A guide to

DTN Enhanced Flight Hazards Forecasts

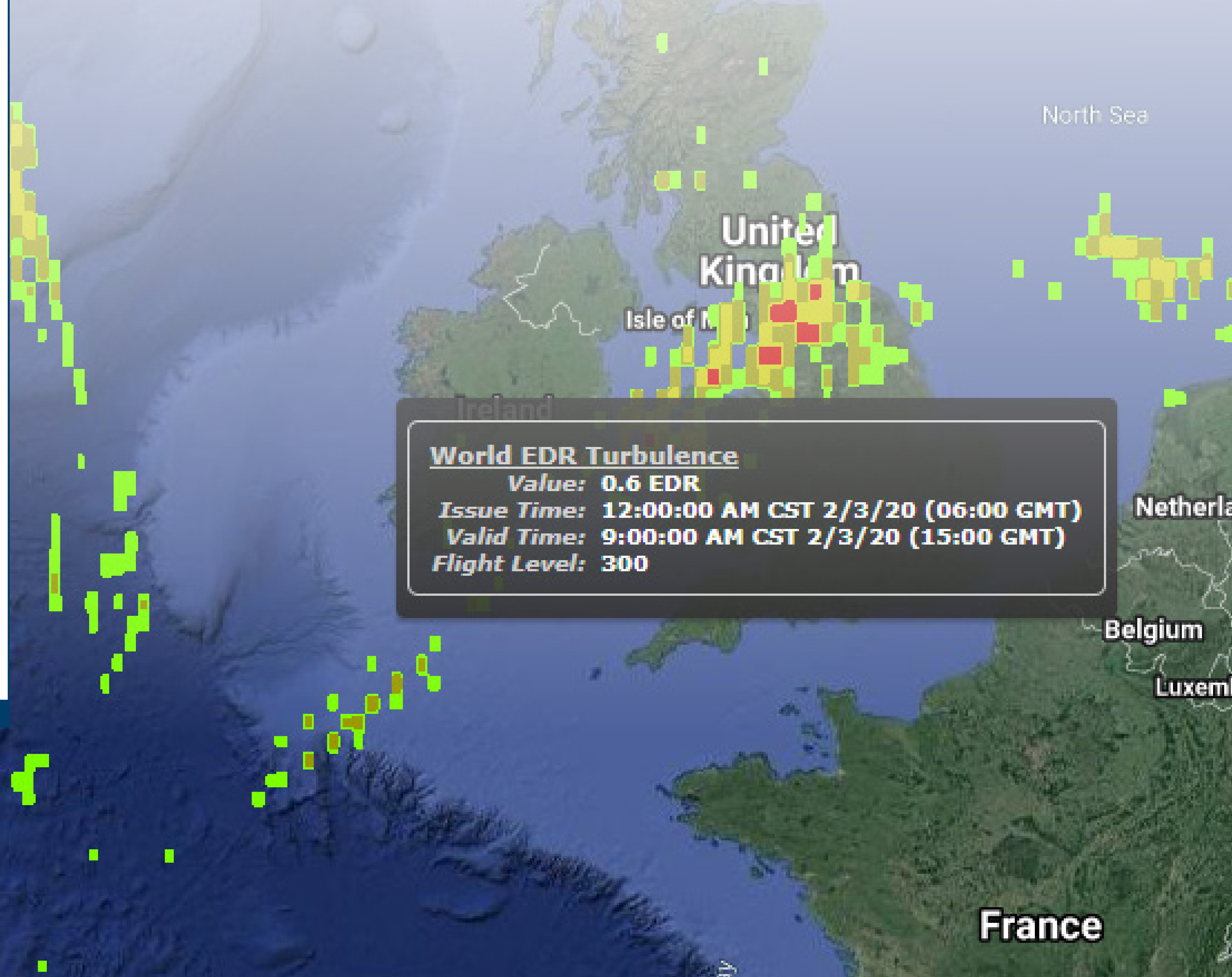
www.dtn.com

CONTENTS

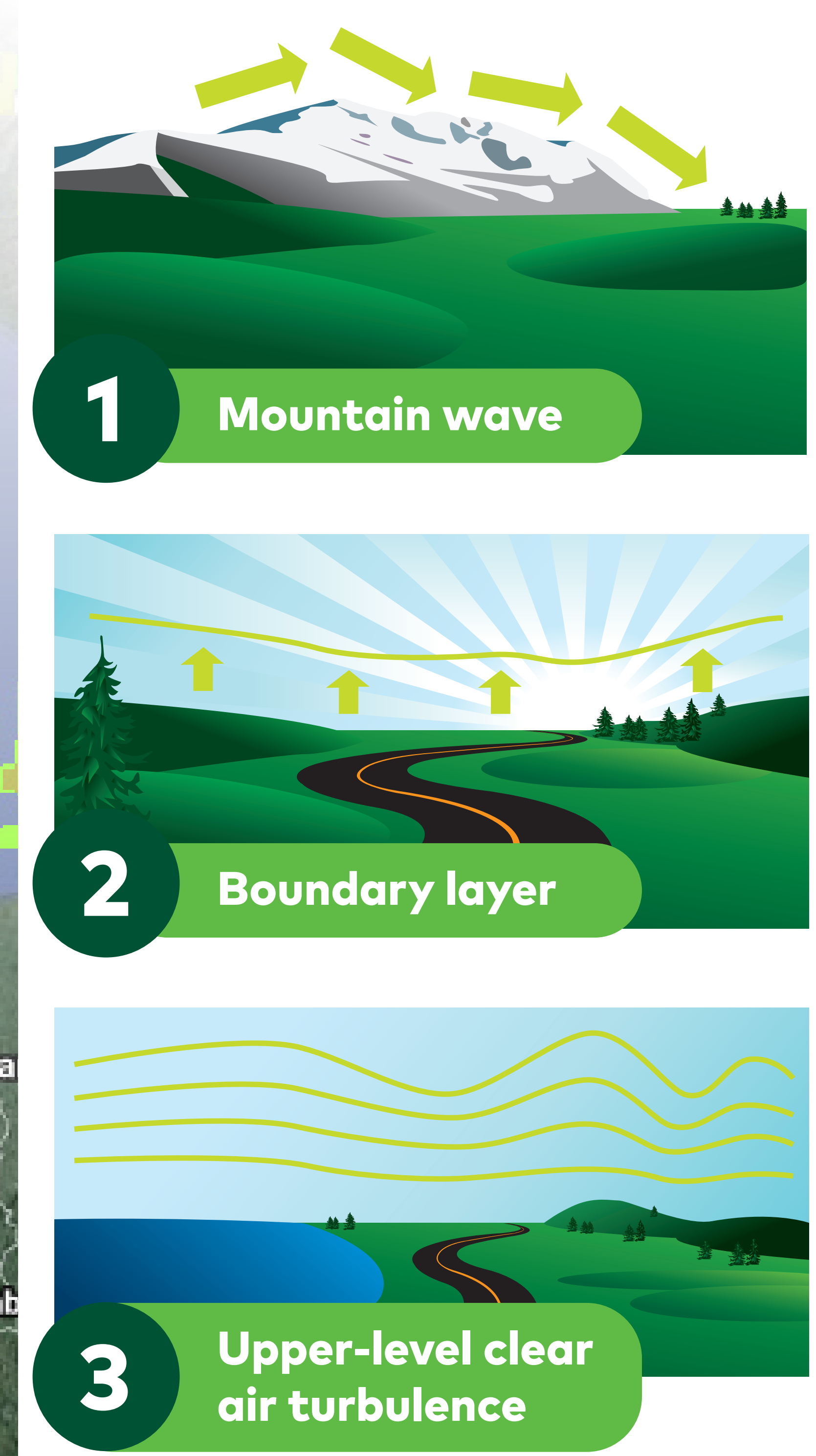
DTN Integrated Turbulence Forecast

The DTN Integrated Turbulence Forecast is a process-driven, physical model derived from numerical weather prediction output. This turbulence potential product covers three primary sources of turbulence: mountain wave, boundary layer, and upper-level clear air.

