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BRIEF REPORT
Study on QNH variations

This report is divided into 6 parts.
The first one presents the context and the problematic of the project then how the working group was built.
The second one explains the methodology used to answer the problematic.
The third one presents the results and a global analysis.
The fourth one suggests a meteorological analysis of the QNH extreme variations.
The fifth one gives an estimation of these variations.
Finally the sixth one sets the wrong alarms frequency for several QNH variation thresholds.

1 – Background

Historical reminder :

On 23 May 2022, a serious incident took place on an Airbus A320 flying from Stockholm/Arlanda to Roissy/Charles de Gaulle during the approach phase. Due to a QNH error (1011 instead of 1001hPa) coupled with poor visibility meteorological conditions, the approach was flown below the glide path. The MSAW alarm was triggered. Not reaching the visual references after the minimum height the crew aborted the approach. Because of the erroneous altitude, the minimum height reached before the go-around was 6 ft at 0,8 NM from the runway's threshold which means that this event was almost a CFIT(Controlled Flight Into Terrain).

The BEA (Bureau d'Enquêtes et d'Analyses / Department of Inquiries and Analysis) ascertains that the incident was caused from the beginning by the transmission of a wrong QNH between the air control and the pilot of the aircraft. The transmission of this data allows the pilot to calibrate the altimeter setting and so on to determine the real altitude. With a pressure which move in the lower layers of the atmosphere about 1hPa every 30ft along the vertical, a error of 10hPa provoked a gap of 300ft (~100 meters) between the real altitude of the aircraft and the one thought by the crew.

By the way, the BEA recommends to the operator to establish without any delay a process allowing to reduce the hazard of a wrong altimeter setting when using the function baroVNAV during the approach. A checking of the QNH compared with an independent source of informations might be used, like the ones given by ATIS when available [Recommendation FRAN-2022-010].

Following this event, a working group formed by several members of industry and flying operations was created by the DSAC (Direction de la Sécurité de l'Aviation Civile) with the collaboration of Airbus. During the definition of the mitigation (exercise of Bow Tie) which allows to prevent such an incident, the possibility and the interest of setting a warning system in the cockpit was studied. This alarm would trigger when the difference is too high between the QNH used by the pilot when he's preparing his approach and the one given by the air control to calibrate the altitude on the display systems.

In order to understand the natural variations of the QNH and establish later an appropriate warning level, it was decided on the recommendation of Airbus to study the variations of QNH on a period of 30 minutes, to take into account the average time needed by a plane from the beginning of the descent and the reaching of the transition altitude.

In addition a study of the natural variations observed at a given time between 2 points separated by 250NM apart is suggested to take into account the aircraft's movements between the beginning and end of the descent.

Call to Météo France :

A partnership is created with Météo France to elaborate a detailed study on QNH data from 2022.

The goal is triple :

- Discriminate among the significant QNH variations the meteorological ones from the non natural ones
- When they are natural, analyse and determinate which kind of meteorological situations are responsible of these significant variations of pressure
- Determinate the probabilities in a year to have a variation of QNH equal to X (in a period of 30 minutes from one side and between 2 points separated by 250 NM in the other side). Then classify those probabilities by class of variations (X=[1,5-2,5]-[2,5-3,5]-...-[6,5-7,5] hPa) to be used by aeronautic manufacturers to confirm the feasibility of this solution and refine the alert threshold with a short level of wrong alarms

In this report, only the QNH variations in a period of 30 minutes would be studied. The ones in a distance of 250 NM will be the object of a subsequent note.

2 – Methodology

Database used :

In order to study QNH, the best database that we have is the METARs' one which describes regularly the weather conditions on an airport. In addition of the QNH, those messages give informations (temperature, wind, significant weather…) which would be very helpful to determinate the causes of significant variations of pressure.

To be as wide and complete as possible, the starting database counts all the METARs enabled for the whole year 2022. This represents 39683442 METARs for almost 3700 airports around the world.
However we have to keep in mind that the distribution of these airports, far numerous in industrialized countries than elsewhere, turns the database rather into a meteorological representation of the climate of the northern hemisphere.

If adding a QNH inside a METAR message is common, we have to precise that this way of doing isn't systematic for every airport. We can suppose that some are not furnished with a pressure sensor. As those METARs haven't any interest for our study, we remove them from the database, such as 150229 METARs (0,0379%).
Obviously, those airports without pressure measurement are local and with almost no commercial flight, which limits the impact on our study.

We precise also that dependent on the country QNH can be measured in hectopascals or in inches of mercury. According to the unit chosen, the QNH field starts with a different letter, 'Q' in the first case, 'A' in the second. For the need of this study, the chosen unit is the hectopascal. Subsequently all the METARs with QNH in inches of mercury were converted in hectopascal multiplying their value by 0,338638 then rounding them to the closest integer.

Limits with the METARs database :

If the METARs database is reliable with its strict standard syntax, we can observe some limits in accordance with the practices from one country to another, especially the ones who still write them manually. By the way encoding errors are frequent.
For these reasons the following METARs have to be removed from the database :

- 56 (0,0001%) for a badly encoded ICAO indicator
- 1501 (0,0038%) for a badly encoded date (usually a missing or an extra character)
- 1675 (0,0043%) for a QNH stuck to the last or next group
- 1106 (0,0027%) for a value of QNH obviously wrong (< à 850hPa or > à 1090hPa), which are the extreme values of pressure at sea level never ever measured on Earth
- 357 (0,0009%) for a recognized but badly encoded QNH (ex : Q1014,5)

We precise here that only the obvious errors have been removed from there. If the METAR editor has written in his message an ICAO indicator, a date or a QNH wrong but credible, we aren't able to suppress those automatically.

Sensors failure :

Like all equipment, the pressure sensor of an airport may be temporarily and sometimes durably in failure. So, for 2022, 72819 METARs (0,184%) were sent with the encoding Q//// or A//// to signal such a failure. The frequency of these failures is far from to be neglected and so would be needed to take into consideration to set up an alert system due to the fact they represent a blocking point when they occur.

Frequency of METARs transmission :

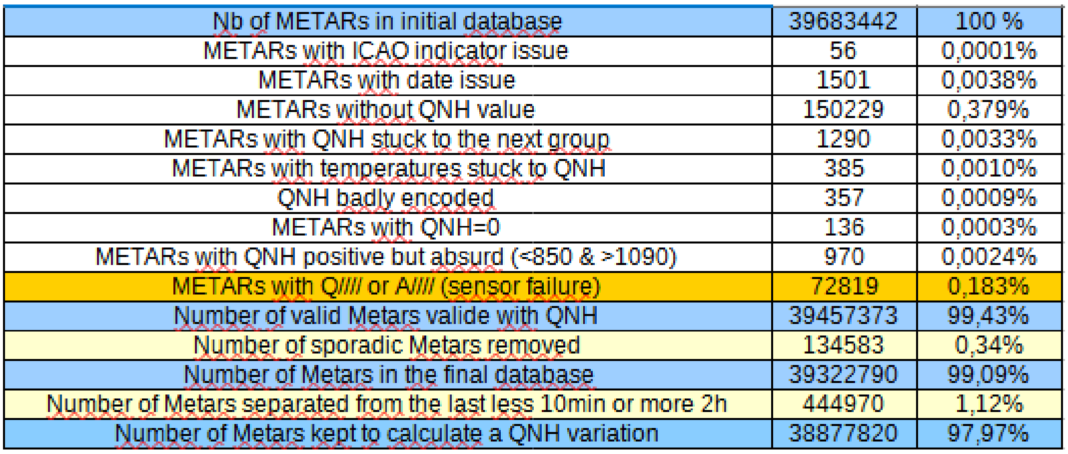
If the METARs encoding practices diverge from one country to another, it's also the case of their transmission frequency. In Europe we get used to have a METAR every 30 minutes but this frequency isn't a rule. The majority of the airports worldwide broadcasts every hour. In the United States the frequency of commercial airport reaches 1 METAR every 20 minutes. Sparsely some airports emit 1 METAR every 3 hours. In the same way sending METARs with no interruption H24 isn't respected by all the airports. For their purpose some of them broadcast only during their opening hours which ones can change during the year. Some others broadcast METARs in a sporadic way, depending likely on their own need.
For the needs of this study and to keep a database close with the uses of commercial airports, we decided to remove the airports which have not broadcast at least 50 METARs at an hourly rhythm minimum during a whole month.
Subsequently 134583 METARs (0,34%) have been removed representing between 100 and 150 airports every month.

