer, Changchun airport (ZYCC) is mostly affected by the southwest warm and humid air flow in the northwest of the subtropical anticyclone, with higher temperature, more precipitation, more thunderstorms, and more low clouds. It is interesting that average temperature of Helsinki airport (EFHK) is much higher than average temperature of Changchun airport (ZYCC), but it seems much more solid precipitation formed in EFHK (as seen by comparing Figure 54 and Figure 56).

10.0.1.2 Visibility and Obscuration

One of the weather conditions impacting operational performance in aviation is visibility at airports. Having days with extremely bad visibility might cause delays in various ways. The number of days with reduced visibility (i.e., days where the visibility dropped below

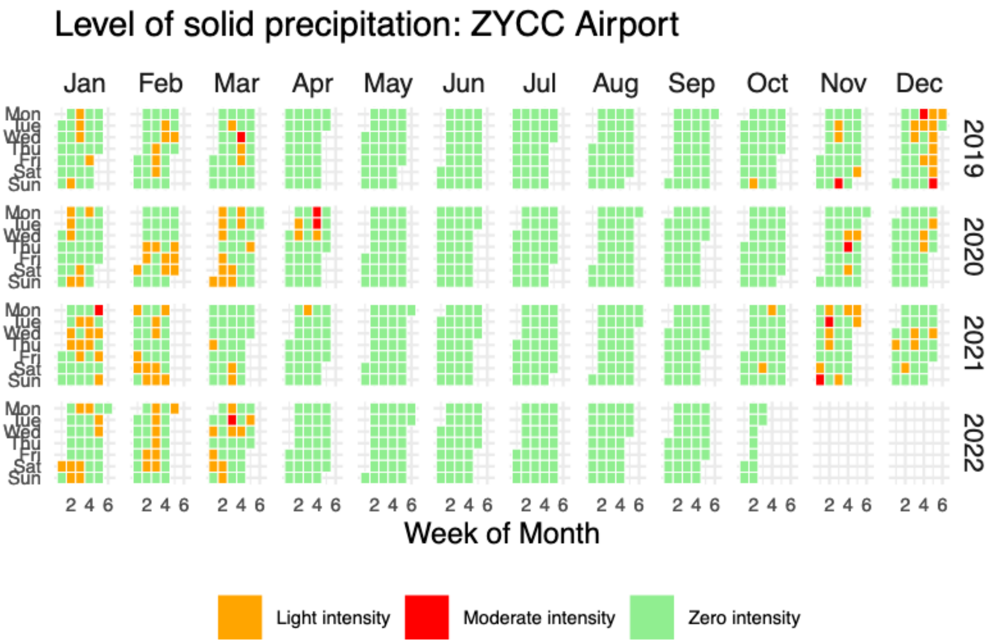

Figure 54: Level of solid precipitation for ZYCC Airport.

