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The accident of AF-447 flight – analysis and reconstruction of weather situation along the flight path

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On 1 June 2009 an A-330-200 airplane (AF-447) crashed over the mid-Atlantic ocean. The flight path crossed a significant squall-line with a strong thunderstorm activity. During the last five minutes of AF-447 flight the ACARS system sent warning and fault messages to Air France Maintenance Centre. In our work we reconstructed the weather situation along the flight path during the last two hours. It is obvious the AF-447 flight flew in moderate turbulent and icing conditions so this environment may have caused its accident. Finally we showed a high resolution WRF model simulation to demonstrate the weather situation with the special regard to icing condition.

Introduction

1 June 2009, AF447 flight during en-route flight from Rio de Janeiro Galeão airport for Paris Charles de Gaulle airport has disappeared over the Atlantic-ocean. The AF447 flight was a popular Airbus A-330-200 (F-GZCP) airplane in contact with the Brazilian ATLANTICO ATC centre on the INTOL – SALPU – ORARO oceanic high altitude route UN873, at FL350 (Figure 1). After the airplane passing INTOL waypoint the communication had broken with the crew. From 02.10 UTC, a position message and some maintenance messages were transmitted by the ACARS automatic system during the last 5 minutes of flight. The first wreckages of the airplane were found 6 June 2009 and there were no survivors at all.[1]

In our work we are going to describe the weather conditions during the last 2 hours of AF447 flight along its flight path with the special regard to that of the last 15–20 minutes. After we demonstrate and analyze the fault and warning messages sent by the A-330-200 airplane during last 5 minutes and examine their possible causes in connection with some meteorological events. Finally, we will show some details of preliminary high resolution reconstruction of weather situation around accident area applying the WRF meso-scale numerical meteorological model.

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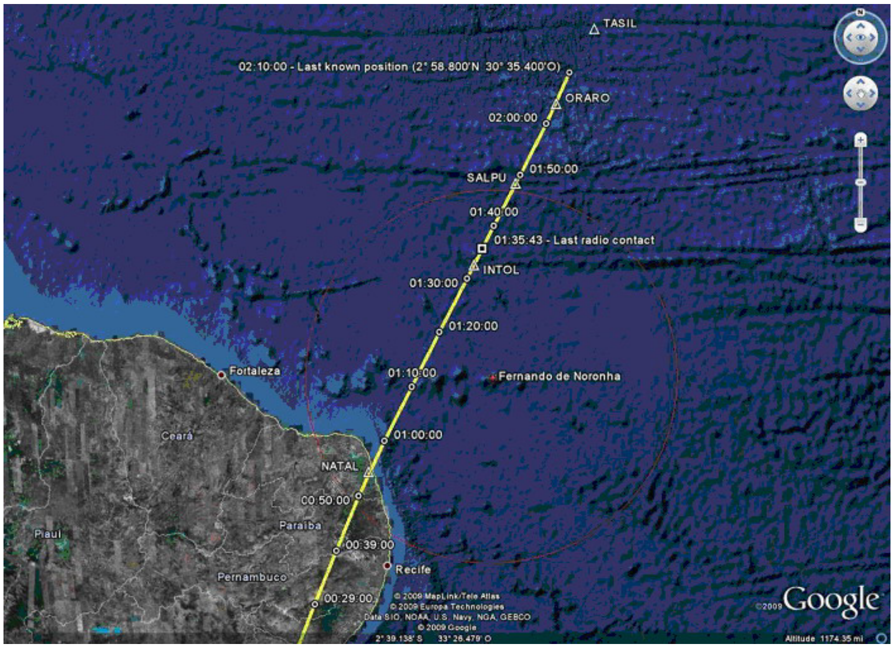


Figure 1. The known flight path of AF447 flight during the last 2 hours along the oceanic high altitude route UN873, at FL350, 01 June, 2009[1]

Basic meteorological conditions during last two hours along flight path of AF447

During en-route flight of AF447 there was a strong thunderstorm activity over the mid-Atlantic ocean along the flight path causing by regular seasonal ITCZ location over this area. The signed thunderstorm pattern (it was really a typical tropical MCS system) can be seen on the METEOSAT MSG-2 IR10.8 channel picture, very well. The thunderstorm cells had a huge vertical extension with the height of 55,000 ft and about –78 °C cloud top temperature (Figure 2).

The surface analysis (NCEP, 01 June 2009, 00 UTC) shows a homogenous maritime air mass with 27–28 °C surface temperature in the region of airplane crash. Also can be seen a significant convergence along the ITCZ which combined a highly unstable air produced a strong upward motion of moist air but there were not tropical cyclone activities at all (Figure 3).