Calculation of QNH variations :

The following methodology were used. For every METAR we also take interest to the last one emitted by this same airport. 4 cases may happen :

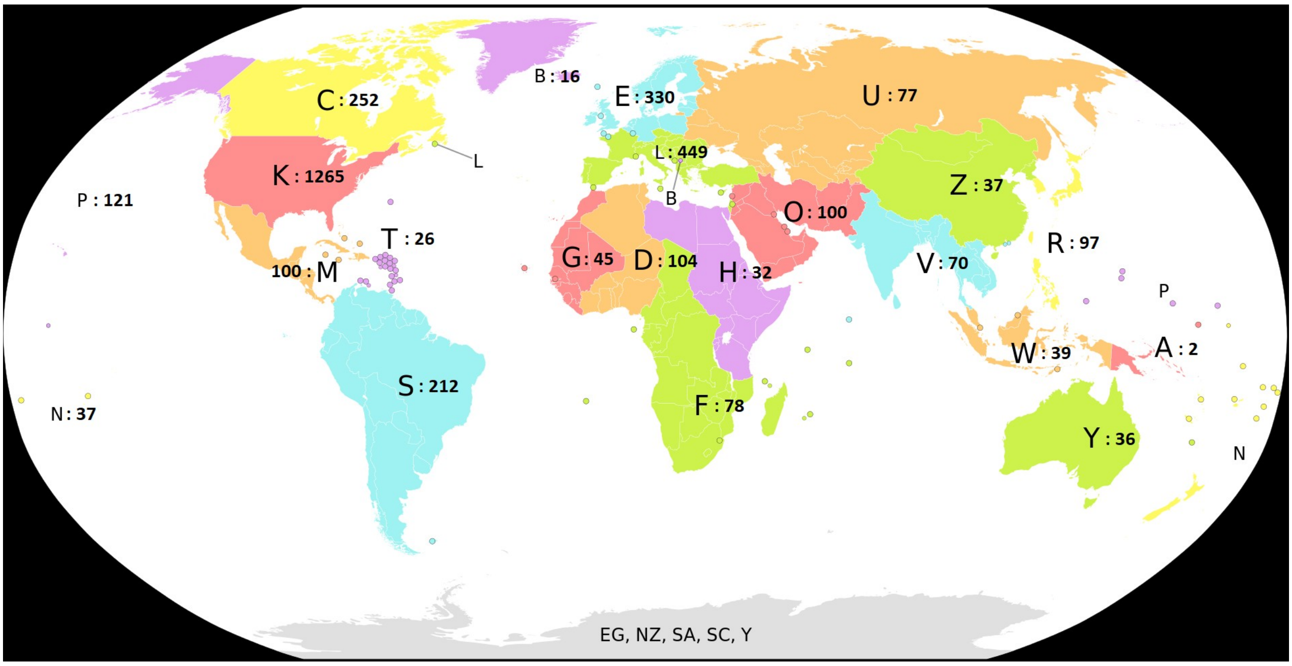
- if there is less than 10 minutes between the 2 METARs, we don't calculate the QNH variation. This case is scarce and usually happen when a first METAR is badly encoded then encoded again few minutes later when the operator realize the first error
- if there is between 10 and 30 minutes between the 2 METARs, we keep the absolute value of the difference of QNH between the 2 METARs
- if there is between 30 minutes and 2 hours between the 2 METARs, we keep the absolute value of the difference of QNH between the 2 METARs multiply by 30 then divide by the difference in minutes between the 2 METARs. Then this value is rounded to the closest integer. The purpose of this operation is to normalize the QNH variation in a period of 30min and so harmonize the results.
- If there is more than 2 hours between the 2 METARs, we don't calculate the QNH variation. The gap of time becomes too important to have a representative result for our study.

Summary table :



Nb of METARs in initial database	39683442	100 %
METARs with ICAO indicator issue	56	0,0001%
METARs with date issue	1501	0,0038%
METARs without QNH value	150229	0,379%
METARs with QNH stuck to the next group	1290	0,0033%
METARs with temperatures stuck to QNH	385	0,0010%
QNH badly encoded	357	0,0009%
METARs with QNH=0	136	0,0003%
METARs with QNH positive but absurd (<850 & >1090)	970	0,0024%
METARs with Q//// or A//// (sensor failure)	72819	0,183%
Number of valid Metars valide with QNH	39457373	99,43%
Number of sporadic Metars removed	134583	0,34%
Number of Metars in the final database	39322790	99,09%
Number of Metars separated from the last less 10min or more 2h	444970	1,12%
Number of Metars kept to calculate a QNH variation	38877820	97,97%

Study airports distribution according to ICAO zone :



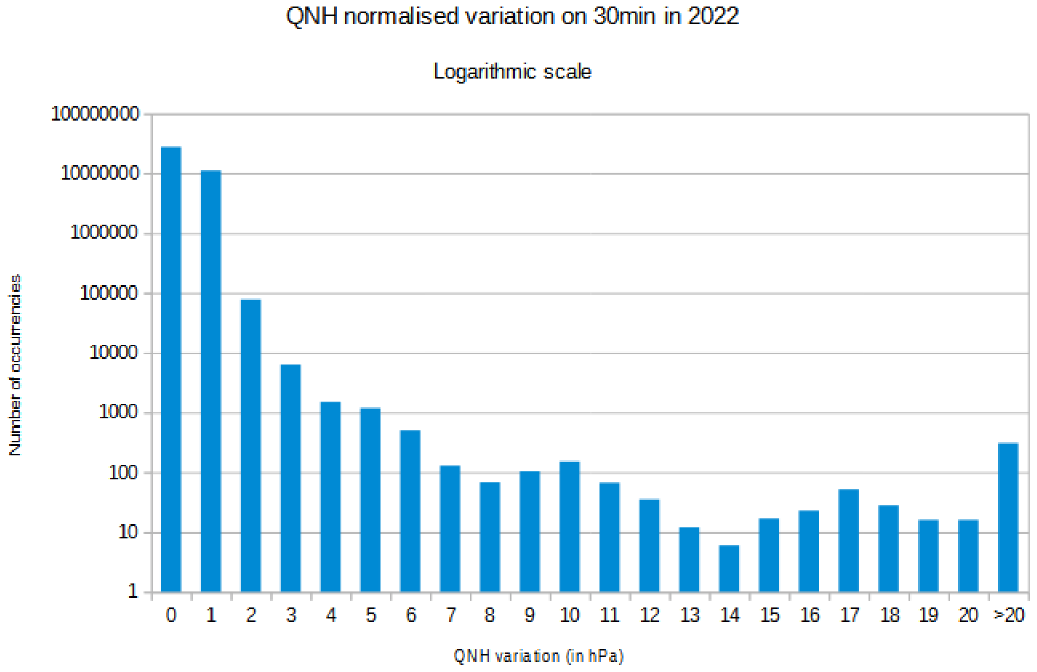
As mentioned upwards, European and North American airports are over represented (~2300) in comparison with the rest of the world (~1200). Indeed the study would rather be the reflection of north hemisphere tempered climate.

3 – Study results

The following table quantifies the QNH variations brought back to 30 minutes from the METARs messages of our final database for 2022.

QNH Difference (in hPa)	Number of occurrencies in 2022	Percentage	Accumulated Percentage
0	27587787	70,96 %	70,96 %
1	11201696	28,81 %	99,77 %
2	77857	0,20 %	99,973 %
3	6251	0,016 %	99,989 %
4	1501	0,004 %	99,993 %
5	1185	0,00305 %	99,996 %
6	505	0,00130 %	99,9973%
7	129	0,00033 %	99,9977%
8	67	0,00017 %	99,9978%
9	103	0,00026 %	99,9981%
10	152	0,00039 %	99,9985%
11	66	0,00017 %	99,99866%
12	35	0,00009 %	99,99875%
13	12	0,00003 %	99,99878%
14	6	0,00002 %	99,99880%
15	17	0,00004 %	99,99884%
16	23	0,00006 %	99,99890%
17	52	0,00013 %	99,99903%
18	28	0,00007 %	99,99910%
19	16	0,00004 %	99,99915%
20	16	0,00004 %	99,99919%
>20	305	0,00078 %	100%
Total	38877820	100,00 %	

The following graphic shows the same results using a logarithmic scale.



Analyse :

We observe that the QNH, on a period of 30 minutes, is a parameter of a very good stability since it varies no more than 1 hPa in 99,77% of the cases. This stability is essential for setting up an alert since it gives us liability without being polluted by a high level of wrong alarms for natural reasons.
Nevertheless, when we proceed further in the graphic, after a brutal lowering of occurrences number when we go from 0 to 3hPa of variation, we observe a relative stabilisation of the occurrences number decrease which is slower. More surprising we observe some little peaks centred around 10 and 17 hPa.
If the QNH variations were following entirely the laws of nature, we'd expect they follow well-known statistic laws like the normal law or the law of Gutenberg-Richter which describe the seismic magnitude variation. If it seems that we approach such laws for the small variations of QNH, it's not at all the case for higher variations.
Let's try to understand why.

Human error :

As said upwards, many countries encoded handily their METARs. This human factor leads naturally to a error hazard during the message writing. Those are evident when a character is missing or superfluous in a group (a date with 5 or 7 digits for instance) or when a group is stuck to another (temperatures group stuck to QNH group). Nevertheless it's a way harder to detect when a character is substitute by another. As a result it's very likely that some METARs are sent with wrong QNH value. If the units digit is wrong, the error can hardly be detected. For example, a METAR which is sent with a QNH value of 1013hPa instead of 1010hPa. However if the tens or hundreds digit is wrong, this should be seen more easily and, so on, it seems to be confirmed with the peak we observed at 10hPa. Furthermore, we have to remind that in addition with the human error the pressure can also change naturally between 2 METARs. If we look back at the previous data, when a error of 10hPa is made by an operator, the final error will be of 10hPa for 88% whereas it'll be 9 or 11hPa for 12% when the natural QNH variation is 1hPa. We can neglect 8 or less and 12 or more since the probability is ridiculously small.