The diagnostics from all three modules are then integrated and globally resolved in four dimensions to depict maximum aircraft turbulence potential as a deterministic value quantified in units of Eddy Dissipation Rate (EDR), the rate at which turbulent energy dissipates into the atmosphere.

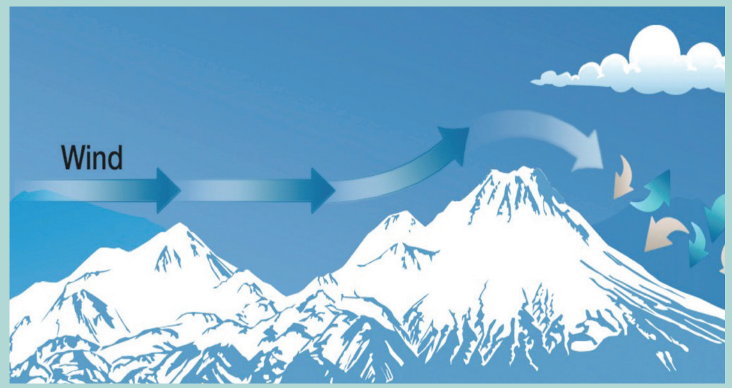


Three Primary Sources of Turbulence



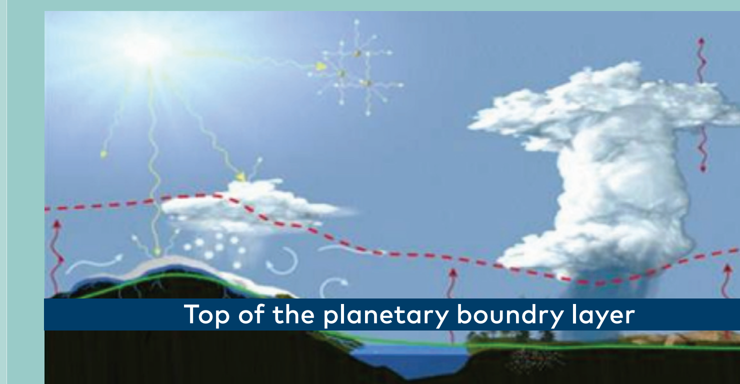
Turbulence Modules

The DTN approach to turbulence potential consists of the following forecast modules:



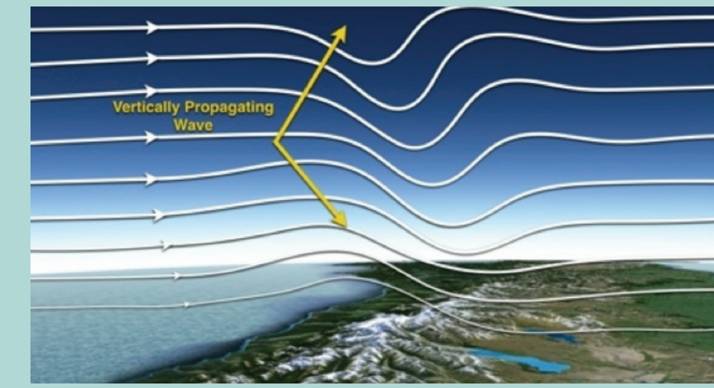
Mountain Wave

Gravity waves induced by airflow over mountains may break when the waves' amplitude is too high. This turbulence is forecast by examining the flow over undulating terrain and computing gravity wave amplitudes in layers aloft. This calculation takes into consideration the attributes of the mountain(s), such as asymmetry and concavity, as well as the wind direction at the mountain top level. Also included are the effects of a hydraulic jump and the reflection/resonance of terrain-induced mountain waves.