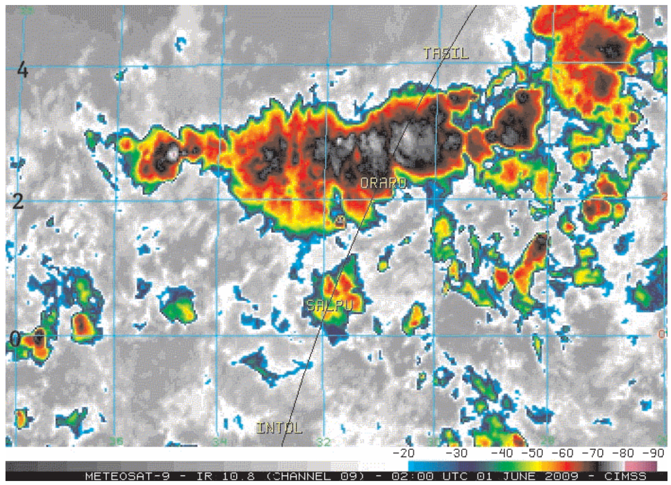


Figure 2. METEOSAT MSG-2 IR10.8 channel picture of intensive MCS systems along the flight path of AF447 01 June 2009. 02.00 UTC[2]

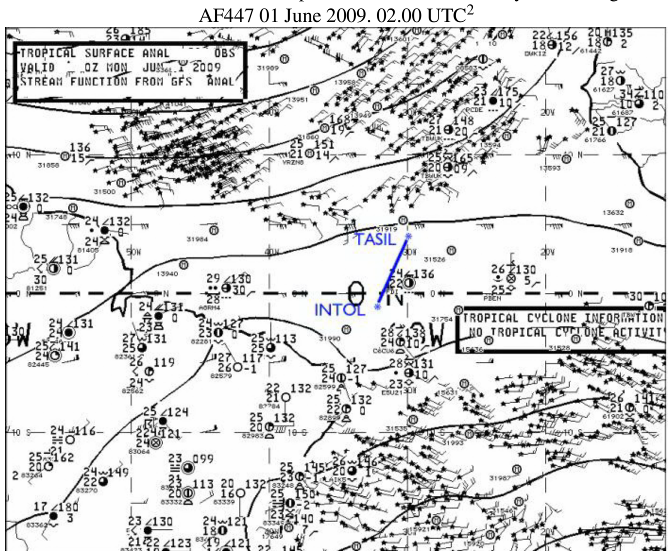


Figure 3. The surface analysis chart for 01 June 2009. 00 UTC by NCEP[2]

The vertical structure of temperature, humidity and wind aloft of tropical troposphere can be seen on the atmospheric sounding diagram of Fernando de Noronha (SBFN – 82400) 01 June 2009, 00 UTC (Figure 4).

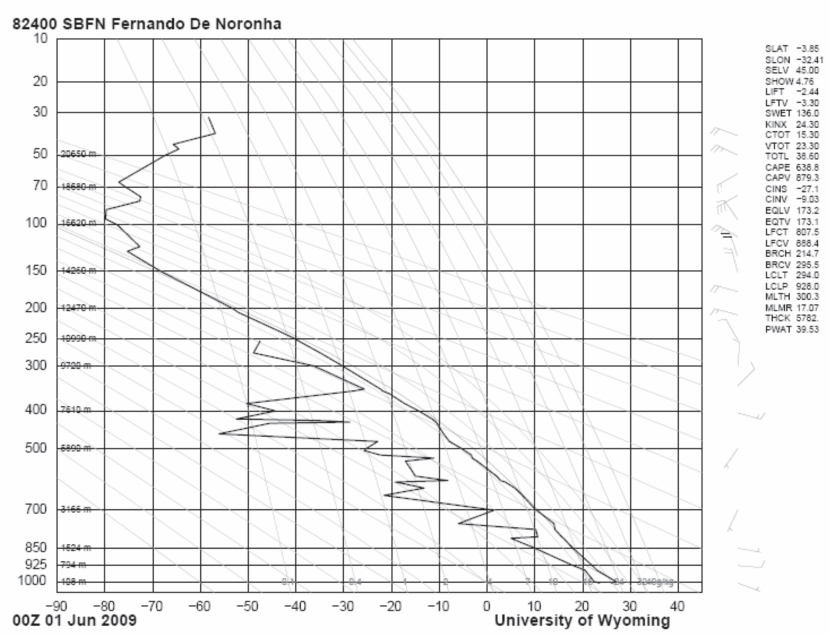


Figure 4. The vertical temperature, humidity and wind distribution of troposphere at Fernando de Noronha 01 June 2009. 00.00 UTC.
(Source: http://weather.uwyo.edu/cgi-bin/sounding?region=samer&TYPE=TEXT%3ALIST&YEAR=2009&MONTH=06&FROM=0100&TO=0100&STNM=82400. Downloaded: 14 April 2010)