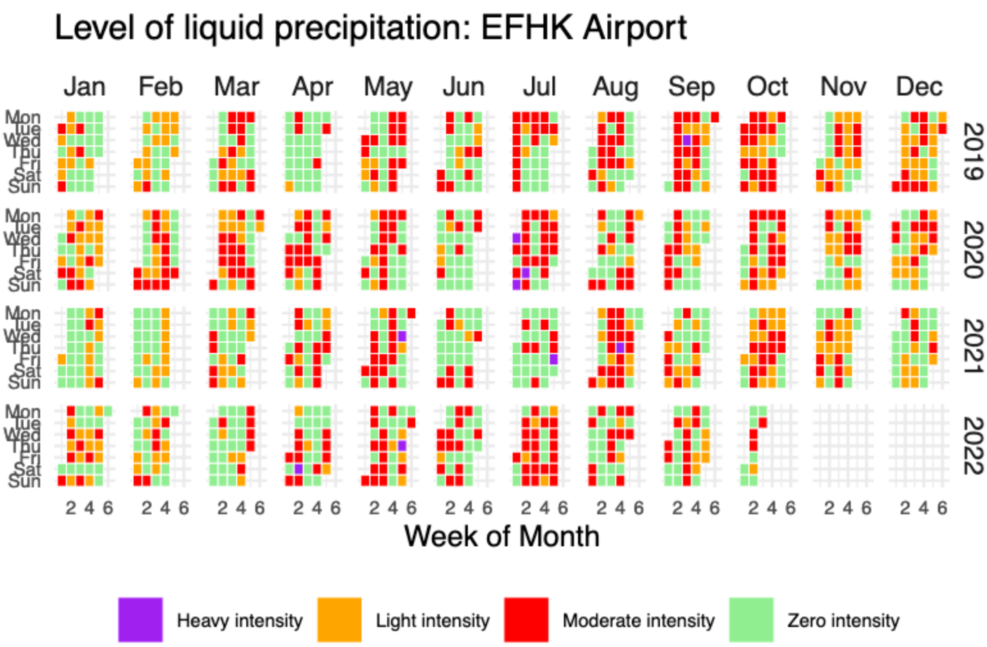

Figure 55: Level of liquid precipitation for EFHK Airport.

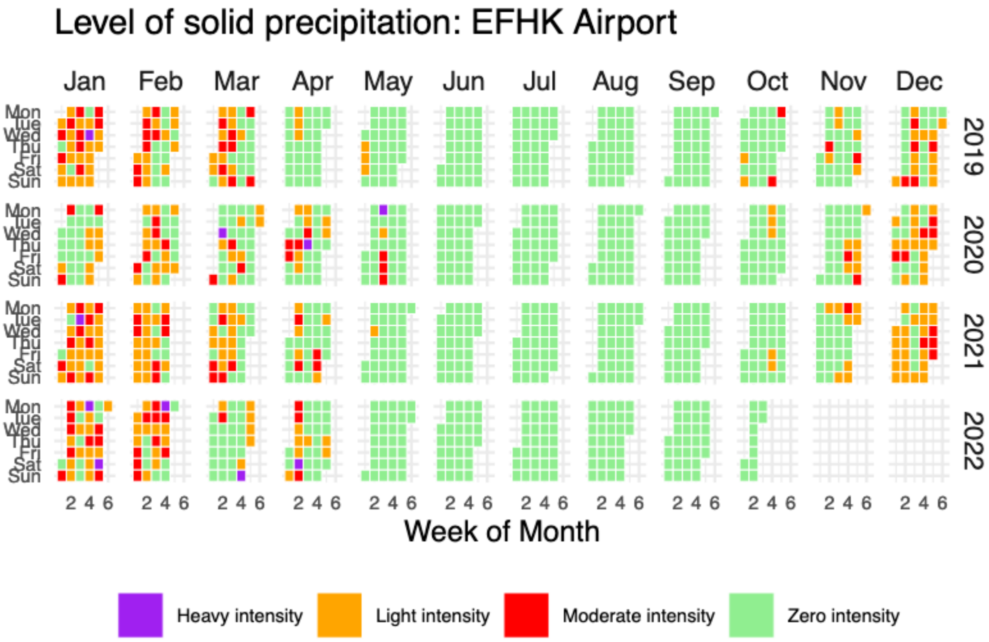

Figure 56: Level of solid precipitation for EFHK Airport.

3 miles or 5.8 km[12]) and obscuration for each airport can be seen in resp. Figure 57 and Figure 58.

Overall, it can be said that the number of days in which a reduced visibility was present tends to be higher in China than in the European region in the summer period. The European airports indicate similar visibility patters whereas the patterns in the Chinese airports are more divergent. The line chart indicates that ZSHC experiences bad visibility more frequently than the other 5 airports in October to June. Hangzhou is nearby Hangzhou bay, from which the wind carries rich water vapor. After a night of cooling this vapor turns into fog.

