Existing/emerging MET capability (MET information provided, Met phenomena)	Phases of flight that will benefit						Support to ATM		Meteorological data information (data source, coverage, resolutions, forecast range, update frequency)	Visualization / data type and format	Verification (scheme, ground truth …)	Current level of capability	Illustration (example, mock-up)
	Strategic planning	Pretactical planning	Tactical planning	Departure	Inflight	Arrival	Post-flight	Benefits to ATM	Support to ATM Concept Component (1)				
Convection and thunderstorms (0-1 hr) for A-HD and TCA-HD			✔	✔	✔	✔		**AO** An early anticipation on expected thunderstorms/convective weather conditions will enable airline and airport operations to minimise the impact of weather on the airport throughput by optimizing flow to the expected capacity throughout the weather event and consequently will enable a better performance. **AOM / DCB** Tailored forecasts of significant convection and thunderstorms for specific holding area and way points of TCA-HD and aerodromes (A-HD) facilitates ATM to better estimate arrival capacity and adjust flight routes to avoid hazardous weather. Adaptive planning used to optimize use of air space, reduce the weather impact and enhance safety. In addition, sharing of such information will improve airport CDM for all stakeholders which will improve efficiency of AOM, reduce the unnecessary fuel burnt due to holding.	AOM, DCB, AO	**Data source :** radar data (reflectivity, maximum reflectivity of a vertical column, height of echo top, vertical integrated liquid water content), lightning and satellite data. **Techniques:** extrapolation techniques, artificial intelligence techniques, expert systems. **Coverage :** Key air traffic control areas and holding areas, typical within 100-200 km from aerodrome. **Spatial resolution** **(a) horizontal :** 500m - 1 km. **(b) vertical :** selected vertical levels (e.g. 3 km of altitude) (Technology of full 3-D multi-layer convection forecasts is yet to be mature). **Temporal resolution :** based on resolution of radar/lightning data (order of several minute interval). **Update frequency :** as soon as radar/lightning data is available (order of 5-10 mintues).	Gridded (include graphical and object oriented approach to highlight location and severity of convection), tabular display with multi-level colour codes to highlight impact on flight path, specific holding area and air traffic control areas. Supplemented by text message as necessary.	To facilitate end user's decision making process, verification can be expressed in terms that are closely related to the user decision processes e.g. time-success diagram that is constructed based on past performance of the system, to provide a "tolerance limit" that defines what can be considered acceptable, and based on these definitions of a "hit", a diagram can be constructed that allows to determine the likely lead time or any desired threshold of success. Verification may be scenario-specific to better differentiate between different weather event types, such as MCS, Cold Frontal passages, airmass convection, etc. **Example methods:** mostly offline objective verification : (1) comparison with ground truth (radar/lightning) data with reference to pre-defined categorized criteria (e.g. intensity, spatial and temporal coverage). The thresholds are chosen that correspond to operating regulations/impact that are directly relevant to the customer (i.e. user-relevant measures) (2) impact-based verification: e.g. identify aircraft routes deviation to discriminate different severity of convection (3) Lead time verification : Lag between onset and forecast (4) Object-oriented Verification : i.e. identify objects in the area of interest, match the objects found in the forecast to the observed. **Performance measures** : M3 (1) diagram of skill scores against forecast lead time. (2) contingency table	Performance and capability are location- and weather-type dependent and also depend on season, climate, verification method (include thresholds and area of concern). This makes it rather difficult to describe one set of current level of capability and compare of forecasts for different stations. Verification of certain convection products could be found in **attachment 1** which provides a rough idea of current level of capability for certain regions.	HK: ATLAS, ATNS, France : ASPOC, Australia: ATSAS
Convection (0-6 hr) for A-HD and TCA-HD			✔	✔	✔	✔		**AO** An early anticipation on expected thunderstorms/convective weather conditions will enable aerodrome operations to minimise the impact of weather on the airport throughput and consequently will enable a better performance. **AOM / DCB** Tailored forecasts of significant convection and thunderstorms for specific holding area and way points of TCA-HD and aerodromes (A-HD) facilitates ATM to better estimate airport capacity and adjust flight routes to avoid hazardous weather. Prior arrangement could be made to optimize use of air space, reduce the weather impact and enhance safety. In addition, sharing of such information will improve airport CDM for all stakeholders which will improve efficiency of AOM, reduce the unnecessary fuel burnt due to holding.	