Obviously this phenomenon can be observed only for the QNH values which stayed unchanged from the beginning, in fact the ones in hectopascals for airports sending METARs every 20 or 30 minutes.

For hourly METARs airports the QNH variation was divided by 2 so the peaks should appear around 5, 10, 15, 20hPa...

For airports with QNH in inches of mercury (mmHg), we have to consider the QNHs in their original unit :
_a 1mmHg error cause a 0,34hPa error, undetectable
_a 10mmHg error cause a 3,4hPa error. For airports sending METARs every 20 or 30 minutes, we should observe a bit more of occurrences every 3 or 4hPa. For the hourly METARs airports it should be every 1 or 2hPa, unnoticeable.
_in contrast a 100mmHg error is responsible of a 34hPa error which signify a 17hPa error for hourly METARs airports. And indeed we have those peeks at 17 and 34hPa (see table below).

Let's try to quantify those human errors with the original data and putting one side the METAR AUTO encoded automatically from others METARs on the other side encoded potentially by human :

Différence de QNH (en hPa)	METAR non AUTO 20/30min en hPa	METAR non AUTO 1h en hPa	METAR non AUTO 1h en mmHg	METAR AUTO en hPa	METAR AUTO en mmHg
0	6665564	3044148	3037643	4912765	10866416
1	1699175	2125418	1596331	1323873	2396392
2	12876	98237	83472	15661	125088
3	1095	6870	9183	1287	14406
4	298	1789	1896	254	2814
5	112	695	386	53	671
6	75	401	140	15	176
7	35	258	83	13	49
8	19	209	25	6	20
9	58	326	27	2	11
10	106	526	42	3	10
11	32	260	9	3	8
12	11	85	9	0	1
13	7	43	6	2	0
14	0	22	6	2	0
15	3	19	2	0	0
16	0	8	7	0	0
17	8	11	10	0	0
18	5	13	10	0	1
19	7	11	2	2	0
20	6	17	4	1	0
21	2	10	1	0	1
22	0	16	1	0	0
23	0	11	4	0	1
24	4	7	1	0	0
25	0	1	0	0	0
26	0	0	1	0	0
27	1	2	1	0	0
28	6	2	1	0	0
29	0	2	0	0	0
30	0	6	6	0	0
31	0	4	8	2	0
32	0	6	2	0	0
33	0	5	7	0	0
34	0	4	35	0	0
35	0	5	7	0	3
36	0	2	3	0	1
37	0	1	2	0	2
38	2	1	2	0	1
39	0	1	0	2	0
40	0	3	0	0	1

Number of QNH variation occurrences depending on the kind of METAR

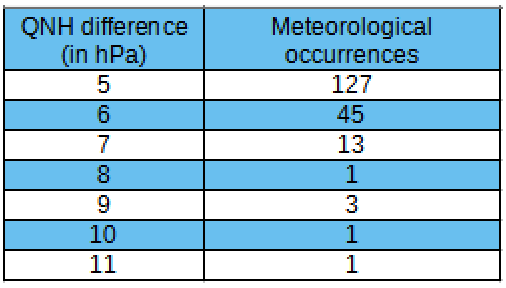
When we compare the QNH variation from automatic and human METARs, it's obvious that we have far more of extreme variations with the second case and so to observe the impact of human factor in the QNH correctness.

As expected, for non AUTO METAR with QNH in hPa, we note actually peaks of occurrences around 10 and 20hPa showing errors on the tens digit.

In the same way, for non AUTO METARs with QNH in mmHg, a high peak is observed around 34hPa showing a error on the hundreds digit. Seeing more attentively we can also observe the errors on the tens digit with more subtle peeks near 3, 7, 10, 13, 17, 20, 23, 27, 31hPa.

4 – Meteorological analyse of QNH natural variations

In the perspective to check the natural possibilities of QNH quick variations, the METARs incriminated in variations higher or equal to 5hPa in 30 minutes would be examinated from a meteorological point of view (2365 cases).
In this package, 191 cases (~8%) were identified as meteorological ones distributed on the following variations :



QNH difference (in hPa)	Meteorological occurrences
5	127
6	45
7	13
8	1
9	3
10	1
11	1

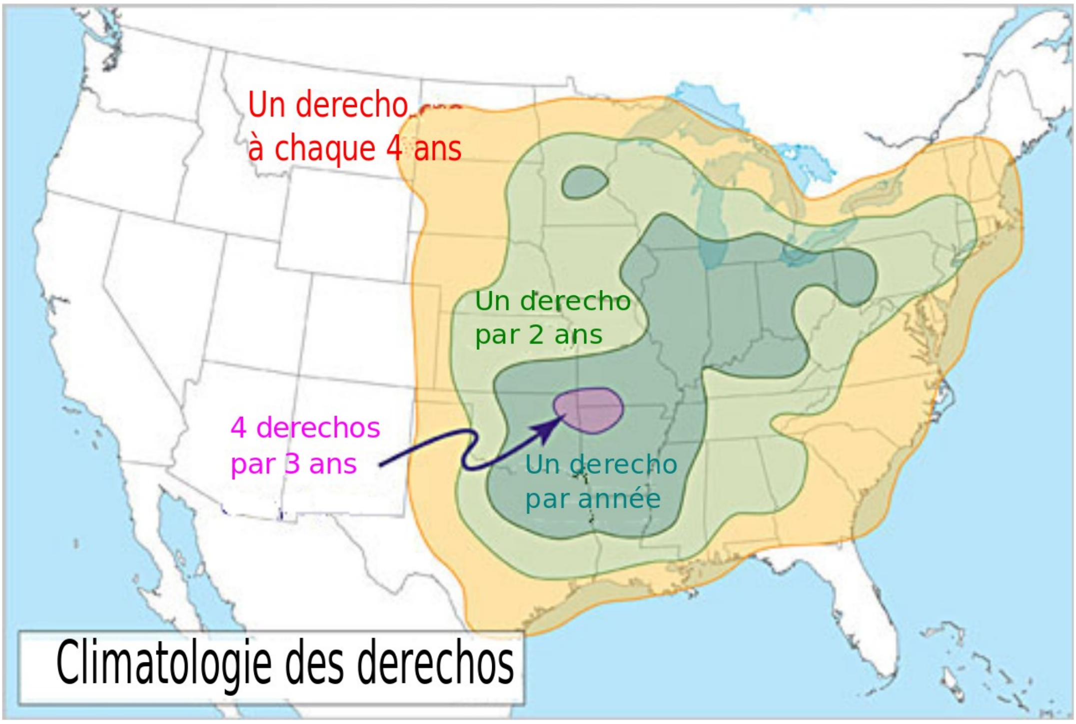
As we can see, the QNH variations meteorological extremes are limited in intensity with a maximum of 11hPa measured in 2022 in about 3700 international airports.

4 kind of meteorological situations were recognized :

- The first and more common (181 cases) is bound to convection, especially when it's organised in meso-scale convective system, often named as a derecho, usually with the presence of a squall line.

It's this kind of phenomenon which hit Corsica during the 18 august 2022 episode responsible of 12 fatalities. The system was born above the Balearic Islands, crossed the Mediterranean See to reach Corsica with gusts over 225km/h, rising the pressure up to 9hPa in Calvi and 11hPa in Ajaccio in 30 minutes. The system went on above northern Italy, Slovenia before collapsing above Austria after being responsible of major damage.

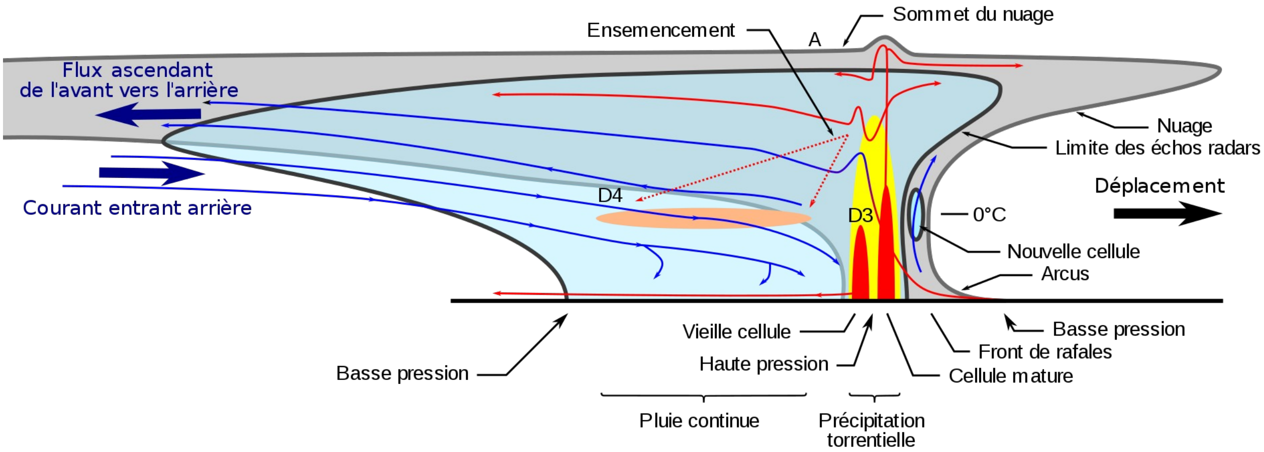
If the more intense seems to happen in Europe for 2022, those convective situations are far more frequent over the north American continent especially the Midwest zone where no less of a dozen of different situations were observed between April and September 2022.