The obscuration profiles highlight the number of days in which any type of obscuration (fog, mist, haze, volcanic ash, widespread dust, smoke, sand or spray) was observed throughout the day. It is noticeable, for the European airports, that whilst the number of days with obscuration diverge significantly the number of days with reduced visibility profiles remains convergent for the different airports. This highlights that whilst the obscuration events seem to be explaining the reduced visibility in China rather well this does not seem to be the case for the European airports. This could be the case due to varying levels of obscuration (low, mid, high) at the different European airports or due to other events causing bad visibility not captured by the obscuration category (e.g., precipitation).

10.0.1.3 Gusts and Winds

[12]This visibility threshold of 3 miles is based on https://www.experimentalaircraft.info/wx/colors-metar-taf.php. i.e., the threshold from where IFR needs to be enabled.

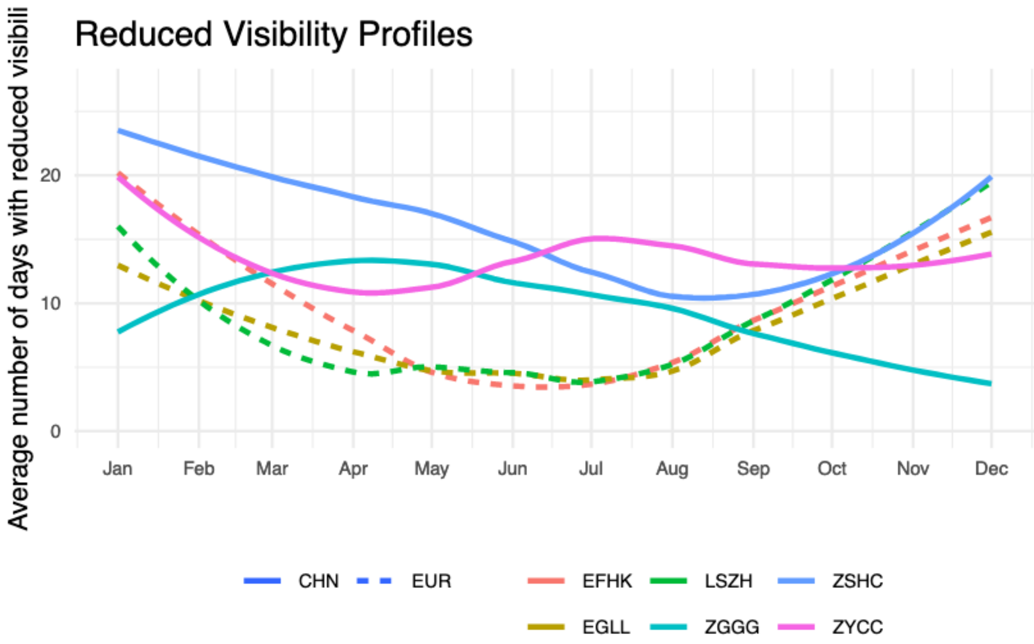

Figure 57: Reduced visibility profiles.