AOM, DCB, AO	**Data source :** numerical weather prediction (NWP) models + nowcasting products, ingestion of radar and satellite data as required. **Techniques:** high resolution NWP models, deterministic or probabilistic approaches, as well as blending with the nowcasting products, ingestion of radar and satellite data, with human-machine interfacing systems as necessary. **Coverage :** typical of about 300-500 km from aerodrome**,** Key air traffic control areas and holding areas. **Spatial resolution :** **(a) horizontal :** 2 km or less. **(b) vertical :** selected vertical levels (e.g. QPF on surface or radar reflectivity on 3 km of altitude from sea-level) (Technology of full multi-layer convection forecasts is yet to be mature). **Temporal resolution of forecast products:** 1 hour. **Update frequency :** 1 - 3 hours.	Same as above. Addition of probabilistic forecast could be provided.	Same as above. Evaluation of probabilistic forecasting systems is possible using measures such as the Relative Operating Characteristics (ROC) diagram or the Brier Score (BS). Additional method (e.g. Radius of Reliability (ROR) concept) can be used to evaluate and verify probabilistic forecasts of high impact weather such as convective forecasts (for terminals, holding areas, corridors)." Event verification" with larger time/scale window should be used to test scenario reliability	see above	Japan : ATMet category forecast; HK: significant convection forecast for ATM France : CDM@CDG products on convection; UKMO : nowcast datafeed to NATS; USA : RAPT, COSPA, min-cut, CCFP, TRACON
Convection (out to several days ahead) for A-HD, TCA-HD			✔	✔	✔	✔		**AO** An early anticipation on expected thunderstorms/convective weather conditions will enable aerodrome operations to minimise the impact of weather on the airport throughput and consequently will enable a better performance. **AOM / DCB** Tailored forecasts of significant convection and thunderstorms for specific holding area and way points of TCA-HD and aerodromes (A-HD) facilitates ATM to better estimate airport capacity and adjust flight routes to avoid hazardous weather. Prior arrangement could be made to optimize use of air space, reduce the weather impact and enhance safety. In addition, sharing of such information will improve airport CDM for all stakeholders which will improve efficiency of AOM, reduce the unnecessary fuel burnt due to holding.	AOM, DCB, AO	**Data source :** regional and global numerical weather prediction (NWP) models. **Techniques:** NWP models, deterministic or probabilistic approaches. **Coverage :** typical of larger area (model coverage). **Spatial resolution** **(a) horizontal:** 10-20 km or better (deterministic), 30-60 km (ensemble prediction system); **(b) vertical :** 500 m to a few km (50 hPa - 100/200 hPa for model products on pressure levels). **Temporal resolution of forecast product:** 1- 3 hours **Update frequency :** every 3-6 hours (regional) and 6-12 hours (global) on par with the regular updating frequency of most NWP models.	Same as above. Addition of probabilistic forecast could be provided.	**Deterministic model output** Categorical (event on/off) or thresholds based verification of precipitation intensity using synoptic and automatic weather station data, or radar-raingauge quantitative precipitation estimate as ground truth; Using point-wise or grid-point verification. **Probabilistics model output** ROC and BS	seea bove	USA : Convective outlook; Australia : Convective outlook
Wind [0-3hr] for A-HD, A-LD, TCA-HD, TCA-LD			✔	✔	✔	✔		**AOM / DCB / AO :** Forecasts of head/tailwind, and crosswind, including gusts, at a high resolution along approach paths and runways will allow to enhance performance and safety in final approach and landing/taking-off phases. An early anticipation of wind direction changes will facilitate ATC/ATM to adjust aerodrome runway configuration and to manage traffic flow consequently.	AOM, DCB, AO	**Data source :** local/regional numerical weather prediction (NWP) models **Techniques:** high resolution NWP models, deterministic or probabilistic approaches. **Coverage :** typical of areas including final approach airspace and aerodrome, ~50NM from aerodrome **Spatial resolution :** **(a) horizontal :** 0,1° or less. **(b) vertical :** NWP model vertical levels, with 50 to 100hPa resolution. Focus on low levels. **Temporal resolution of forecast products:** 1 hour. **Update frequency :** NWP model update frequency (every 6 hours or less)	Gridded. Could be time-series product with multi-level colour codes to highlight impact on approach glide and on runways. Adddition of probabilistic information could be provided.	Verification of wind intensity and direction changes, based on thresholds and/or lead time before a wind event hits points of interest within TCA or aerodrome, using on-board observations (in altitude) and ground observations (at aerodrome)	Provision of head/tail wind, and crosswind, including gusts, at the surface and along approach paths, from NWP models. Could include probabilistic information. Verification using surface observations esp. verification of TAF wind forecast (direction changes)	Japan : ATMet forecast (wind at airports) France : Wind related decision aid product for approach path on CDM@CDG website HK : Time series surface and/or low-level wind forecast for one aerodrome : deterministic and probabilistic forecast of wind (incl. crosswind).