The mechanism is all the time very similar with warm tropical air in the lower layers which travel up from the southern states associated to a cold in higher atmosphere coming directly from the Alaska/Canada zone. Over the surface a low deepen near the Canadian boundary and the convection develops over this southern side with arc-shaped squall line. If the more intense activity (tornadoes, torrential rains, lightnings…) happens on the southern part of the system where the air is warmer, it’s not the case for variations of pressure. The highest QNH variations were measured instead on the northern part which concerned for 2022 the states of Minnesota, Wisconsin, Michigan, Nebraska, Iowa, Illinois and Indiana.

In one hand we can observe quick rises of pressure when reached by the squall line due to the fact of the strong subsidence which comes compress the air against the ground.

In the other hand falls of pressure can also be quick when the system has gone especially since this lowering adds up with the passage of the low up north.



Cross-section of a derecho system

The 2022 data shows that this variation of pressure can reach usually 5/6hPa in 20 minutes with some occurrences at 7/8hPa. The derecho which took place in the Mediterranean sea being a priori unmatched in 2022.

We have to remark that theses situations may happen in intermediate seasons above further south areas. For instance it was twice the case in March and November 2022. The cold air enters then deeper into the core of United States and the low widens on the southern states, above Virginia for these 2 situations. As said before, if the strongest damages were observed in Georgia and South Carolina, the highest variations of pressure was registered further north in North Carolina.

If more frequent in United States, those systems may happen also everywhere on the planet except on polar area. In 2022 every continent were concerned with squall line observed in countries such as Australia, Mali, Uganda, Algeria, Paraguay, Iran and of course in Europe and North America.
From one METAR to another the signal of a squall line is often seen thanks to a strengthening wind paired usually with a change of direction, a fall of the temperature due to the lowering cold air reaching the ground, a slight rise of the dew point temperature caused by the humidity brought by rainfall and of course the presence of CB (cumulonimbus) in the cloud group and TS (thunderstorm) in the significant weather one.

