W O R L D M E T E O R O L O G I C A L O R G A N I Z A T I O N

WORLD WEATHER RESEARCH PROGRAMME (WWRP)

STANDING COMMITTEE ON SERVICES FOR AVIATION (SC-AVI)

A subsidiary body of WMO's Commission for Weather, Climate, Water and Related Environmental Services and Applications (SERCOM)

2ND MEETING OF THE AVIATION RESEARCH AND DEVELOPMENT PROJECT – PHASE 2 (AvRDP2) SCIENTIFIC STEERING COMMITTEE

26 - 28 September 2023

Meeting minutes

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1. OPENING OF THE MEETING

Chris Davis and Piers Buchanan, co-chairs of AvRDP2 SSC, greeted participants at the meeting held both in-person at NCAR premises in Boulder, Colorado, USA, and online via Zoom on September 26, 27, and 28, 2023. The list of attendees is provided in Annex 1.

Following self-introductions in a 'tour de table,' the co-chairs opened the meeting, reflecting on the project's progress since its inaugural meeting a year ago. The experts, now deeply engaged, reviewed activities over the two chosen routes. The meeting aimed to assess scientific progress and plan real-time trials in 2024 and 2025 for the designated airport pairs. Refer to the detailed agenda in the provided Agenda document

On the first day, the meeting covered an overview of relevant AvRDP2 activities, 'big picture' items like the 'Early Warnings for All' initiative, and common themes such as Artificial Intelligence and Research-to-Operations. Results of a scientific study by the Hong Kong University of Science and Technology (HKUST) within the AvRDP2 framework were presented. NCAR scientists delivered seven presentations, with subsequent discussions focusing on key points relevant to AvRDP2.

Day 2 concentrated on progress along the selected routes, including the presentation of convection nowcast and forecast prototype products. Participants engaged in detailed discussions on the verification and validation phase, outlining what a verification plan should include.

Day 3 concluded with SSC members agreeing on actions and next steps. They considered similarities and key differences in developments along the two routes, aiming for a consistent approach. Discussions also covered the planning of trials, experiments, and user engagement strategies.

2. PROGRAM UPDATES, BIG PICTURE ITEMS, WORK OF RELEVANCE OUTSIDE AVRDP

2.1 Big picture items include:

2.1.1 The ICAO Hazardous Weather Information Service (HWIS)

In this session's first topic, Stephanie W provided an overview and progress update on the International Civil Aviation Organization (ICAO) Meteorology Panel (METP)'s initiative for a new Hazardous Weather Information Service (HWIS) — a major initiative outside AvRDP2 but relevant to it. HWIS aims to deliver globally consistent, phenomena-based en route hazardous weather information. Users will receive information through a SWIM-compliant provision of observations and forecasts, collaboratively harmonized from designated aeronautical meteorological providers, including regional, local, and global entities. The HWIS will present the best available intelligence on current and predicted meteorological hazards.

The global HWIS will be supported by production automation, quality assurance, harmonization, and appropriate human input and controls. The primary information source for HWIS is the World Area Forecast System (WAFS) data, augmented with information from local, and regional providers, and harmonized for a globally consistent dataset. Hazardous phenomena covered by HWIS include convection, turbulence, and airframe icing. The ICAO working group is currently considering performance and functional requirements for each of these HWIS phenomena.

Stephanie W informed the SSC that the group is actively researching existing 'HWIS-like' products worldwide, aiming to compile a comprehensive list of current and anticipated hazardous weather detection and nowcast capabilities, including multinational or regionally coordinated ones. AvRDP2 is among the initiatives that could demonstrate HWIS concepts. Stephanie W suggested potential areas where AvRDP2 could contribute, such as:

- Translating information along a flight route (e.g., accumulated probabilities along different routes)

- Utilizing probabilistic information (e.g., probability of convective cloud tops > 30 ft) and understanding its implications
- Exploring the use of high-resolution ensemble systems for hazards related to convection, such as CIT.
- Defining expectations for a full suite of seamless convection forecast blending systems.

The meeting was encouraged to consider how AvRDP2 developments could aid in demonstrating HWIS concepts.