Wind [0-6hr] for A-HD, A-LD	✔ ✔ ✔ ✔	**AO / DCB :** Forecasts of wind at a very high resolution on the aerodrome (several locations on the aerodrome) will allow to better manage ground operations. An early anticipation on stormy conditions and strong winds will enable aerodrome operations to minimise the impact of weather on the airport throughput and will enhance safety in ground operations (e.g. embarking/disembarking). Consequently it will enable a better balancing of demand and capacity.	AO, DCB	**Data source :** local numerical weather prediction (NWP) models **Techniques:** medium to high resolution NWP models, deterministic or probabilistic approaches. **Coverage :** typical of areas including track from TCA entry points to aerodrome of arrival, ~150NM from aerodrome **Spatial resolution :** **(a) horizontal :** 0,1° or less. **(b) vertical :** NWP model vertical levels, with 50 to 100hPa resolution. **Temporal resolution of forecast products:** 1 hour. **Update frequency :** NWP model update frequency (every 6 hours or less)	Gridded. Could be tabular display with multi-level colour codes to highlight impact on locations of interest within aerodrome.	Verification of wind intensity based on thresholds and/or lead time before a wind event hits points of interest within aerodrome, using ground observations (at aerodrome).	Provision of surface wind forecast (intensity and direction), of probability of wind intensity over thresholds, from NWP models. Verification using surface observations ; . Physical and numerical modelling of the aerodrome area (incl. towers, buildings, roads anf highways …) and of surface wind flow over this area.	Japan : ATMet forecast (wind over thresholds at airports) France : surface wind related decision aid product on CDM@CDG (incl. crosswind) UKMO : surface wind datafeed for Heathrow airport
Wind [0-12hr] for TCA-HD (,ER-HD)	✔ ✔ ✔ ✔	**AOM / TS / DCB :** Forecasts of wind at a high resolution within TCA (from entry points to aerodrome) will allow better synchronization and management of air traffic in high density TCA. An early anticipation on strong winds at TCA entry points or in descent phase will allow to adjust flight caracteristics (speed, level) to avoid congestion in approach and final phases. **CDO :** Forecasts of upper air wind (and temperature) will improve efficiency of CDO through minimizing fuel burning and consequently a better performance.	AOM, TS, CDO, DCB	**Data source :** regional numerical weather prediction (NWP) models **Techniques:** medium to high resolution NWP models, deterministic or probabilistic approaches. **Coverage :** typical of areas including track from TCA entry points to aerodrome of arrival, ~150NM from aerodrome **Spatial resolution :** **(a) horizontal :** 0,1° or less. **(b) vertical :** NWP model vertical levels, with 50 to 100hPa resolution. **Temporal resolution of forecast products:** 1 hour. **Update frequency :** NWP model update frequency (every 6 hours or less)	Gridded. Could be tabular display with multi-level colour codes to highlight impact on flight path at TCA entry points, specific waypoints or fixes in TCA, and other areas of interest within TCA. Adddition of probabilistic information could be provided.	Verification of wind intensity, based on thresholds and/or lead time before a wind event hits points of interest within TCA, using mainly actual aircraft observations.	Provision of upper air wind (intensity) forecast gridded or over areas of interest (e.g. waypoints or TCA entry points) ; classical verification of wind forecast is performed by the MET community using metrics such as bias or RMS based on radiosoundings or synoptic observations.	HK: wind forecast for arrival/departure management France : upper wind datafeed to the ANSP (DSNA) (at several waypoints) UKMO : wind datafeed to NATS