Boundary Layer

Near the earth's surface, the atmosphere is often heated enough to lower its stability so that turbulence may be produced by stability and/or wind shear. Turbulence values are calculated from the surface to the top of the boundary layer, defined as where boundary-layer EDR becomes zero.



Upper-level Clear Air Turbulence (CAT)

An unbalanced atmospheric flow also causes gravity waves. Not only can a gravity wave break as in a mountain wave, but it can also reduce atmospheric stability and increase wind shear enough to cause Kelvin-Helmholtz instability. Turbulence is forecast via the Lighthill-Ford theory by finding unbalanced flow zones, then examining how the resulting gravity wave amplitudes will modify the atmospheric stability and wind shear.

The Turbulence Forecast includes the above modules in to a quasi-integrated deterministic solution. The outputs from the CAT and mountain wave module outputs are physically integrated through their respective wave amplitudes where they can enhance each other. Otherwise, the boundary level turbulence module will become the final forecast turbulence value if it is greater than the integrated upper level and mountain wave turbulence value.

DTN Rapid Update Turbulence Forecast

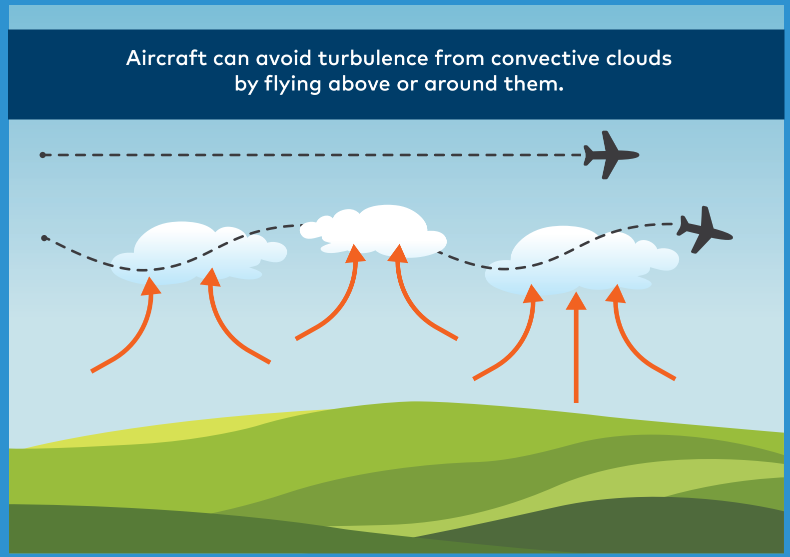
The DTN Rapid Update Turbulence Forecast is a "NOWcast," tactical forecast product that helps users understand the potential for convective turbulence in relation to their assets.

Because convection often forms in situations that are difficult for numerical weather prediction models to resolve and strong convection is easy to observe, the DTN Rapid Update Turbulence Forecast utilizes convection observations instead of model forecasts to identify areas of turbulence potential.

Observation of strong convection is easily detected through real-time lightning information. Lightning forms within storms when the turbulent updraft flow separates precipitation of different charges. Therefore, the stronger the updraft, the more frequent these charge separations occur and the more frequent lightning flashes. Since lightning forms in turbulent updrafts, it is an ideal platform to observe updraft locations.

To initiate the forecast process, DTN leverages a blend of world-class lightning networks to create a global lightning density grid, every 10 minutes at a 0.1-degree latitude/longitude resolution. The DTN algorithm then computes turbulence potential from updrafts, downdrafts, and above overshooting tops.

DTN forecasts this grid of turbulence potential to one hour ahead. Each grid point is moved by two different vectors: (1) the advecting vector, which represents how individual thunderstorm cells will move, and (2) the propagating vector, which represents how the storm body will develop.