Example with Tebessa airport in Algeria the 27th August :

```
DABS 271300Z 10017KT 9999 TS FEW030CB FEW030TCU SCT033 30/12 Q1013=
DABS 271330Z 01031KT 0800 +TSRA FEW030CB SCT030TCU BKN033 14/14 Q1019=
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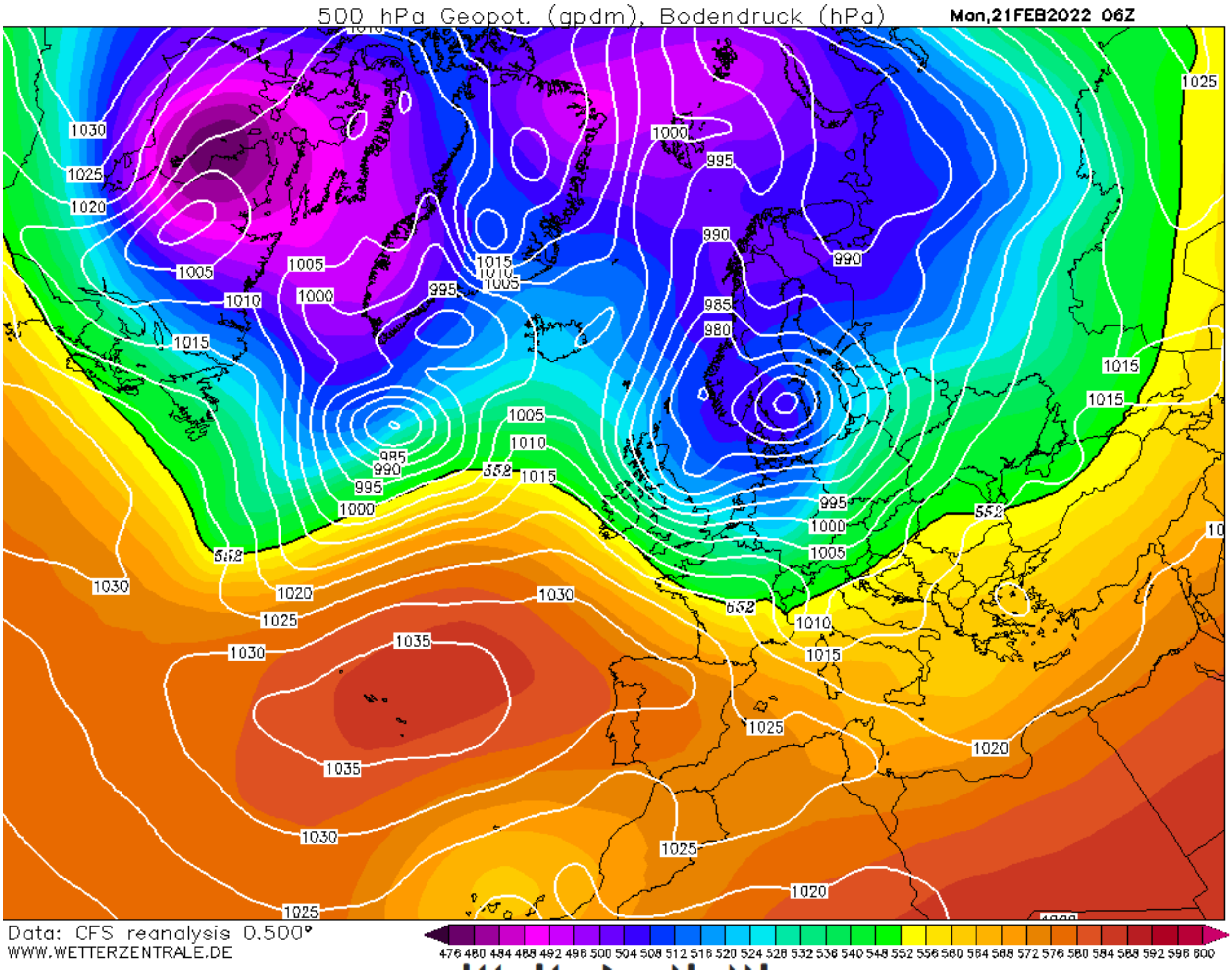
- The second meteorological cause concerns the winter storms which circulate along the mid-latitudes (4 cases). They happens usually during January or February in the north hemisphere but it's more than likely that the south hemisphere such as the southern part of South America is concerned in a similar way during the austral winter. When we take a look to the variations in one hour of the Canadian METARs, we note many occurrences with 5/6hPa but this threshold is no more reached as soon as we calculate the variation in 30 minutes. The report is the same with north-Atlantic and north-Europe airports.

4 cases still remain where 5hPa in 30 minutes were reached. They come from storms which are characterised at the same time by high movement speed, a powerful pressure gradient and a rising or falling core.
In 2022 those happened with storms Izzy (14th-17th January) and Kenan (27th-31th January) for Canada and United States and the storms Malik (28th January to 3rd February) and Franklin (21th February) for northern Europe.



Sea level pressure and Z500hPa the 21/02/2022 at 6hUTC (GFS model reanalysis)

Example with Stornoway airport in Scotland the 30th January :
EGPO 301820Z AUTO 31056G75KT 2200 RA BKN003/// BKN006/// BKN010/// 05/04 Q0995 REDZ=
EGPO 301850Z AUTO 33044G58KT 5000 -RA SCT006/// OVC011/// 03/03 Q1001 RERA=

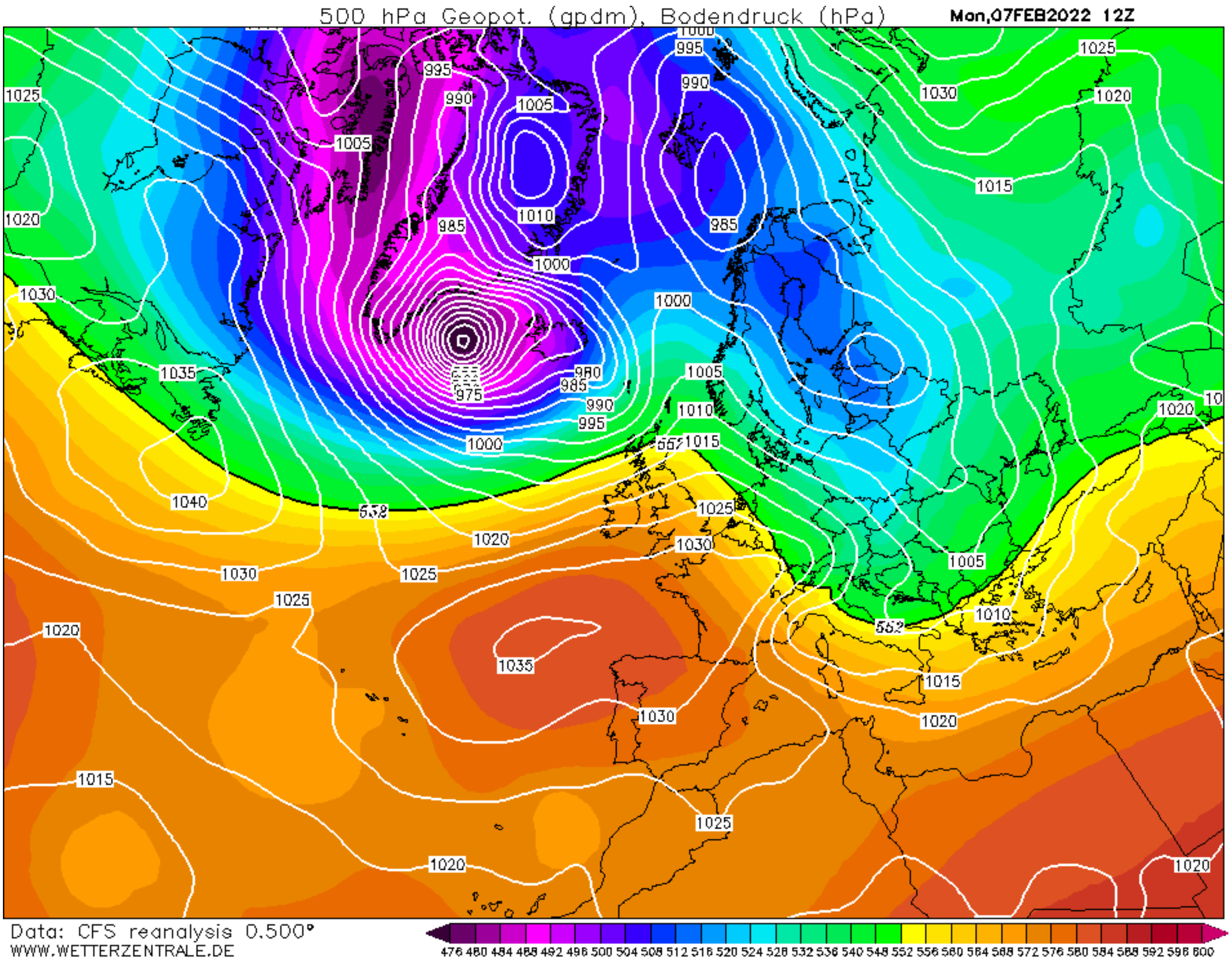
- The third meteorological cause concerns the tropical hurricanes which can also be responsible of strong variations of pressure.

In 2022 the best example is the Hinnamnor typhoon which crossed south of Japan the 30th of August, hurricane of category 5 with gust up to 250 km/h :

RORK 301900Z AUTO 30037G56KT 1000 -RA BR FEW007 OVC010 //////CB 27/26 Q0983=
RORK 302000Z AUTO 23068G94KT 0500 // BKN003 OVC007 //////CB 27/26 Q0964=
RORK 302100Z AUTO 18059G78KT 0700 -RA FG SCT008 OVC010 //////CB 27/27 Q0977=
RORK 302200Z AUTO 14065G80KT 0100 +RA FG FEW003 SCT018 BKN024 //////CB 26/26 Q0988=

When the typhoon core is coming we see that the QNH falls up to 19hPa in 1 hour which is about 10hPa in a period of 30 minutes before rising again at a rhythm of about 10hPa per hour.

- The fourth meteorological cause is remarkable since only one case was seen in 2022 with a variation of pressure reaching 5hPa in 30 minutes. This happened during a surge of wind which swept along northern Italy and Ex-Yugoslavia the 7th of February.



Sea level pressure and Z500hPa of the 07/02/2022 at 12hUTC (GFS model reanalysis)

As we can see on this map, the Alps area is touched by a strong gradient of pressure widespread along all the layers of the troposphere.
This gradient is responsible of a strong gusty wind which blows down from mountains before spreading along the Pô valley. The gust front generated many damages, such as some city like Milan.

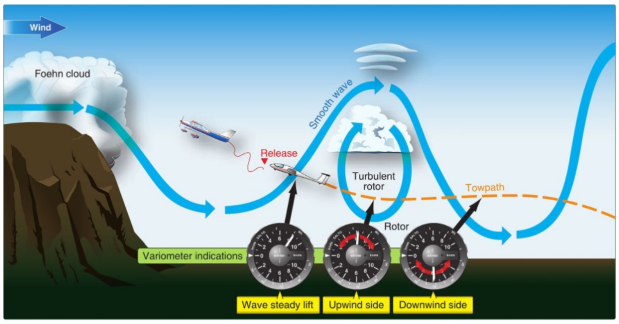


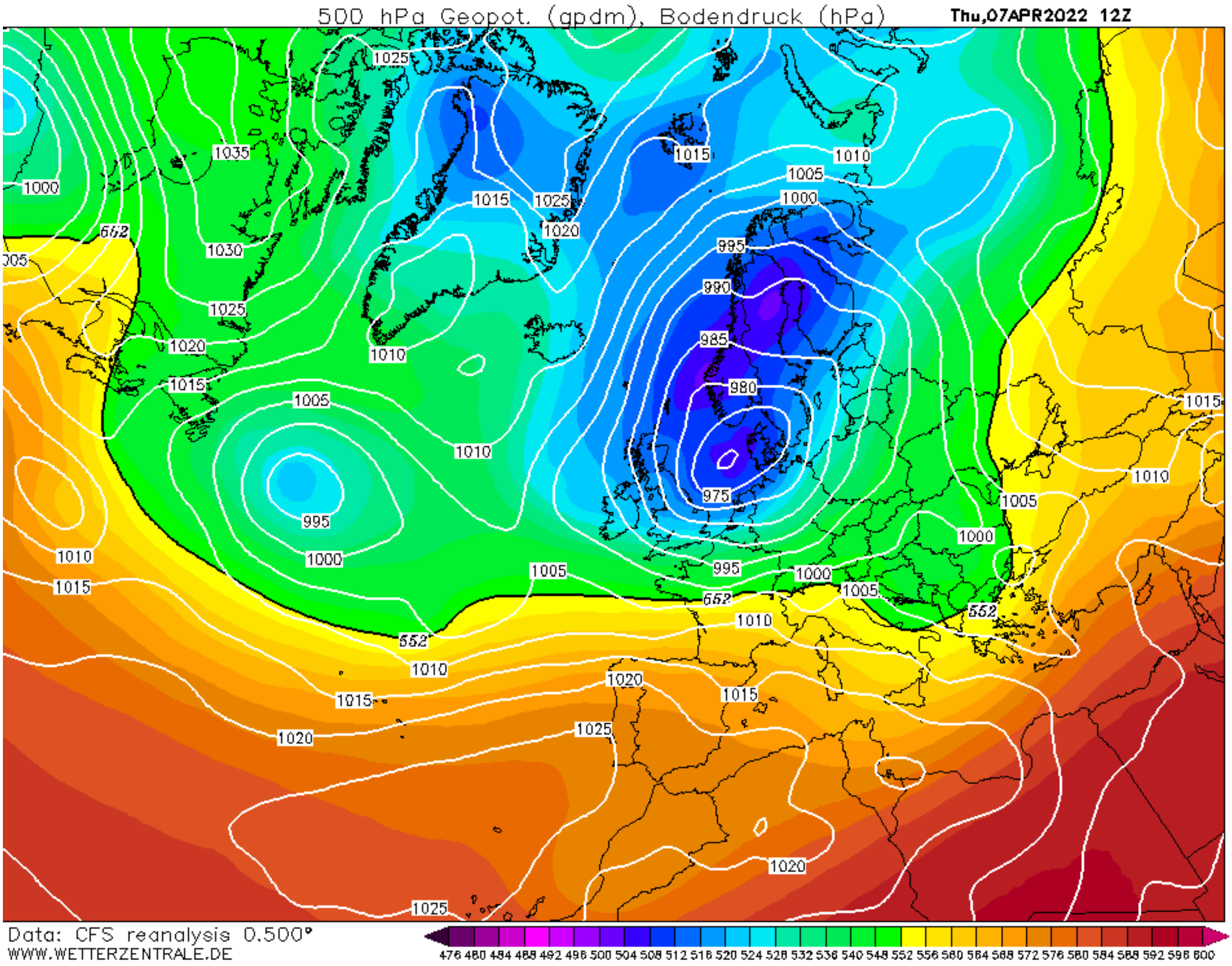
Schéma illustrant la formation de rotors lors d’une situation de déferlement

Example with Monte Sant'Angelo airport in Italy :

LIBE 071455Z 34038G56KT 0000 -RA FG VV/// 01/01 Q1005=
LIBE 071555Z 34049G72KT 0000 -RA FG VV/// 02/00 Q1001=
LIBE 071655Z 34045G66KT 9999 OVC012 02/M01 Q1007=
LIBE 071755Z 36030G42KT 9999 SCT012 01/M03 Q1012=

- To finish with, a last case stayed unexplained. It happened at Dalaman in Turkey the 7th April :

LTBS 071450Z VRB04KT 9999 FEW030 BKN100 21/11 Q1006 NOSIG=
LTBS 071520Z 13018G31KT 9999 FEW030 BKN100 22/10 Q1001 NOSIG=

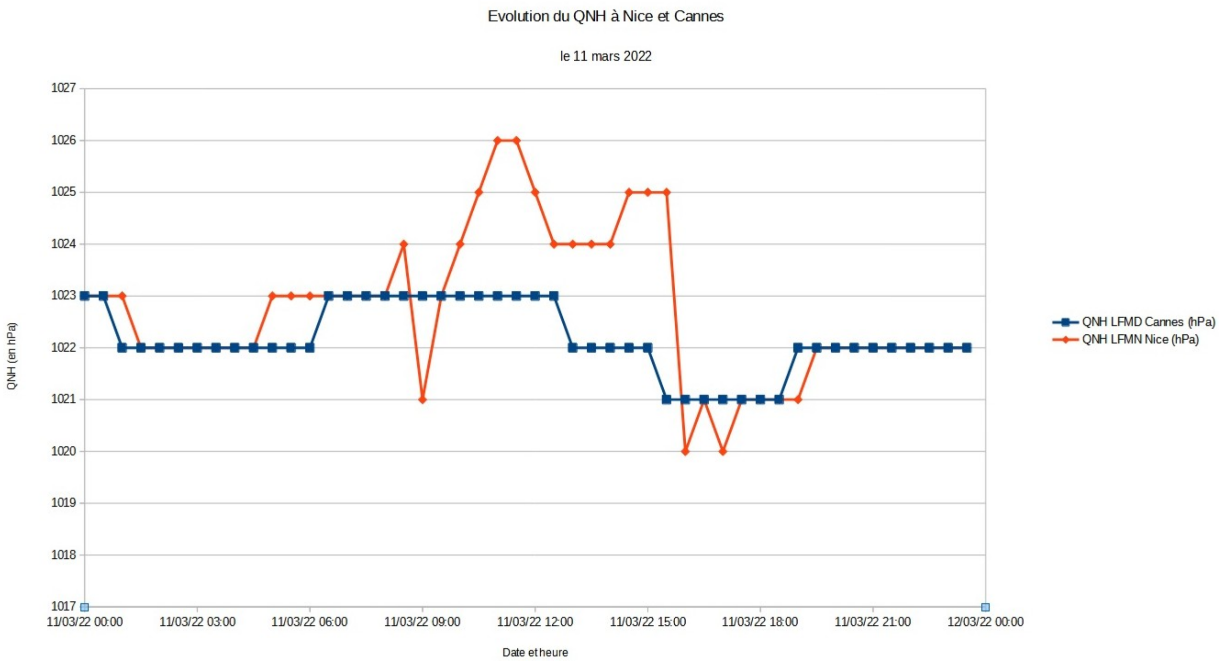


Sea level pressure and Z500hPa the 07/04/2022 at 12hUTC (GFS model reanalysis)

Despite the slight reinforcement of the wind and the presence of a small low, nothing can obviously explain the reason of this quick variation of pressure.
We can be sure that it's from meteorological origin since the same kind of variation takes place at Rhodes airport some kilometres further west few hours before.

Failed sensor :

Besides natural variations and human errors, the third cause generating important pressure variations in a short laps of time is the failing of a pressure sensor which can then give wrong QNH values.
In 2022 this happened at Nice airport the 11th of March. Next to a maintenance operation near 8hUTC a lid has been forgotten on the sensor which causes a sensor shutter. For several hours the delivered pressure by the sensor was wrong, usually increased by few hectopascals, before a back to normal next to a new intervention near 16hUTC.



We note that as an human encoding error, a wrong pressure measurement will be usually responsible of 2 jumps of pressure, first when it appears, second when it’s resolved and so for one event we have usually 2 variations of pressure higher than 5hPa.

The following METARs coming from Storm Hills, Canada, shows this kind of sensor failing :

CWVH 011600Z AUTO 09018KT ////SM OVC013 M15/M17 A3024=
CWVH 011700Z AUTO 09017G22KT ////SM OVC011 M16/M17 A2593=
CWVH 011800Z AUTO 09019KT ////SM OVC008 M16/M17 A3023=

Moreover these kind of failures are especially frequent with the Canadian airports so much so that a note[1] has been written to describe the phenomenon. It happens usually between 15 and 20 times per month in the C area (OACI zone) with very important QNH variations (from 50 to 200mmHg).

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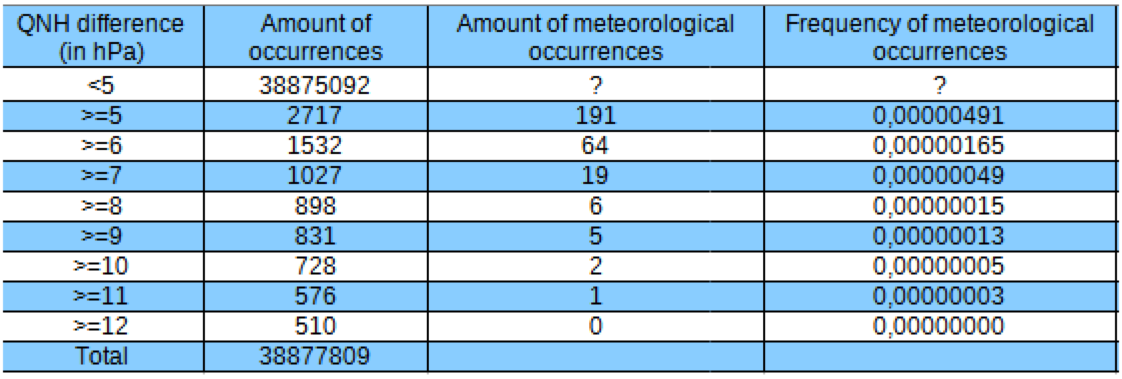