2.1.2 The UN 'Early Warnings for All' initiative (EW4All)

Mr. Fred Branski from NOAA/NWS, co-chair of the Expert Team on EW4All of the SERCOM Standing Committee on Disaster Risk Reduction (SC-DRR), provided a brief overview of the 'Early Warnings for All' initiative. He reminded the meeting that the initiative was launched approximately one year ago by the UN Secretary-General in response to the increasing frequency of disasters and their impact on the population. The initiative involves several international organizations, including UNDRR for overall coordination, ITU for information communication and dissemination-related matters, and WMO, which focuses on improving disaster forecasting.

In comparing the ICAO HWIS project with the EW4All initiative, Mr. Branski highlighted that while the latter focuses more on delivering warning information, the ICAO project addresses existing gaps in warning information services and emphasizes data sharing between providers for globally consistent information.

2.1.3 The World Weather Research Program (WWRP) Implementation Plan
Hellen shared the new WWRP implementation plan (2024-2027), emphasizing multidisciplinary research that considers both physical and social sciences. The plan underscores the critical role of weather research in transitioning to operations as the foundation of information. User engagement and awareness of the benefits of severe weather is noted as crucial component for building trust. AvRDP2 is mentioned among the projects included in the new IP2.2 on critical common themes.

2.2.1. Developments around Artificial Intelligence (AI)

The scientific community views emerging AI techniques as promising solutions to address challenges in convection nowcasting and forecasting. Claire illustrated various applications of AI techniques, including radar-based, satellite-based, and NWP-based methods, highlighting their respective advantages and limitations. Notably, these techniques can also enhance the calibration of existing forecast products, as seen in the UK Warn-on-Forecast system where machine learning is employed for severe weather likelihood guidance.

While AI techniques present challenges such as data limitations, representativeness, and explainability (the ability to understand and interpret the decisions or outcomes of an AI model) that require resolution to establish trustworthiness, they also offer significant opportunities. These include expanding machine learning applications for characterization, identifying new causal relationships crucial in convection nowcasting, leveraging existing models, and translating hazards into impacts (e.g., estimating minutes of delay and likelihood of diversion)."

2.2.2. Update on the HKUST study - Convection Induced Turbulence

Xiaoming provided an overview of the Short-Term Prediction of Convection-Induced Turbulence project. He noted that in the past two years, two tasks have been completed, and the research has been documented in two manuscripts. A new method to estimate turbulence intensity from convection-permitting resolution simulations was developed, investigating dynamics causing severe aviation turbulence encountered by Hawaii Airlines. Manuscripts for these studies are either under review or pending submission.

There is an ongoing task by Haoming CHEN aims to extend the research to end users. One task seeks to provide a probabilistic forecast of convectively induced turbulence, potentially applying

EDR estimation and probability weighting methods to the 9-km ECMWF ensemble forecast with calibration. The other research focuses on forecasting turbulence near the airport using machine learning and LiDAR observation. A final ongoing project involves nowcasting satellite images of clouds, combining machine learning and remote sensing for predictions of convection development. Collaboration with HKO is planned to connect predictions with forecasters' experiences and metrics for estimating aviation hazards. Breakthroughs in unfinished tasks are anticipated within one or two quarters, with corresponding manuscripts to be submitted within one year.

2.2.3. Research-to-Operations at NOAA

Piers, on behalf of Fanglin, who was unable to attend the meeting, presented an overview of NOAA's approach to considering and managing the transition from research to operations (R2O). He began by emphasizing the advantages of operational implementation, including increased reliability, potential speed, ease of integration with other services, and enhanced support for a broader range of services. The presentation acknowledged that the R2O transfer might take time and emphasized the importance of considering it well in advance of the target implementation date.

Piers then explained NOAA's existing process for R2O transfers, known as Capabilities and Requirements Decision Support (CaRDS), and detailed the actors involved in this process. The presentation underscored that introducing a new service into operations would necessitate inviting downstream users to evaluate the new products.