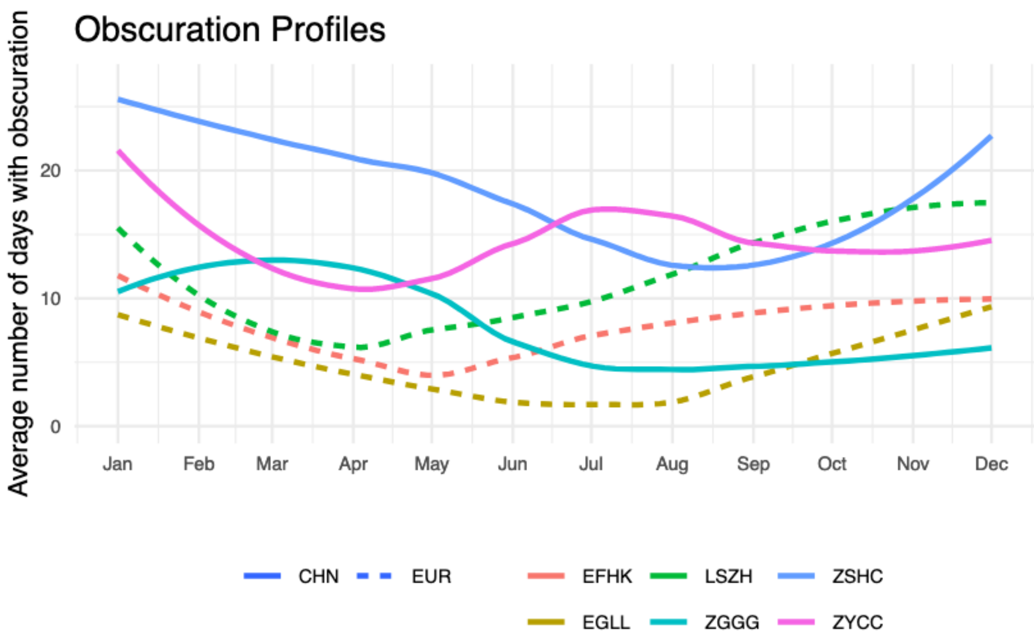

Figure 58: Obscuration profiles.

Gusts and windspeeds are displayed for the study airports in Figure 59, Figure 60, Figure 61 and Figure 62.

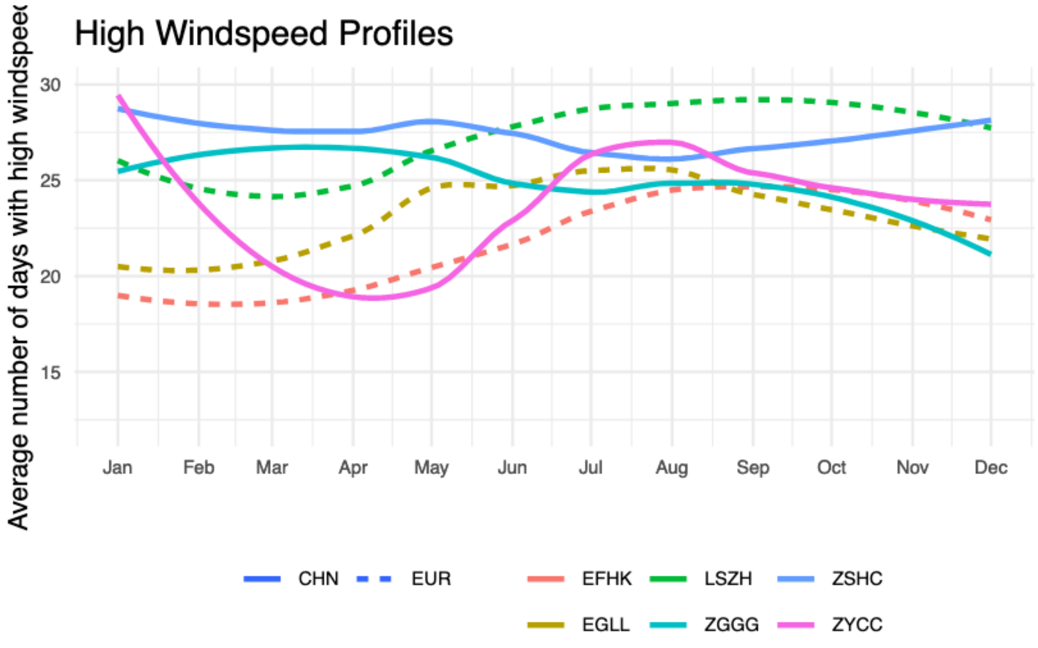

Figure 59: Wind profiles.

10.0.1.4 Thunderstorms

Thunderstorms are capable to disrupt airport traffic. From the graphs below we note that the occurrence of thunderstorms is a summer event both in the European airports and Chinese airports. The most impacted airports due to this weather phenomena are ZGGG, LSZH and ZYCC.