[1] https://www.icao.int/safety/meteorology/amofsg/amofsg%20meeting%20material/amofsg.7.sn.023.5.en.doc

5 – QNH variations estimate depending on their cause

Meteorological natural cause :

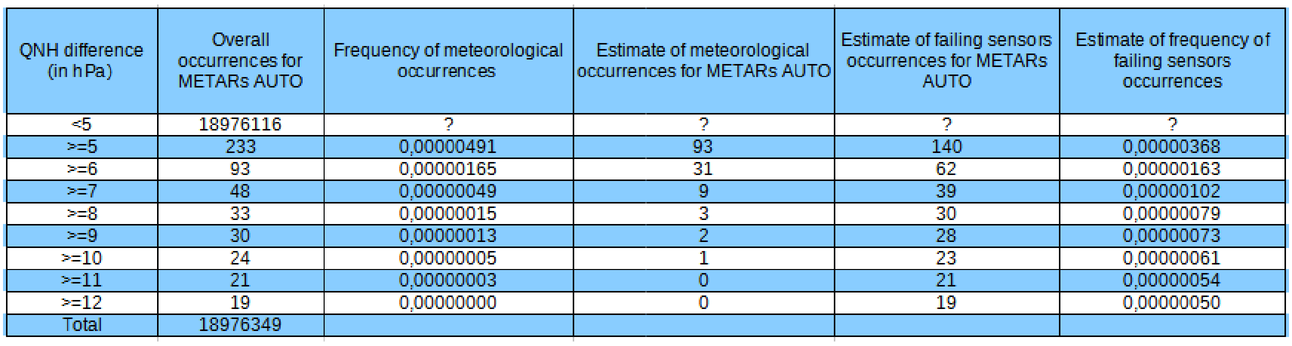
From the previous meteorological analysis we can estimate in an order of magnitude way the occurrences frequency of the natural QNH variations when they reach at least 5hPa in 30 minutes :



QNH difference (in hPa)	Amount of occurrences	Amount of meteorological occurrences	Frequency of meteorological occurrences
<5	38875092	?	?
>=5	2717	191	0,00000491
>=6	1532	64	0,00000165
>=7	1027	19	0,00000049
>=8	898	6	0,00000015
>=9	831	5	0,00000013
>=10	728	2	0,00000005
>=11	576	1	0,00000003
>=12	510	0	0,00000000
Total	38877809		

Failing sensor cause :

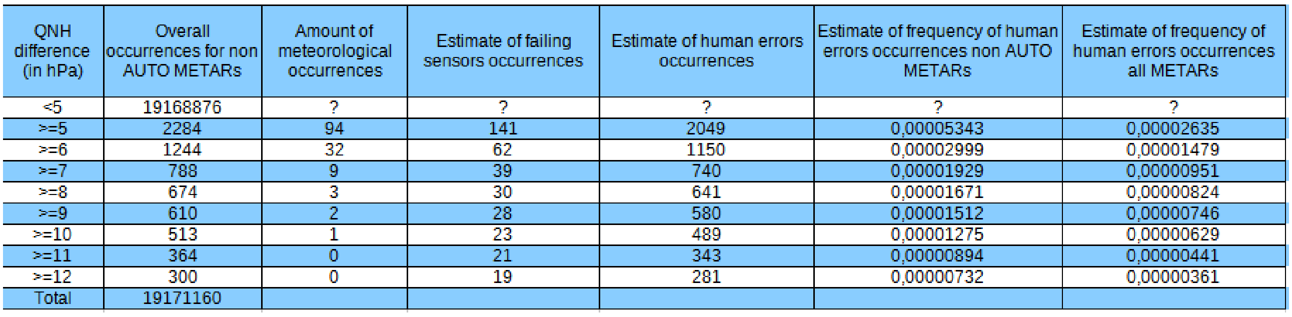
Then, to discriminate important QNH variations due to a failing sensor from the ones due to a human error we're going to take interest only to automatic METARs where there is no human error. Those METARs are easily recognizable since the term 'AUTO' is written inside the message.
Thanks to the frequency of natural occurrences we specified previously we can now have an estimate of the one from failing captors by subtracting the first from the global one.
As said before, when we have a sensor issue, this usually means that we have 2 important QNH variations, one when it occurs, one when it's fixed. So we have to divide the estimate amount of occurrences by 2 to have the real estimate frequency of occurrences coming from a failing sensor which gives a wrong value of QNH.
To have this estimate we put aside the METARs AUTO from area C (Canada). The reason was mentioned above. Indeed the pressure sensors from small Canadian airports have a well-known failure which report aberrant QNH values at a higher rate than every another airports in the world. Integrate them would have completely distorted the estimate.



QNH difference (in hPa)	Overall occurrences for METARs AUTO	Frequency of meteorological occurrences	Estimate of meteorological occurrences for METARs AUTO	Estimate of failing sensors occurrences for METARs AUTO	Estimate of frequency of failing sensors occurrences
<5	18976116	?	?	?	?
>=5	233	0,00000491	93	140	0,00000368
>=6	93	0,00000165	31	62	0,00000163
>=7	48	0,00000049	9	39	0,00000102
>=8	33	0,00000015	3	30	0,00000079
>=9	30	0,00000013	2	28	0,00000073
>=10	24	0,00000005	1	23	0,00000061
>=11	21	0,00000003	0	21	0,00000054
>=12	19	0,00000000	0	19	0,00000050
Total	18976349				

Human errors cause :

Now that we have an estimate of frequencies of both occurrences for natural and sensor failing reason, we can deduct an estimate of occurrences frequency for human errors by subtracting the first two from the data coming from human METAR.
Same problematic as for sensor failure, we have also to divide the frequency of human error occurrences by 2 as each error involves a trigger and a back to normal.
This estimate of frequency for human errors applies only for airports which product non-automatic METARs.



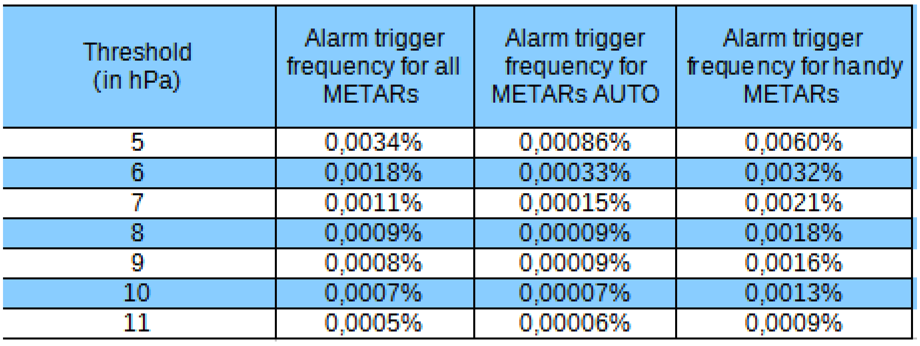
QNH difference (in hPa)	Overall occurrences for non AUTO METARs	Amount of meteorological occurrences	Estimate of failing sensors occurrences	Estimate of human errors occurrences	Estimate of frequency of human errors occurrences non AUTO METARs	Estimate of frequency of human errors occurrences all METARs
<5	19168876	?	?	?	?	?
>=5	2284	94	141	2049	0,00005343	0,00002635
>=6	1244	32	62	1150	0,00002999	0,00001479
>=7	788	9	39	740	0,00001929	0,00000951
>=8	674	3	30	641	0,00001671	0,00000824
>=9	610	2	28	580	0,00001512	0,00000746
>=10	513	1	23	489	0,00001275	0,00000629
>=11	364	0	21	343	0,00000894	0,00000441
>=12	300	0	19	281	0,00000732	0,00000361
Total	19171160					

For these non-automatic METARs, thanks to the calculations made above, we can estimate that 0.0053% of them are issued with a human error of QNH greater than or equal to 5hPa. This percentage of error is reduced to 0.0026% if we consider all the METARs in our database.

6 – Determination of a threshold

Approach by occurrences frequency

From the previous estimates of frequencies that we did, we can now have an estimate of false alarms for different thresholds and even to refine it according to the kind of METARs, automatic or not.



Threshold (in hPa)	Alarm trigger frequency for all METARs	Alarm trigger frequency for METARs AUTO	Alarm trigger frequency for handy METARs
5	0,0034%	0,00086%	0,0060%
6	0,0018%	0,00033%	0,0032%
7	0,0011%	0,00015%	0,0021%
8	0,0009%	0,00009%	0,0018%
9	0,0008%	0,00009%	0,0016%
10	0,0007%	0,00007%	0,0013%
11	0,0005%	0,00006%	0,0009%

With the studied thresholds (between 5 and 11hPa) we can estimate the frequency of false alarms would be about 1 in 100000.
Between 5 and 7hPa increasing the threshold by 1 is significant since it allows to divide the false alarms rate by 2. Above 7hPa the frequency decreases at a slower pace involving a very small profit.

As we are conscious that a 5hPa QNH error is significant regarding the difference of altitude (~150ft), we're now going to estimate false alarms frequencies for smaller thresholds thanks to another method.

Approach by time steps

This method is going to study the percentage chance of triggering a false alarm at an instant 't' after the last METAR.
It assumes that the pressure varies linearly with time. It means that if the pressure is 1010hPa at 10h and 1013hPa at 10h30, it reaches 1011hPa at 10h10 and 1012hPa at 10h20. This estimate makes sense as the average of it is right with natural variations of pressure.
This estimate is obviously wrong when considering QNH variations bound to human errors and failing sensors where the pressure jump is immediate.