There was a medium high (moderate) instability in the tropospheric air at the location of weather station of Fernando de Noronha with 639 J/kg CAPE and –2.44 LI values. Before the last 15–20 minutes of the flight at FL350 the temperature and average wind must have been about between –35 °C and –40 °C and 330–340° with speed of 5–7 m/s, respectively. Of course, the vertical structure of atmosphere at the mentioned weather station should have been significantly discrepant from the region's one the AF447 flight had abruptly disappeared, since the distance between two meteorological situation is about 800 km in space and 2 hours in time.

Despite of strong thunderstorm developments nobody could detect any lightning activities along the flight path of AF447 in the time interval between 01.00 UTC and 02.15 UTC.[2–4]

When the airplane had passed the INTOL waypoint, it entered an extended region which had enormous cumulonimbus (Cb) and towering cumulus (TCu) clouds with a high thunderstorm activity involved strong up- and downward air motion, hard 3D wind shear, fast and high intensity condensation, appreciable icing potential and mixed phased precipitation (hail, snow, graupel), too. The intensive MCS had crossed by AF447 flight appears the large East-West (about 700–800 km) and North-South (about 150–200 km) extended area in a light grey color on the satellite picture made by GOES satellite at 02.15 UTC (Figure 5). The squall-line had an extremely sharp stratiform Cb anvil edge and strong updraft cold spots in it as it can be seen in Figure 5.

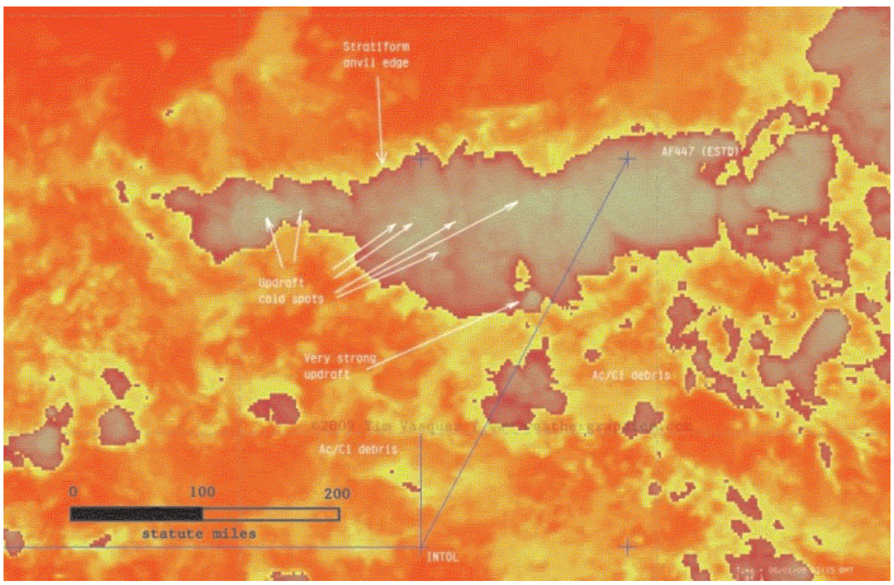


Figure 5. The GOES satellite imagery with the estimated flight path of AF447 flight from INTOL waypoint to its last estimated known position 01 June, 2009.[2]

Possible causes of improper air pressure measurements involved by atmospheric conditions during AF447 flight

Generally the most important hazardous factor related to air pressure sensors during thunderstorm activity is the icing process when the high amount of supercooled water droplets collide the air pressure sensors (Figure 6). As a result of icing the Pitot probe diameter decreases or obstructs. Although, this sensors are usually heated by electrical system but if the heating rate is not enough to keep the temperature of sensors higher than zero, the icing will happen. After INTOL waypoint the freezing level in the atmosphere was approximatively above 4,500 m (FL150) and the supercooled water droplets may located from this level to about 12,000 m (FL390) 01 June 2009.