In-flight icing diagnosis for A-HD, A-LD, TCA-HD, TCA-LD	✔ ✔ ✔ ✔	**AUO / AO :** Diagnosis of in-flight icing will allow to enhance performance and safety in final approach and landing/taking-off phases.	AUO, AO	**Data source :** local/regional numerical weather prediction (NWP) models, remote sensing data (radar & satellite), surface observations & PIREPs **Techniques:** high resolution NWP models, deterministic approach. **Coverage :** typical areas including TMA and regional areas (e.g. Europe, US CONUS) **Spatial resolution (of underpinning NWP model):** **(a) horizontal :** local 1km ; regional about 10km **(b) vertical :** NWP model vertical levels **Update frequency :** NWP model update frequency (every hour or less)	Graphical based on Gridded data; colour codes to highlight icing intensity. Object oriented approach also available which allows to highlight severity of turbulence (low data volume, could be uplinked)	Verification of icing areas and intensity by using staellite data and PIREPs	Provision of icing categories and icing intensity based on NWP models enhanced by observational data. Verification using satellite observations and pilot reports.	France: SIGMA France & SIGMA TMA Germany (DWD): ADWICE DIA US: CIP
In-flight icing forecast for TCA-HD, TCA-LD, ER-HD, ER-LD	✔ ✔ ✔ ✔ ✔	**AUO / AOM :** Forecast of in-flight icing will allow to enhance performance and safety and optimal flight trajectory planning	AUO, AOM	**Data source :** regional numerical weather prediction (NWP) model **Techniques:** high resolution NWP models, deterministic approach. **Coverage :** typical areas including regional areas (e.g. Europe, US CONUS) **Spatial resolution (of underpinning NWP model):** **(a) horizontal :** about 10km **(b) vertical :** NWP model vertical levels **Time resolution :** 1 hour up to typically T+48 **Update frequency :** NWP model update frequency (every hour)	Graphical based on Gridded data; colour codes to highlight icing intensity.	Verification of icing areas and intensity by using satellite data and PIREPs	Provision of icing categories and icing intensity based on NWP models. Verification using satellite observations and pilot reports.	France: SIGMA France, Europe Germany (DWD): ADWICE PIA US: FIP

In-flight icing forecast for ER-HD, ER-LD	✔ ✔	**AUO / AOM :** Forecast of in-flight icing will allow to enhance performance and safety and optimal flight trajectory planning	AUO, AOM	**Data source :** global numerical weather prediction (NWP) model **Techniques:** NWP models, deterministic & probabilistic approaches. **Coverage :** global **Spatial resolution (of underpinning NWP model):** **(a) horizontal :** about 40km **(b) vertical :** NWP model vertical levels (focus on aviation related levels) **Time resolution :** 3 hours up to typically T+84 **Update frequency :** NWP model update frequency (every 6 hour)	Graphical based on Gridded data; colour codes to highlight icing intensity. Adddition of probabilistic information could be provided.	Verification of icing areas and intensity by using satellite data and PIREPs	Provision of icing categories and icing intensity based on NWP models. Could include probabilistic information. Verification using satellite observations and pilot reports (POD, FAR ..).	France: NWP icing index UKMO: UM icing intensity
Surface icing & Airframe icing forecast for AD-HD, AD-LD	✔ ✔ ✔ ✔ ✔	**AO / AUO :** Forecast of surface & airframe icing will allow preventive treatment of runways and de-icing of airframes. Early icing warnings should represent a safety increase, pollution decrease and financial savings.	AO, AUO	**Data source :** local/regional numerical weather prediction (NWP) models, nowcasting tools, surface observations **Techniques:** nowcasting tools; high resolution NWP models deterministic & probabilistic approaches. **Coverage :** AD **Spatial resolution :** **(a) horizontal :** N.A. / selected locations at AD **(b) vertical :** N.A. **Time resolution :** related to used NWP model; typically used resolutions at current: - hourly up to T+24 - 6-hourly up to T+5days **Update frequency :** NWP model update frequency or surface obs measurement frequency	Graphical or tabulated data Deterministic or probabilistic Use of colour