2.2.4. Convection diagnosis/forecasting at JMA

The final session showcased innovative products and applications for diagnosing and forecasting significant convection, primarily relying on Himawari satellite imagery and Numerical Weather Prediction (NWP). Michiko demonstrated these tools, presenting the High-resolution Cloud Analysis Information (HCAI) package, which offers cloud height and type datasets at a 0.02° horizontal resolution, updated every 10 minutes. Another product, the Convective Cloud Information (CCI) dataset, designed for aviation users, includes high-resolution products such as Cumulonimbus Area (CBA), Rapidly Developing Cumulus Area (RDCA), and Mid/Low Cloud Unknown Area (MLUA). However, researchers at JMA noted a high false alarm rate in thick cirrus cloud areas during the assessment of these diagnosis capabilities. To address this, they explored ways to enhance CBA detection using deep learning methods, aiming to reduce false alarms in high opaque cloud regions and improve accuracy. The presentation extended to satellite-based nowcasting and forecasting of convection, currently under trial at JMA. RDCA and optical flow are combined with develop/decay algorithms to forecast the movement, development, and decay of Cumulonimbus clouds, providing seamless hazardous weather (convection) diagnosis nowcast and forecast information for a large area, including the HKG-SIN route.

Additionally, JMA operates a radar-based nowcast application, delivering a high-resolution precipitation nowcast for the next 60 minutes. For short-term forecast ranges beyond one hour, an extrapolation of rain gauge-analyzed precipitation fields is calculated, considering the growth and decay of precipitation systems for hourly time steps up to +6 hours. The final step involves blending this extrapolation dataset with NWP forecast data, resulting in Very Short-Range Forecasting of Precipitation (VSRF) information up to +15 hours. JMA has also developed products providing probabilities of Cumulonimbus existence or Cumulonimbus top over certain thresholds, based on Cumulonimbus parameters from the 21-member Meso-scale Ensemble Prediction System (MEPS). These products, utilized over the national airspace in Japan, were introduced as technologies that can assist the project.

3. NCAR RESEARCHERS' PRESENTATIONS

Continuing the review of research work and scientific developments relevant to AvRDP2, we were pleased to have the participation of scientists from the National Center for Atmospheric Research (NCAR) in our meeting. They generously shared insights through seven presentations covering a range of topics, including the detection of convective turbulence, nowcasting and

forecasting, probabilistic forecasting, ensemble prediction of turbulence and convective hazards, and ice crystal detection and forecast:

- Global Convective Diagnostic Oceanic and Cloud Top Height products (CDO/CTH), by Ken Stone
- Global Ensemble Prediction of Convective Hazards (EPOCH) in support of the WAFS, by Ken Stone
- Turbulence forecasting including in-cloud turbulence, by Wiebke Deierling
- Observational estimates of turbulence inside convection and turbulence nowcasts, by Wiebke Deierling
- Probabilistic Forecasts of Upper-Level Aviation Turbulence, by Hailey Shin
- WRF-model simulations of observed cases of widespread convectively induced aviation turbulence, by Stan Trier
- Detection of High Ice Water Content (HIWC) Conditions: Recent Developments by NCAR and the FAA, by Julie Haggerty

Participants expressed their gratitude to the speakers for their insightful presentations. Following the talks, they engaged in discussions to distil key points relevant to AvRDP2 and explored potential benefits the project could derive from these developments and research activities. Of particular interest were discussions on the spread ensemble system outputs for turbulence forecasts and the methods that could be employed to control this spreading. Additionally, participants acknowledged a challenge related to high-density ice crystals, given their infrequent occurrence, leading to a lack of observational datasets for verification and validation of detection or nowcast models. To address this gap, it was suggested that more flight campaigns be conducted in regions of the globe with deep convection where high-density ice crystal areas tend to form.

4. DEVELOPMENTS FOR LHR-JNB

The report on the LHR-JNB route encompassed two case studies conducted by Masters students from Reading University: "Using ensemble weather forecasts to reduce the risk of aircraft encountering convection" by Victoria Vetrees and "Using probabilistic information to reduce the risk of aircraft encountering high-altitude ice crystals" by Yui Wang Ying.

Victoria Vetrees' study focused on three parameters: Convective Available Potential Energy (CAPE), 3-hour precipitation accumulation from convection parameterization, and outgoing Long Wave Radiation (LWR). The study concluded that the method could enhance aviation forecasting, particularly in mitigating convective hazards, but underscored the need for further research.

Yui Wang Ying's study aimed to estimate the probability of High-Altitude Ice Crystals (HAIC) along the LHR-JNB route, evaluate the HAIC nowcast product by the Met Office, and assess the usefulness of probabilistic information for flight planning. The case study's conclusions highlighted that HAIC nowcasts effectively capture HAIC-prone regions at short lead times (3-4 hours), contingent on the initialization time. The nowcasts provide valuable information for flight planning and can be delivered as en-route updates, with the data translated into an integrated probability along different route options.