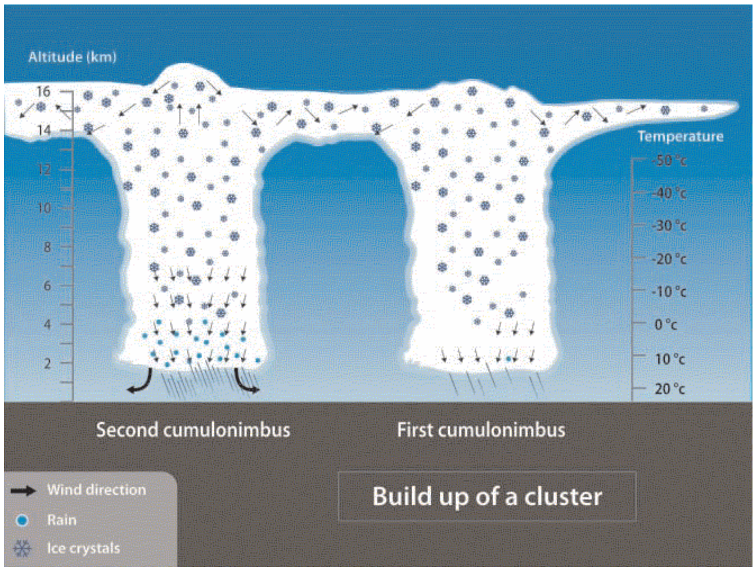
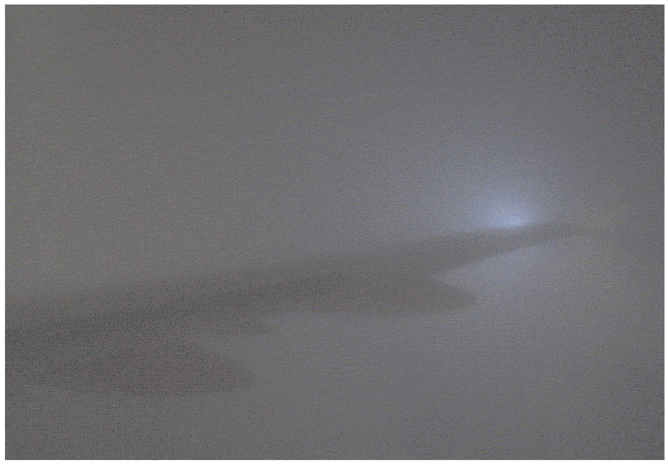


Figure 6. Build up of a thunderstorm cluster in the tropics with the dangerous icing conditions between 0 and –30 °C.

In a tropical maritime Cb cloud between the 4,000 m and 10,000 m there is a high probability of mixed phase precipitation e.g. shower, snow, hail, graupel which also may cause the improper behavior of air pressure sensors. For example, the collision with large ice crystals may produce many splints and they are able to get inside of sensors. On the other hand in a strong hailstorm the pressure sensors are liable to physical forces, too.

Although, based on satellite observation there were no significant lightning activities along the AF447 path the thunderstorm electricity may impinge on airplane. Nevertheless the LH507 (B-747-400) flight flew about 20 minutes earlier than AF447 (also at FL350) and the LH507 crew saw bright St Elmo's fire on the windshield! It means that numerous pregnant electrostatic processes had hardly worked there (Figure 7). This phenomenon is observed when an airplane flies across or close to a region of the atmosphere having intensive thunderstorm activity and there is a strong electric field around the airplane.[3,4,6]

Crews often observed bad or very poor radio transmittance during their flight under such meteorological conditions, maybe it was happened to AF447.



(a)

(b)

Figure 7. St. Elmo's fire around an airplane wingtip (a) and on the windshield of an A-320 airplane (b)

High resolution reconstruction of thunderstorm activity along the AF447 flight path during the last 45 minutes applying of WRF meso-scale numerical model

To demonstrate quantitatively the icing situation at FL350 in the signed time period we applied the WRF meso-scale numerical weather forecast model and also used the NCEP GFS archive 0.5 degree global data as initial and boundary conditions. The theoretical background of this work based on the downscale procedure of a global model. In the course of downscaling we used the mentioned global model data as input for our WRF software to determine high resolution main meteorological parameters both in time and space along the AF447 route.[7,8] The high resolution is very important because the order of lifetime of a thunderstorm cell and spatial extension are about 1 hour and 10 km, respectively.

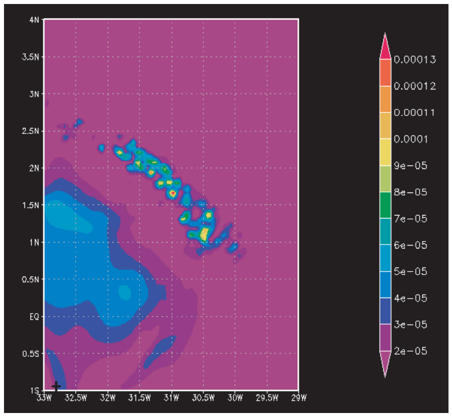
Conversely, in the WRF simulation the applied horizontal grid size and time step were 5×5 km and 30 s, respectively. The chosen parameterizations can be seen in Table 1.