Convective Turbulence

The convective turbulence component computes the turbulence related to vertical motions within convective clouds. This component is proportional to the updraft/downdraft strength. Furthermore, two additional thunderstorm features are taken into account in the turbulence computation: gravity waves emitting outward from storm updrafts and the mountain wave-like turbulence associated with overshooting thunderstorm tops.

Eddy Dissipation Rate

To provide a turbulence forecast for a variety of different aircraft, an objective forecast must be provided as every aircraft responds uniquely to turbulence. As an International Civil Aviation Organization (ICAO) standard, EDR is an atmospheric turbulence metric that provides a quantitative measurement of turbulence based on a scale from zero to one.

EDR reflects the rate at which turbulent energy is absorbed by breaking down eddies into smaller and smaller eddies until they are ultimately converted into heat by viscous forces. It is the kinetic energy per unit mass per second, with units of velocity squared per second (m2/s3).

0 → 1

EDR provides a quantitative measurement of turbulence based on a scale from zero to one.

EDR Scale	0.1	0.2	0.3	0.4	0.5	0.6	0.7+
Small Aircraft							
Medium Aircraft							
Large Aircraft							
Turbulence	Light		Moderate		Severe		

How the different levels of EDR relate to qualitative categorical turbulence measurements for different types of aircraft.

Turbulence Modules

DTN provides aircraft-specific EDR tolerances so that end users can better understand how EDR forecasts will adversely affect their aircraft. The DTN Turbulence engine outputs EDR values based on light, moderate, and severe EDR thresholds for a Boeing 737-800. Adjustments to the EDR thresholds for more than 750 other aircraft is based on the formula:

$$EDR_{acft} = EDR_{B738}\left(\frac{A_{B738}}{A_{acft}}\right)^{1/3} \quad \text{where} \quad A = \frac{VS}{M}$$

In A (aircraft), V is the typical cruise velocity, S is the wing surface area, and M is the aircraft maximum take-off mass. In this way, the DTN EDR-based turbulence potential forecast defines the specific aircraft types at risk from the turbulence.

Aircraft Type	Reference	Light	Moderate	Severe
A320	0.3605	0.2	0.4	0.5
A380	0.3595	0.2	0.4	0.5
B737	0.398	0.2	0.4	0.5
B747	0.3243	0.2	0.4	0.5
B757	0.3698	0.1	0.3	0.5
B767	0.3669	0.1	0.3	0.5
B777	0.3601	0.2	0.4	0.5

Sample extraction from the DTN Aircraft EDR turbulence thresholds list.

Numerical Weather Prediction Input

The DTN Turbulence Engine modules are model-agnostic, meaning that any numerical weather prediction model can be utilized as long as the model used has the sufficient parameters describing the atmospheric conditions (stability, wind shear, etc...) and is of suitable vertical resolution to uniquely resolve the key flight levels.

DTN currently utilizes the National Oceanic and Atmospheric Administration (NOAA) Rapid Refresh (RAP) model over the North American domain. For global output, DTN uses the NOAA Global Forecast System (GFS).

Integrated Turbulence Forecast

Model	Domain	Forecast time step	Forecast length	Update frequency	Horizontal resolution
RAP	North America	1 hour	18 hours	Every hour	13km
GFS	Global	1 hour	36 hours	Every 6 hours	13km

Rapid Update Turbulence Forecast

Model	Domain	Forecast time step	Forecast length	Update frequency	Horizontal resolution
RAP	North America	N/A	Rolling 1 hour	10 minutes	13km
GFS	Global	N/A	Rolling 1 hour	10 minutes	13km

DTN

Vertical Resolutions

The output of both the DTN integrated turbulence engine and Rapid Update Turbulence Forecast is 29 flight level-specific forecasts of EDR for both the North American and global domains.