Considering that the natural variations are predominant for small QNH variations, the smaller the threshold, the more reliable is this method.

Let’s take some examples with a 3hPa threshold :

1) 2 METARs separated by 30 minutes, the first at t1 with 1010hPa of QNH, the second at t2 with 1013hPa. The 3hPa in 30 minutes threshold has been reached but the alarm wouldn’t have triggered for the whole period of time. If a pilot validates the QNH at t1+15 minutes, with a linear variation, we may estimate that the pressure would be at 1011,5hPa which means 1,5hPa higher than the last METAR. The threshold is not reached so no alarm.
As the QNH is a value rounded at the closest integer, let’s considerate that the pressure must reach 1012,5hPa to have a 1013hPa QNH and so reaching the threshold. With a linear variation 1012,5hPa is reached at t1+25 minutes which is the moment when the alarm triggers. So, during this 30 minutes laps of time, the alarm would indeed have triggered only the five last minutes.

2) 2 METARs separated by 30 minutes, the first at t1 with 1014hPa of QNH, the second at t2 with 1009hPa. To reach the 3hPa threshold the pressure must this time fall at least at 1011,5hPa to have a 1011hPa QNH. With a linear approach this pressure is reached at t1+15 minutes. This time, during this 30 minutes laps of time, the alarm would have triggered for 15 minutes.

3) 2 METARs separated by 1 hour, the first at t1 with 1014hPa of QNH, the second at t2 with 1010hPa. The QNH variation is 4hPa in 1 hour which means 2hPa in 30 minutes as we work on period of half an hour. The threshold is not reached so no alarm.

4) 2 METARs separated by 1 hour, the first at t1 with 1000hPa of QNH, the second at t2 with 1010hPa. Here the QNH variation has well overpassed 3hPa in 30 minutes. The alarm would have triggered when the pressure reaches 1002,5hPa, so t1+15 minutes. In this laps of 1 hour the alarm would have been active for 45 minutes.

If we resume, when the threshold is reached, the period of time (d) when the alarm is triggering can be obtained with this next formula :

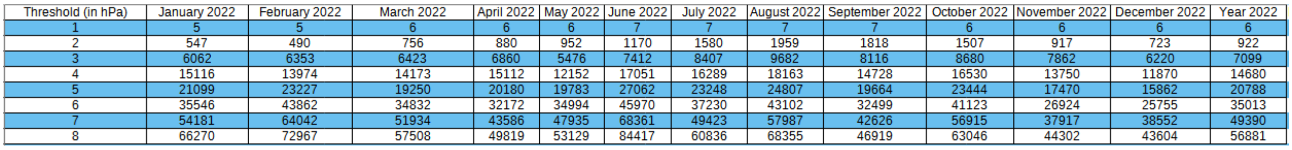
$$d = \Delta t*(1+(1-2*S)/2/\Delta P)$$

with Δt time between 2 METARs, S the chosen threshold and ΔP the QNH difference between the 2 METARs

For each airport, for the whole year 2022, for a chosen threshold, we compare every METAR with the previous one and we determinate the time when the alarm would have ringed compared with the total time between the 2 METARs. Then we have to sum on one side all these triggering times and on the other side all the lapses of time between every METAR. The ratio between these two values gives us the frequency of wrong alarms for the chosen threshold.

$$\mathrm{freq}_{\mathrm{triggering}}=\Sigma(\mathrm{times}_{\mathrm{triggering}})/\ \Sigma(\mathrm{times}_{\mathrm{total}})$$

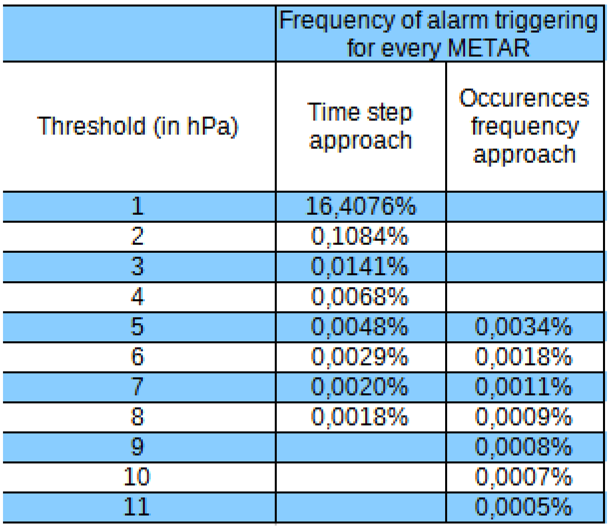
For comparison reasons with the previous method we are going to determinate the frequency of wrong alarms for thresholds going from 1 to 8hPa :



Threshold (in hPa)	January 2022	February 2022	March 2022	April 2022	May 2022	June 2022	July 2022	August 2022	September 2022	October 2022	November 2022	December 2022	Year 2022
1	5	5	6	6	6	7	7	7	7	6	6	6	6
2	547	490	756	880	952	1170	1580	1959	1818	1507	917	723	922
3	6062	6353	6423	6860	5476	7412	8407	9682	8116	8680	7862	6220	7099
4	15116	13974	14173	15112	12152	17051	16289	18163	14728	16530	13750	11870	14680
5	21099	23227	19250	20180	19783	27062	23248	24807	19664	23444	17470	15862	20788
6	35546	43862	34832	32172	34994	45970	37230	43102	32499	41123	26924	25755	35013
7	54181	64042	51934	43586	47935	68361	49423	57987	42626	56915	37917	38552	49390
8	66270	72967	57508	49819	53129	84417	60836	68355	46919	63046	44302	43604	56881

For every threshold the table gives the period of wrong alarms month after month and a average for the whole year 2022. For instance, for the 1hPa threshold, in January, the alarm would have been activated 1 minute every 5 minutes. For the 4hPa threshold, the same month, it'd have been 1 minute every 15116 minutes.
This kind of representation month after month allows to well realise the seasons impact on the pressure variations. Indeed, as already said at the beginning, the airports distribution all over the world is rather representative of the climatology of the northern hemisphere. In this part of the world where the thermic contrasts are stronger during winter time it gives way to important pressure variations during this season. Indeed the pressure variations from 1 to 3hPa in 30 minutes have a peak focused on January and February and a hole around July and August.
As we have seen previously QNH variations above 3hPa in 30 minutes are very scarce, often generated by extreme phenomenons as thunderstorms, winter storms, hurricanes… which can happen in every season depending on the part of the world. And indeed it's more difficult to establish a seasonality for those variations especially since the meteorological natural variations are confused with the ones coming from human errors and failing sensors.

With the method we just used here is the following table of wrong alarms frequency :

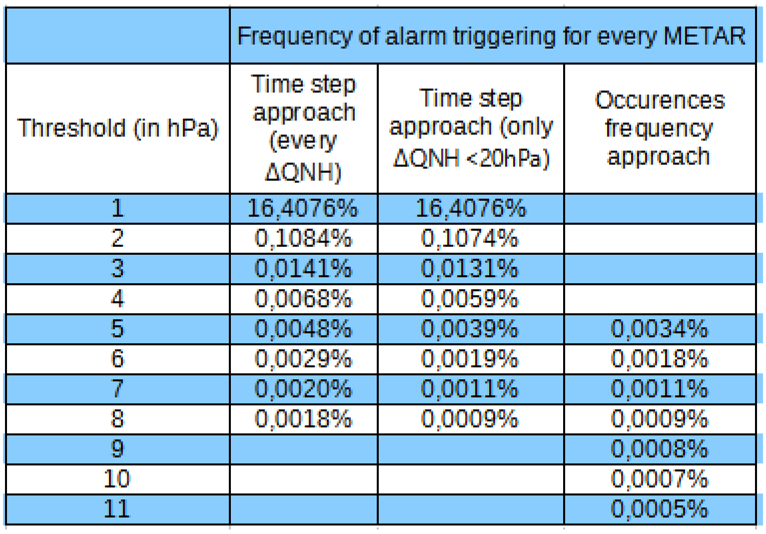


Threshold (in hPa)	Frequency of alarm triggering for every METAR	
	Time step approach	Occurences frequency approach
1	16,4076%	
2	0,1084%	
3	0,0141%	
4	0,0068%	
5	0,0048%	0,0034%
6	0,0029%	0,0018%
7	0,0020%	0,0011%
8	0,0018%	0,0009%
9		0,0008%
10		0,0007%
11		0,0005%