Table 1. Applied WRF model parameterization

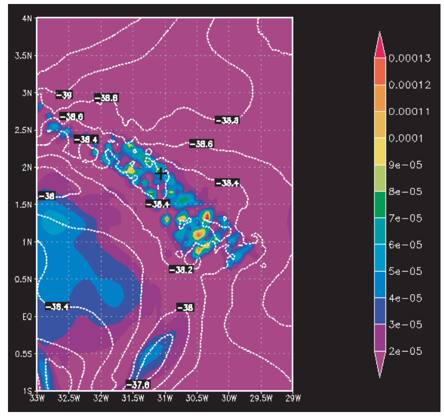
Atmospheric processes	WRF
Radiation	LW: RRTM; SW: Goddard
Surface layer	Monin-Obukhov
Boundary layer	MYJ
Cumulus	Grell – Devenyi ensemble
Microphysics	WSM – 3
Land surface layer	Noah

In our work we show the preliminary results of a substantial thunderstorm parameter (ice mixing ratio) distribution in time and space based on our WRF estimate (Figure 8). (Ice mixing ratio shows the ice particle content in the air.) Like in the IR10.8 satellite picture.

The isotherms and black crosses represent the temperatures (°C) and the airplane position retrieved by ACARS system (Figure 2) we can also see a strong squall-line in the WRF output pictures. This thunderstorm pattern was in progress with many active cells inside it and the maximum of mixing ratio reached the 0.13 g/kg value. The highest ice particle content could be found inside of the thunderstorm cells but not at the altitude of FL350. As it can be seen well the number of ice particles in the atmosphere outside of the sqall-line was very low. However the AF447 flight entered the vertically active zone after it had passed INTOL waypoint at about 01.33 UTC. (Figure 2 and Figure 8a) It means the AF447 flight crew may have observed a progressing thunderstorm activity with turbulence, icing and electricity, too. After 20–30 minutes, the A-330-200 airplane had arrived to the border of the strongest part of the mentioned squall-line with high values of positive charged ice particles mixing ratio. The air temperature calculated by WRF model would have been about –37– –39 °C (Figure 8b).



(a)



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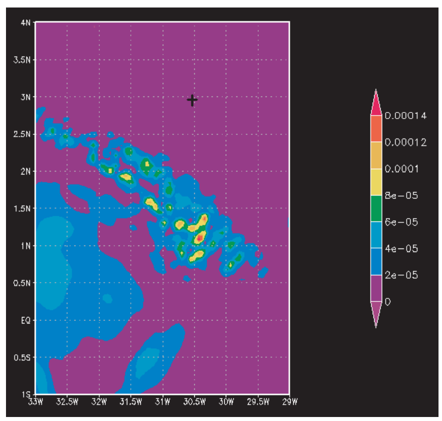

(c)

Figure 8. The WRF model estimation of spatial distribution of ice mixing (kg/kg) ratio at FL350 along the AF447 flight path 01 June 2009. (a) 01.30 UTC. (b) 02.00 UTC. (c) 02.15 UTC.

This fact is checked up with the LH507 report regarding St. Elmo's fire phenomena and other airplanes OAT data. At 02.15 UTC the thunderstorm activity was heavy enough to produce for example more ice particles and the atmospheric environment around AF447 had not get better (Figure 8c).

Based on the satellite images, our WFR simulation and airplane position reports we predict the AF447 flight could never left the squall-line (MCS) cloud system at all. It follows among the possible causes of examined fatal accident the impacts of observed and modeled thunderstorm activity may had been the most important ones.

We have to note our WRF estimate of squall-line location differs from its position derived by satellite images but this difference is a natural behavior in this case derived from several errors of GFS input data and WRF model.

The WRF simulation made by ZMNDU, Department of Air Traffic Controller and Pilot's Training, Aviation Weather Laboratory (AWL).

Summary

01 June 2009, the AF447 flight crashed over the mid-Atlantic ocean.

There was a strong thunderstorm activity along the flight path during the last 30–40 minutes of the flight.

The airplane had sent fault and warning messages which indicated the problem with air pressure sensing system.

The high resolution WRF simulation confirmed an intensive ice particles accumulation in a squall-line crossed by AF 447 at FL350 when the accident happened.

The thunderstorm activity may have played an important role in the fatal accident of AF 447 flight.

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