A comparison of the two most impacted airports (ZGGG and LSZH) can be seen in Figure 65 and Figure 66. It's noticeable that the frequency of heavy intensity thunderstorms in the Chinese airport is significantly higher than in the European counterpart.

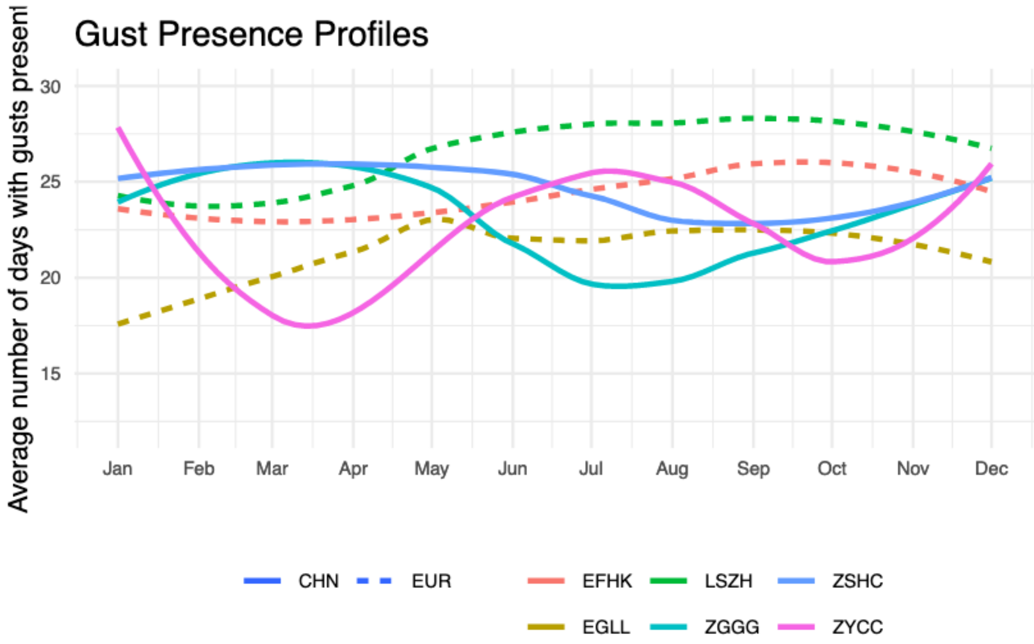

Figure 60: Gust profiles.

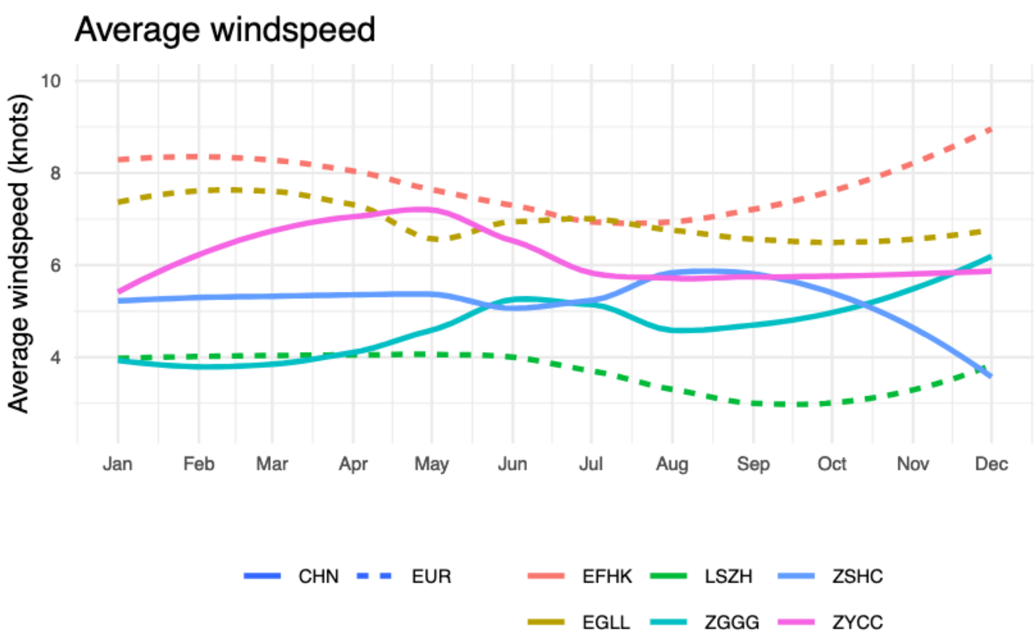

Figure 61: Average windspeed profiles.