5. DEVELOPMENTS FOR HKG-SIN

Danice presented a prototype product, a case study developed using Blending Model techniques. The blending involved combining NWP Global and regional products, real-time airline route planning, satellite data, and radar data. Subsequently, the resulting products were shared with the airline for verification purposes. The quantification of impacts was assessed by examining flight time in two distinct categories.

- Flight time within the convective area
- Estimation required deviation.

6. WAY FORWARD, PRIORITIES FOR PILOTS AND DEMONSTRATION, DISCUSSION OF READINESS, WORK PLAN FOR THE NEXT YEAR

Experts examined the products developed and used by the two project routes. A comprehensive analysis of the similarities and differences between the two pairs was conducted, leading to the identification of key tasks and resolutions for the project's future.
From the key discussion points listed below, the meeting derived and agreed upon some actions as follows:

1. Piers will explore the potential use of certain elements of the products and gather information regarding the European side of the trip. Additionally, Piers will share a summary of the UK Testbed activity during the summer.
2. John's presentation centered on the MSc students' work, specifically addressing Probabilistic Cumulonimbus (Cb) forecasts and High-Altitude Ice Crystals (HAIC) nowcasts for the LHR – JNB route. It was suggested that the students' work, especially Victoria's, could find practical application on the London-Johannesburg route.
3. Morne's presentation focused on Nowcasting options, particularly in the context of turbulent products. The meeting participants agreed to further investigate the availability of these products, assess the actual requirements, and explore methods to integrate them into route planning.
4. Stephanie L. presented the verification methodology and Verification plan. It was agreed to conduct a survey consisting of approximately five questions, which will be sent to users in early 2024. Additionally, it was suggested to conduct two rounds of surveys—one before (in 2024) and another after (in 2025).
5. Ensembles (HKG-SIN Route): Emphasis was placed on the need for further development of ensemble-based guidance for the HKG-SIN route, with a specific focus on perturbing optical flow. Ping C to lead a product trial between April and September 2024. Further development of the ensemble-based guidance for the HKG-SIN route is needed.
6. User Engagement (LHR-JNB Route): Engaging users in the testing of prototype products for the LHR-JNB route was agreed upon, with the goal of having this engagement carried out by a specified deadline. Brent offered to help in providing airline contacts.
7. Nowcasting (LHR-JNB Route): Claire B. and/or Morne G. have been tasked with investigating the existing nowcasting products that are available for the LHR-JNB route, both at the regional and sector-wide levels. The objective is to construct a seamless end-to-end prototype nowcast product. The initial scoping of available products will be presented during the November 2023 meeting discussions.
8. Flight Planning (LHR-JNB Route): The development of ensemble NWP products featuring multiple route options was agreed upon; it was suggested to have the first completion by half of 2024. Piers will lead the discussion on ensemble NWP products and coordinate with his colleague Jacob Cheung (Met Office). An update is expected in the November meeting. It was suggested that Piers and Mr Cheung conduct a sensitivity analysis for the optimum routing study, including verification with truth datasets.
9. Parameters (Both Routes): Both routes have a shared task involving the derivation of significant convection data from reflectivity and/or CTH (Cloud Top Height). This data will then be compared to independent data sources such as lightning and CLOUDSAT. Michiko and Danice will spearhead these activities, and it is anticipated that this

comprehensive process may take up to 6 months. An initial update on the progress is expected to be provided during the November 2023 meeting.

7. ANY OTHER BUSINESS

No other business was discussed during the meeting.