codes to indicate severity	Comparison with observations (pure met observations and pavement parameters measurements)	Provision of MET parameters linked to winter wx (temperature, precipitation) => NWP model output Provision of surface parameters (pavement temperature and rwy condition) => dedicated nowcast model output Provision of probability values	- Nowcast tool: METRo (ENV Canada) - Probability fcst: Schiphol gladheidsvoorspelling (KNMI) - Airframe de-icing service (UK MET Office) - France : CDM@CDG products on onground airframe icing, provision of surface parameters (pavement temperature forecast)
Forecast of winter weather conditions for A-HD, A-LD, TCA-HD	✔ ✔ ✔ ✔ ✔	**AO** An early anticipation of winter weather (snowfall, snow storm, low temperatures...) will enable aerodrome operations to minimise the impact of weather on the airport and consequently will enable a better performance. Anticipated snow removal operations will improve efficiency of AO, and consequently reduce delays in departure and landing, and all ground operations. **AOM / DCB** The improved efficiency of AO and the sharing of winter weather forecast information for all CDM stakeholders will allow to better estimate airport capacity and consequently to improve efficiency of AOM and DCB.	AUO, AOM, AO	**Data source :** local/regional numerical weather prediction (NWP) models, remote sensing data (X-band radar), surface observations & PIREPs **Techniques:** high resolution NWP models, enhanced model microphysics, deterministic approach. **Coverage :** typical areas including TMA **Spatial resolution (of underpinning NWP model):** **(a) horizontal :** local 1km ; regional about 10km **(b) vertical :** NWP model vertical levels **Update frequency :** NWP model update frequency (every hour or less)	Textual and graphical. Tabular display with multi-level colour codes to highlight impact of snow on runways, taxiways …Additional probabilistic information could be provided	Verification with observations at aerodrome. Metrics such as onset/cessation of snow event, or lead time before the snow storm hits the aerodrome could be used.	Provision of warnings, nowcast and forecast products for snowfall or snow storm incl. probabilistic information.	France : CDM@CDG products for snow forecast ; UKMO : provision of MET parameters linked to winter weather ; The Netherlands : probability fcst of snow at Schilphol
Ceiling and Visibility	✔ ✔ ✔ ✔ ✔	**AOM/TS** High resolution forecasts of ceiling and visibility within a TCA (from entry points to aerodrome) will allow better synchronization and management of air traffic in congested airspace. Improved analysis and forecasts of ceiling and visibility will allow smoother metering of inbound aircraft into high-density terminals. **AUO/AO** Forecasts of ceiling and visibility will enable aerodrome operations to minimise the impact of weather on airport throughput and will benefit operational users in planning alternate landing sites and efficient fuel loads. Also, improved gridded ceiling and visibility forecasts will facilitate low-level operations, such as search and rescue and medical evacuation.	AOM, TS, AUO, AO	**Data source :** local/regional numerical weather prediction (NWP) models, nowcasting tools, surface observations **Techniques:** nowcasting tools; high resolution NWP models deterministic & probabilistic approaches. **Coverage :** typical of areas including track from TCA entry points (AOM/TS) to aerodrome of arrival (AUO/AD), −150 NM from aerodrome. **Spatial resolution :** **(a) horizontal : depends on** resolution of model used, e.g., 2.5 km **(b) vertical :** 100 - 1000 m, depending on model **Time resolution :** related to used NWP model; typically used resolutions at current: hourly up to T+24. Experimental models in development with 5-minute refresh and hourly forecasts. **Update frequency :** NWP model update frequency or surface obs measurement frequency	Graphical with separate charts for ceiling, visibility, and possibly flight category Deterministic or probabilistic Use of colour codes to indicate restrictions to visibility and/or height of ceiling	Verification of ceiling/visibility en route using PIREPs. Verification of visibility en route with additional observational networks related to agriculture and highway safety. Verification of ceiling/visibility at aerodromes by comparison with observations.	