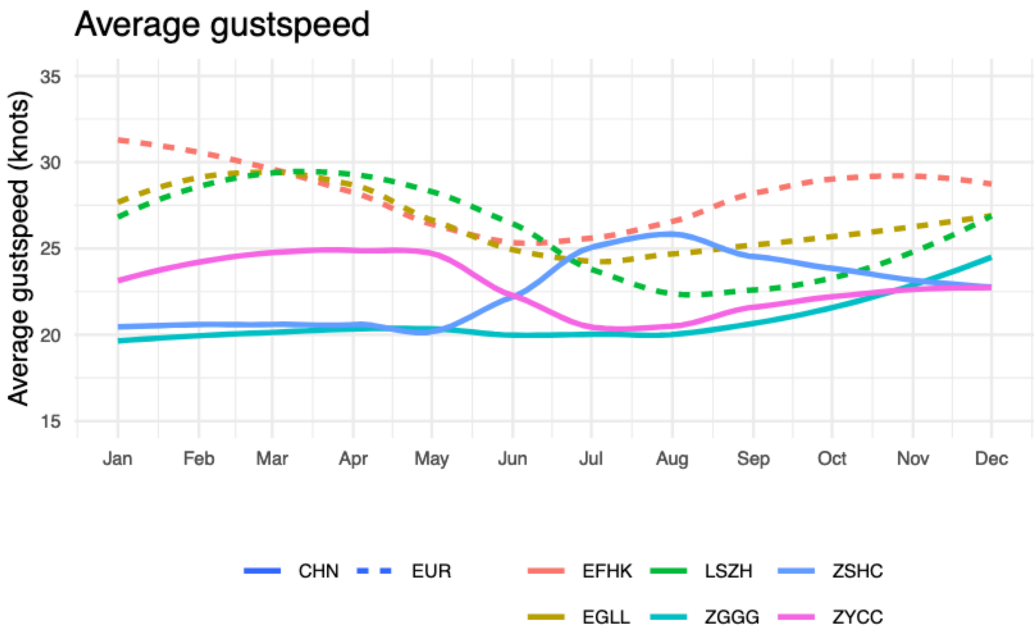

Figure 62: Average gustspeed profiles.