With this method which allows us on smaller thresholds we note that the frequency of wrong alarms would be 1 in 6 for a 1hPa threshold. It drops to about 1 in a thousand for a 2hPa threshold and 1 in 10000 for 3hPa. With the decrease of the preponderance of natural variations from 3hPa, the frequency reduces far slower as soon as we exceed this threshold.

When we compare the 2 methods we used, we note a similarity in the order of magnitude between the estimated frequency. However a factor from 1,5 to 2 remains between the 2 methods and seems to go increasing as the threshold rises.
As mentioned above this difference can be explained by the preponderance made by big QNH variations (>20hPa) when we work on high thresholds, variations caused by human errors or failing sensors. Indeed these variations being far higher than the chosen threshold it involves a duration when the alarm triggers almost equal to the whole laps of time during the 2 METARs, given them a significant weight as long as the amount of threshold triggering is small.

To convince us let’s apply the same method without considering the QNH variations > or = at 20hPa. Here is the results table :



	Frequency of alarm triggering for every METAR		
Threshold (in hPa)	Time step approach (every ΔQNH)	Time step approach (only ΔQNH <20hPa)	Occurences frequency approach
1	16,4076%	16,4076%	
2	0,1084%	0,1074%	
3	0,0141%	0,0131%	
4	0,0068%	0,0059%	
5	0,0048%	0,0039%	0,0034%
6	0,0029%	0,0019%	0,0018%
7	0,0020%	0,0011%	0,0011%
8	0,0018%	0,0009%	0,0009%
9			0,0008%
10			0,0007%
11			0,0005%

We can see that removing the extreme variations has a very small impact on the triggering frequency of smalls thresholds (<=3hPa). However, for bigger thresholds, it gives us about the same results that the ones we found with the first approach, the occurrences frequency one.

Conclusion of the study

The study we have just carried out has enabled us to demonstrate that the variations in QNH over a 30-minute time step are generally small, less than 2hPa in 99.77% of cases.
Thus, the idea of establishing an alarm to compare the QNH entered by the pilot with that given by the last METAR seems quite appropriate.
However a few limitations have been highlighted.
On the one hand, the reliability of the METARs which, when they are written by humans, can contain several types of errors ranging from the impossibility of using them because a group has been incorrectly coded to an error in the writing of the QNH giving a false pressure value. The study showed that about 0.0026% of the METARs started out false with an error of at least 5hPa due to human coding error, with small QNH errors below 5hPa not being able to be determined.
On the other hand, the reliability of the pressure sensors which can either fail or give false values due to a failure. Concerning the failures, this represents 0.183% of the METARs and implies a non-operational alarm system during the time of the failure. For failures, the study showed that they represent at least 0.00037% of METARs (failure of at least 5hPa) and will often cause false alarms.

The study looked at large 30-minute pressure variations due to natural meteorological causes. It showed that deep convection is most often responsible for these large variations with derecho and squall line systems. Other phenomena that can cause pressure to vary abruptly include tropical cyclones, winter storms and wind surges from mountains. The study found that the pressure never varied by more than 11hPa in 30 minutes in 2022 for all the observations it has at its disposal. Of course, this is not an absolute. As the study is limited in time and space, it is likely that even larger variations will be observed sporadically.
In summary, large natural variations in the 30-minute QNH are possible :

- with organised thunderstorm systems (mostly in the USA but potentially all over the world)
- with cyclone (tropical zone, June to November in the Northern Hemisphere, November to May in the Southern Hemisphere)
- with winter storms (airports > 50° latitude)
- with situations of strong winds over the terrain (airports in the mountains or near a mountain range)

Although these significant variations in QNH are sometimes natural, it should be borne in mind that they are mostly caused by human error or sensor failure. We therefore recommend always raising doubts when a QNH value seems abnormal.

Finally, the study focused on establishing a threshold for triggering the alarm. It was estimated that the false alarm rate would be about 1 in 1000 with a threshold set at 2hPa, 1 in 10000 with a threshold set at 3/4hPa and 1 in 100000 with a threshold at 7/8hPa.
Here, it is important to stress that these frequencies have been established thanks to all the airports in the database. It should be noted that the database includes airports with little or no commercial activity where METARs are more sporadic, often human-coded and potentially with lower quality pressure sensors. For these reasons, given that the alarm will be used predominantly for landings at busy hubs with many movements, it is very likely that the frequency of false alarms actually observed will be slightly lower than that estimated by the study, due to a reduction in human or sensor error at such airports.
Furthermore, the limitation of these false alarm rates is primarily related to the use of METARs as a basis for comparison with the QNH entered by the pilot rather than for reasons of natural pressure variations. Indeed, this limit largely reflects the reliability limit of METARs. Rather than using these messages, an improvement could be to compare the QNH entered by the pilot directly with that measured by the pressure sensor at the airport concerned, if such a technical procedure can be carried out.

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