Provision of ceiling and visibility using - Aerodrome instrumentation (real-time) - Terminal Aerodrome Forecasts to 30 hours - NWP model output (largely experimental)	US: Localised Aviation MOS Program gridded ceiling and visibility (graphic), National Ceiling and Visibility Program, both experimental France: CDM@CDG LVP bulletin = probabilistic forecast of LVP conditions, verification by comparison with actual data (vis, ceiling), scores The Netherlands: probability forecast of LVC conditions at Schilpol
Upper-air turbulence forecast for TCA-HD, TCA-LD, ER-HD, ER-LD	✔ ✔ ✔ ✔ ✔	**AUO / AOM :** Forecast of upper-air turbulence will allow to enhance compliance with trjectory while maintaining safety thus optimizing flight trajectory planning	AUO, AOM	**Data source :** regional numerical weather prediction (NWP) model **Techniques:** high resolution NWP models, indices for turbulence potential, deterministic approach. **Coverage :** typical areas including regional areas (e.g. Europe, US CONUS) **Spatial resolution (of underpinning NWP model):** **(a) horizontal :** about 10km **(b) vertical :** NWP model vertical levels **Time resolution :** 1 hour up to typically T+48 **Update frequency :** NWP model update frequency (every hour)	Graphical based on gridded data; colour codes to highlight turbulence severity. Object oriented approach also available which allows to highlight severity of turbulence (low data volume, could be uplinked)	Verification of turbulence areas and severity by using PIREPs /AMDAR data	Provision of turbulence potentiel or severity forecast based on NWP models (Ellrod indices) Verification using pilot reports.	France: NWP turbulence index WAFS : NWP turbulence potential

Windshear monitoring (remote-sensing) and nowcasting for A-HD, A-LD, TCA-HD, TCA-LD	✔ ✔ ✔ ✔	**AUO / AOM :** Detection and nowcasting of windshear will allow to enhance performance and safety in final approach, landing and departure phases. An early anticipation of windshear events will enable airspace operations management to minimise the impact of weather in the approach area and before departure, and consequently will enable a better performance.	AUO, AOM	**Data source** : remote-sensing (LIDAR) data, TDWR data, vertical wind profiler data, wind sensors data **Techniques:** expert systems based on fuzzy logic, data fusion or combination **Coverage :** departure and final approach paths, ~ 8 km from runway thresholds **Spatial resolution :** 100 m (LIDAR) at most, depending on spatial resolutions of different data sources **Time resolution :** 10 s (wind sensors) at most, depending on the time resolutions of different data sources Update frequency : 1 s at most, depending on the update frequencies and arrival time of different data sources	Textual and graphical alerts and warnings; colours and polygons to highlight affected runway corridors.	Verification with PIREPs, ATIS reports and commercial flight data.	Provision of windshear alerts, warnings and windshear magnitudes for different runway corridors. Verification and performance (POD, FAR).	HK : Windhsear alerting system

Notes :
(1) ATM Concept Components, from Manual for FF-ICE Doc. 9965
Airspace Operations and Management: AOM
Aerodrome Operations : AO
Demand and Capacity Balancing : DCB
Traffic Synchronization : TS
Airspace User Operations : AUO
Continuous Descent Operations : CDO
Service Delivery Management : SDM

(2) A-HD = Aerodrome, High Density traffic.
A-LD = Aerodrome, Low Density traffic.
TCA-HD = Terminal Control Area, High Density traffic.
TCA-LD = Terminal Control Area, Low Density traffic.
ER-HD = En Route, High Density traffic.
ER-LD = En Route, Low Density traffic.