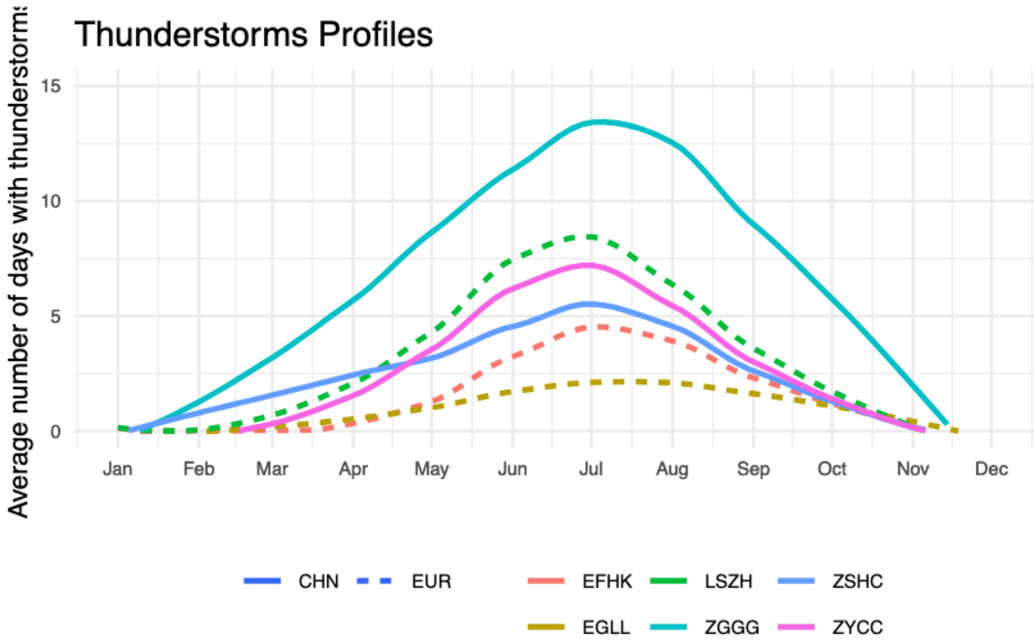

Figure 63: Thunderstorm profiles.

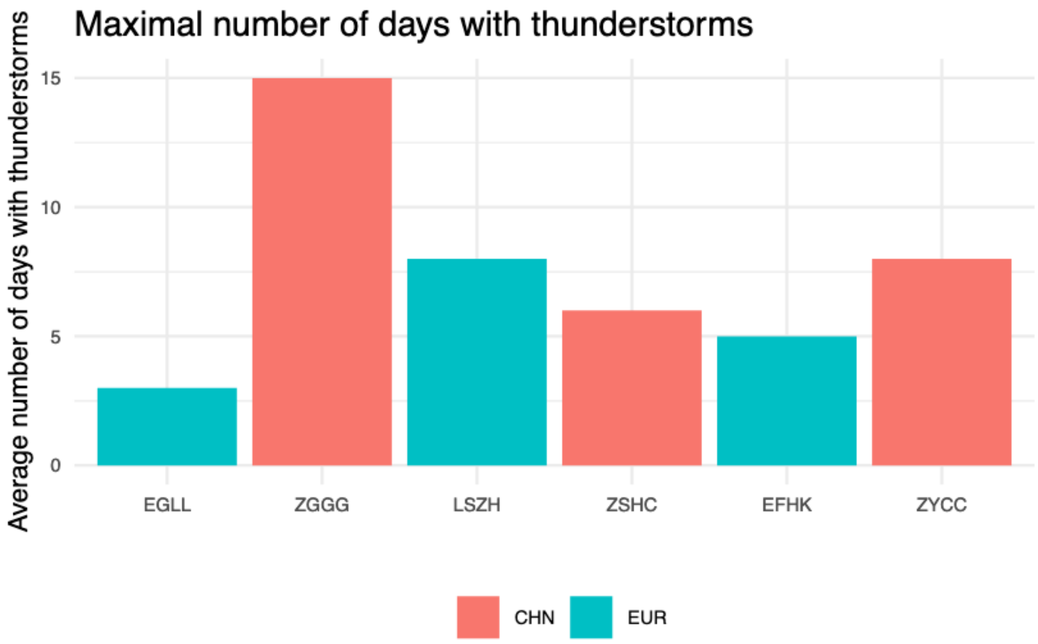

Figure 64: Maximal number of days with thunderstorms for the different airports.