8. SUMMARY OF AGREED ACTIONS

AvRDP2-SSC-actions	Who/Due date
• Pair 1 and Pair 2 teams to submit progress reports to co-chairs.	Piers, Claire and Morne – Ping, Danice / November 2023
• Co-chairs to draft the half-term project report and consolidate it with the support of the whole SSC	Piers/Chris and all SSC members / December 2023
• Pair 1 and Pair 2 teams to work on other parameters - explore more on the global verification products such Lightning, CLOUDSAT, MGPB	Piers, Claire, Morne, Ping, Danice and Stephanie L by 15 September 2023
○ Michiko and Danice to provide an initial comparison report in November 2023 and final report in 2024. ○	November 2023
○ Piers and Jacob Cheung to discuss ensemble NWP products	November 2023
○ Morne to provide feedback on available turbulence nowcasting products	November 2023
○ Verification - User engagement: contact with airlines establishedd by end of November 2023; feedback to be provided during the AvRDP2 online meeting.	Stephanie L, Piers and Brent (Before 22 November 2023)
○ Paper - Initial results of the AvRDP2	Chris and Pier by 2024
○ Stephanie W. to develop an Information Paper to be submitted for the upcoming meeting of the ICAO METP working group dealing with HWIS, presenting work progress and outcomes of AvRDP2 SSC-2.	Stephanie W / Mid October 2023

9. NEXT MEETINGS PLANNING AND CLOSURE OF THE MEETING

As the next deliverable of the project is the interim report and has to be finalized by December 2023, it was agreed to hold the next virtual meeting (VTC) of the SSC at the end of November. The agreed date and time are Wed 22 Nov 13UTC.
The next VTCs will be scheduled in March and June 2024. Exact dates and times remain to be confirmed.

Finally, the participants considered the planning of the third (in-person) meeting of the SSC (AvRDP2 SSC-3). It was agreed to further investigate the option of having AvRDP2 SSC-3 back-to-back the WWRP SSC meeting: WWRP SSC week commencing 26 August 2024 and AvRDP2 SSC-3 on 2, 3 and 4 Sept, both at WMO HQ in Geneva, Switzerland (Note: Thursday 5 September is a Public Holiday in Geneva).

After warmly thanking the NCAR for their kind hospitality and all arrangements made for this successful meeting, the SSC co-chairs closed it on Thursday 28 September, at 12h00 (20h00 UTC).

ANNEX 1

LIST OF ATTENDEES

1. SSC MEMBERS

COUNTRY	NAME	E-MAIL	WMO AFFILIATION
HONG KONG, CHINA	SHI, Xiaoming	shixm@ust.hk	WWRP
JAPAN	IKEDA, Michiko	michi-ikeda@met.kishou.go.jp	SC-AVI
SOUTH AFRICA	GIJBEN, Morné	morne.gijben@weathersa.co.za	SC-AVI
UNITED KINGDOM	BUCHANAN, Piers [1]	piers.buchanan@metoffice.gov.uk	SC-AVI
UNITED STATES OF AMERICA	DAVIS, Chris [1]	cdavis@ucar.edu	WWRP

[1] Co-chair of AvRDP2-SSC

2. WMO Secretariat

NAME	POSITION	E-MAIL
WIGNIOLLE, Stéphanie	Scientific Officer, Services for Aviation Division, Services Department	swigniolle@wmo.int
MSEMO, Hellen	Scientific Officer, World Weather Research Division, Science and Innovation Department	hmsemo@wmo.int

3. List of online participants

COUNTRY/ ORGANISATION	NAME	E-MAIL	WMO AFFILIATION
UNITED KINGDOM	METHVEN, John	j.methven@reading.ac.uk	WWRP
HONG KONG, CHINA	CHEUNG, Ping	pcheung@hko.gov.hk	SC-AVI
URUGUAY	DE ELIA, Ramon	rdelia@smn.gob.ar	WWRP
IATA	KING, Brent	kingb@iata.org	AvRDP2 SSC CAG
IFALPA	SIEVERS, Klaus	klaus.sievers@vcockpit.de	AvRDP2 SSC CAG
UNITED STATES OF AMERICA	BRANSKI, Fred [2]	fred.branski@noaa.gov	SERCOM SC-DRR ET-EW4All

[2] Part-time attendance

4. Invitees

NAME	COUNTRY OR ORGANIZARION	E-MAIL

Yin Lam (Danice) Ng	HONG KONG, CHINA	ylng@hko.gov.hk
Claire Bartholomew	UNITED KINGDOM	claire.bartholomew@metoffice.gov.uk
Wiebke Deierling [3]	NCAR	deierlin@ucar.edu
Hailey Shin [3]	NCAR	hshin@ucar.edu
Ken Stone [3]	NCAR	kstone@ucar.edu
Julie Haggerty [3]	NCAR	haggerty@ucar.edu
Stan Trier [3]	NCAR	trier@ucar.edu

[3] Attendance to Day 1 only