FL010
FL030
FL050
FL080
FL100
FL120
FL140
FL160
FL180
FL200
FL220
FL240
FL260
FL270
FL280
FL300
FL320
FL330
FL340
FL350
FL360
FL370
FL380
FL390
FL400
FL410
FL430
FL450
FL530

DTN Airfoil-specific Icing Forecast

The DTN Icing Forecast Engine is the first of its kind, where aircraft-specific icing is calculated with numerical weather prediction input to an ice accretion model developed by the National Aeronautics and Space Administration (NASA), simulating five minutes of accretion on a specified airfoil.

The Icing Forecast comprises an atmospheric forecast of cloud liquid water in 3D space coupled with an airfoil specific accretion model to create a gridded 3D deterministic forecast of the effect of icing on that specific airfoil over a five-minute window. The unit to quantify this effect is percent power increase (PPI), which is defined as the minimum power increase required to maintain the speed and altitude after a five-minute exposure to the icing conditions.

The forecast output is available per grid cell, per flight level. These forecasts are used for the two primary functions of aviation flight decision support: route planning and in-flight tactical use.

Icing Engine Description

The DTN Icing Engine creates aircraft-specific icing forecasts utilizing expectations of air temperature (T), cloud liquid water (LWC), and droplet size distributions (MVD).

Forecast air temperature is computed by numerical weather forecast models. Some of these models forecast LWCs also, albeit not very well in general. Even fewer forecast MVDs.

The DTN icing algorithms post-process any numerical model to output the expected LWC and MVD. The output parameterizes vertical motions, even convective motions, then uses these in straight-forward cloud physics relationships to create the LWC and MVD parameters.

The engine then integrates the three parameters, T, LWC, and MVD, into the NASA LEWICE (LEWis ICE accretion) software to begin simulations of how the water droplets grow ice on aircraft while in flight.

LEWICE predicts ice shapes very well and has been extensively validated in conditions defined by the Federal Aviation Administration (FAA) Regulation Title 14, Chapter 1, Part 25, Appendix C. In fact, LEWICE software is the primary software that airplane manufacturers use to test their airplane designs for certification of their aircraft to meet those regulations.

Once the ice accretion is forecast, the quantitative aircraft performance loss metric PPI is computed by aircraft type to determine the power necessary to maintain speed and altitude after five minutes of ice exposure.

DTN

Percent Power Increase (PPI)

PPI is a quantitative icing metric described as follows:

In level flight, weight balances lift

$$\text{Weight} = \text{Lift} = C_L A \frac{pV^2}{2}$$

If $C_{L:iced} < C_{L:clean}$, then airspeed must increase to maintain altitude.

To increase speed, additional thrust is needed.

At constant speed, thrust balances drag

$$\text{Thrust} = \text{Drag} = C_D A \frac{pV^2}{2}$$

If $C_{D:iced} > C_{D:clean}$, then to maintain airspeed, thrust must increase to maintain altitude.

Percent Power

Forecast Thresholds

Because the PPI values are a measure of how quickly the aircraft performance deteriorates, they can be related to the following subjective icing intensity definitions:

- **Less than 10 percent PPI (light)** — the rate of accumulation may create a problem if the flight is prolonged in this environment (over one hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation.
- **Greater than 10 percent PPI (moderate)** — the rate of accumulation is sufficient that even short encounters become potentially hazardous and the use of deicing/anti-icing equipment or diversion is necessary.
- **Greater than 60 percent PPI (severe)** — the rate of accumulation is so great the deicing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

The forecast intensity output is based on a lookup table for small, medium, and large aircraft sizes.

Numerical Weather Prediction Input

The input used in icing processing is a single numerical atmospheric model. The icing algorithm is model-agnostic as long as the model used has sufficient parameters describing the atmospheric conditions (stability, wind shear, moisture, etc.) and is of suitable vertical resolution to uniquely resolve the key flight levels relevant for icing.

DTN currently utilizes the NOAA RAP model over the North American domain. For global output, DTN utilizes the NOAA GFS.