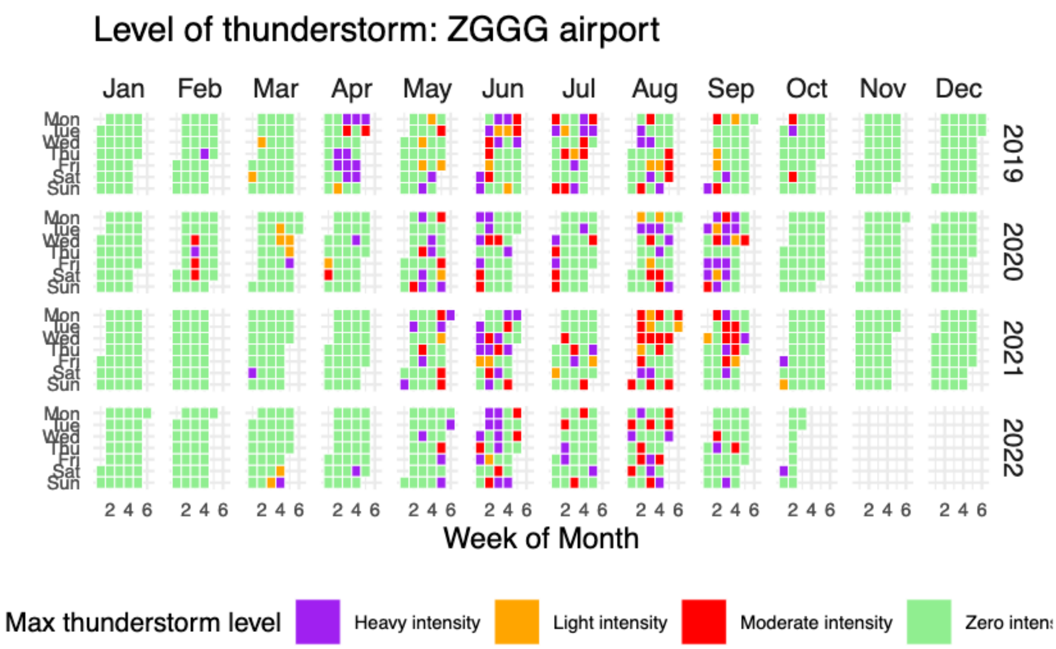

Figure 65: The level of thunderstorms for ZGGG.

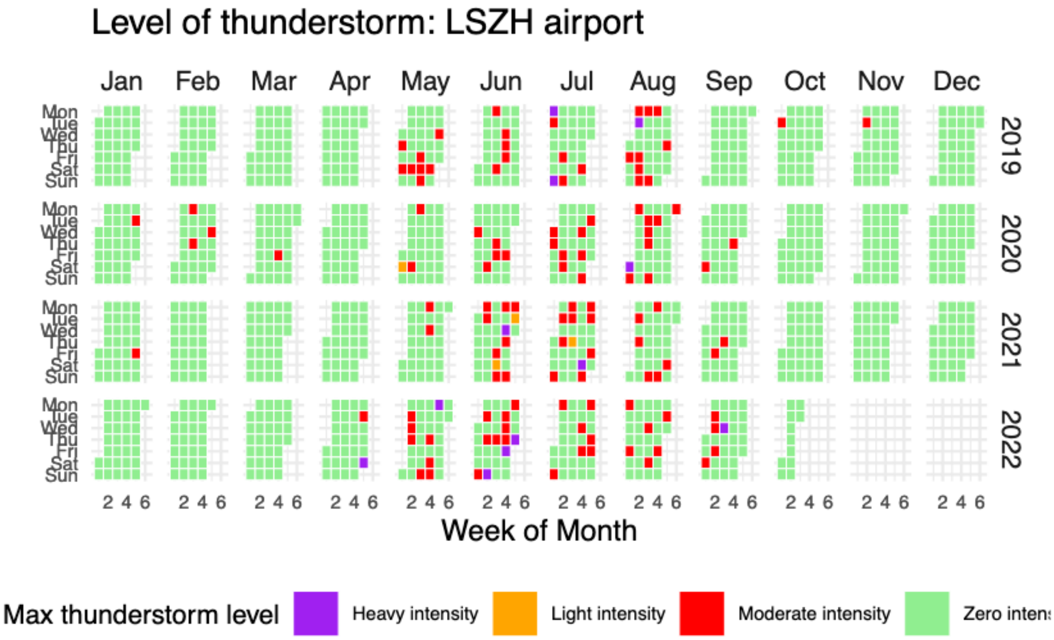

Figure 66: The level of thunderstorms for LSZH.

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