Model	Domain	Forecast time step	Forecast length	Update frequency	Horizontal resolution
RAP	North America	1 hour	18 hours	Every hour	13km
GFS	Global 80N-80S	1 hour	36 hours	Every 6 hours	13km

Vertical Resolution

The output of the DTN Icing Forecast Engine is six flight-level-specific forecasts of icing intensity for both the North American and global domains:

- FL010
- FL030
- FL050
- FL080
- FL100
- FL140
- FL180
- FL240
- FL270

High Ice Water Content (HIWC)

HIWC can be ingested into aircraft engines as small ice crystals. When ice crystals hit warm aircraft engines, they start to melt and evaporate, cooling the engine core surfaces to temperatures below freezing. The cooling engine causes the melted ice crystal water to refreeze, and ice accumulates inside the engine core. Ice in this location may cause temporary power loss or engine blade damage.

DTN computes ice crystal forecasts as a component of its lower altitude icing forecasts. One of the unique aspects of the DTN icing forecasts is the ability to forecast both liquid and ice water content in convective storms. Since dangerous HIWC occurs near convective storm cores, DTN HIWC forecasts are created by simply extending upward these lower altitude forecasts.

Ice crystal encounters are difficult to avoid because of their poor radar reflectivity characteristics. To assist operators utilizing engines impacted by HIWC, DTN has developed a forecast that highlights areas of potential engine icing.

Forecast Thresholds

DTN HIWC forecasts are output in the following subjective icing intensity definitions:

- 1 g/m3 (Light)
- 2 g/m3 (Moderate)
- 3 g/m3 (Severe)

Numerical Weather Prediction Input

The input used in the ice crystal forecast processing is a single numerical atmospheric model. The icing algorithm is model-agnostic, as long as the model used has the sufficient parameters describing the atmospheric conditions (stability, wind shear, moisture, etc.), and is of suitable vertical resolution to uniquely resolve the key flight levels relevant for icing.

DTN currently utilizes the NOAA RAP model over the North American domain. For global output, DTN utilizes the NOAA GFS.

Model	Domain	Forecast time step	Forecast length	Update frequency	Horizontal resolution
RAP	North America	1 hour	18 hours	Every hour	13km
GFS	Global 80N-80S	1 hour	36 hours	Every 6 hours	13km

Vertical Resolution

The output of the DTN Icing Forecast Engine is six flight-level-specific forecasts of icing intensity for both the North American and global domains:

- FL010
- FL030
- FL050
- FL080
- FL100
- FL140
- FL180
- FL240
- FL270

DTN Global Thunderstorm Forecast

Thunderstorms create some of the most intense turbulence and icing known to aviators. Avoidance is the best strategy, and good thunderstorm forecasts help aircraft avoid or minimize the storm hazards.

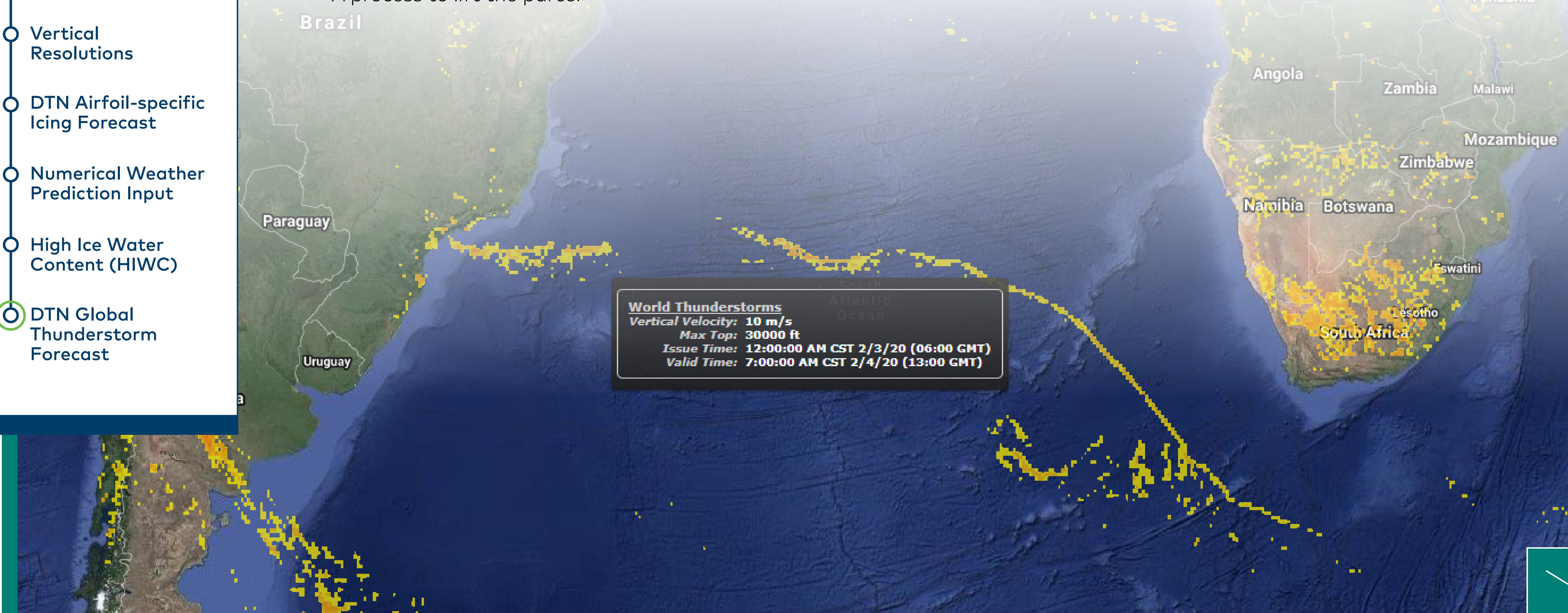
An ingredients-based forecast method for thunderstorms is standard in the meteorological community. The ingredients are:

- An unstable environment
- Sufficient heat and moisture
- A process to lift the parcel

Forecast challenges in predicting thunderstorms include discerning how much of each ingredient is present in a given environment and if there is enough of each ingredient to produce a thunderstorm.

The DTN Global Thunderstorm Forecast examines numerical weather prediction data to find the buoyancy in the column and the overall strength of the updraft to be able to calculate the maximum top of the thunderstorm and associated vertical velocity.

Having an understanding of the vertical velocity in a given environment allows the user to understand the potential intensity of the storm and the associated flight hazard risks.



Forecast Thresholds

Vertical velocity can be related to the following subjective thunderstorm intensity definitions:

vertical velocity less than **20m/s**	vertical velocity **20-30m/s**	vertical velocity **30-40m/s**	vertical velocity greater than **40m/s**
Weak thunderstorm	**Moderate thunderstorm**	**Strong thunderstorm**	**Severe thunderstorm**

Numerical Weather Prediction Input

The DTN Global Thunderstorm module is model agnostic, meaning that any numerical weather prediction model can be utilized as long as the model used has the sufficient parameters describing the atmospheric conditions to predict thunderstorms.

DTN currently utilizes the NOAA RAP model over the North American domain. For global output, DTN utilizes the NOAA GFS.

Model	Domain	Forecast time step	Forecast length	Update frequency	Horizontal resolution
RAP	North America	1 hour	18 hours	Every hour	13km
GFS	Global (80N-80S)	1 hour	36 hours	Every 6 hours	13km

“DTN has over 40 years successfully supporting airlines Weather Intelligence needs. Our team of dedicated aviation meteorologists currently support airlines globally 24/7. The product leadership, sales and support all have direct airline operations experience. Ensuring you have all the most up to date weather to make proactive decisions. Allowing your airline to operate safely and efficiently.”

– DTN Product Manager

www.dtn.com