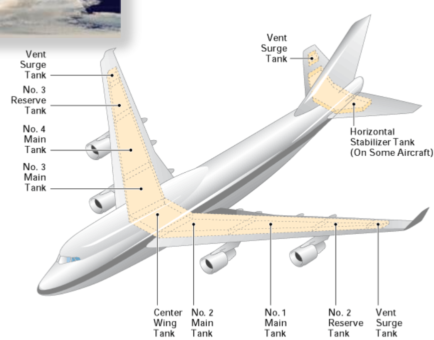
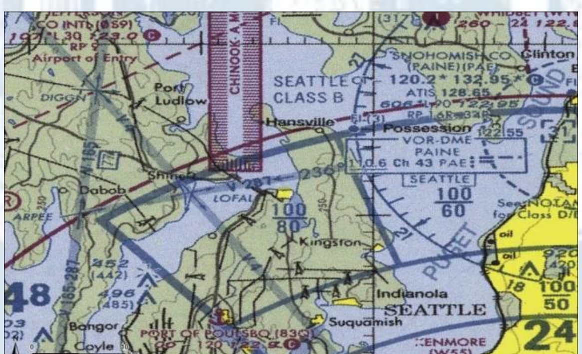
RISKS OF ATMOSPHERIC RE-ENTRIES ON AIRCRAFTS
CNES PROGRESS ON STUDIES





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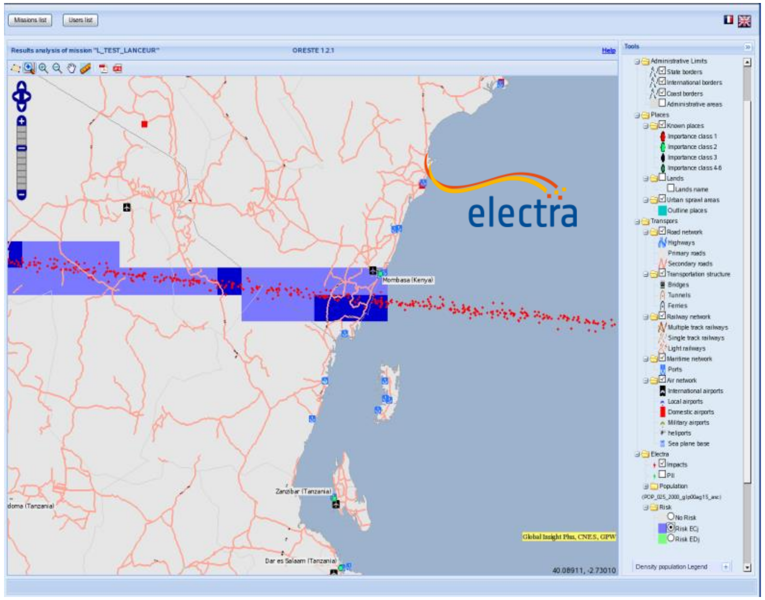
IAASS 20-23 october 2014

Since 2010, the ELECTRA risk calculation model of falling debris to the public have been used by French space operators on launch and atmospheric re-entries to guarantee optimum safety for residents on the ground.

Considerations on air traffic have now to be developed, especially as planes fly over unpopulated areas such as oceans, so currently identified as safe.

Numerical representation of "air occupation" over the world is the first step for risks calculations.



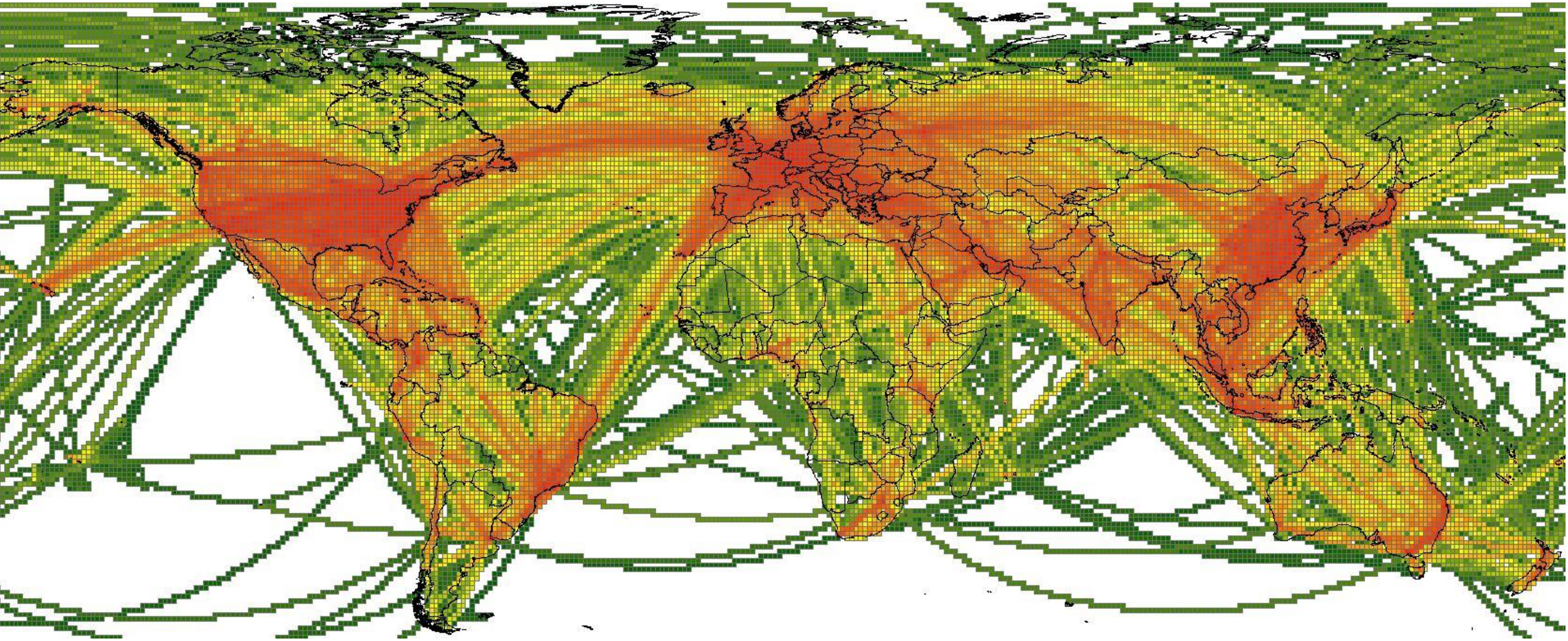
*Computed **ELECTRA** Impact footprint and level of risk by cell, on **ORESTE** display.*

Over ocean, assessed level of risk is zero

CNES Partner : SERTIT, Image Processing and Remote Sensing Service of the University of Strasbourg, France

R&T program

The first global grid of « air occupation » (1)



Display of « Air occupation » global grid – 1 deg. arc

CNES asked SERTIT to study the feasibility and method of constructing global grids of « air occupation ».
This lead to the first usable ASCII grids of air occupation and density, with precision 1° and 15'

The first global grid of « air occupation » (2)

Fichier Accueil Insertion Mise en page Formules Données Révision Affichage Foxit Reader

B13 f_x 0.01339994

	A	B	C	D	E	F	G	H
1	ncols	360						
2	nrows	174						
3	xllcorner	-180						
4	yllcorner	-90						
5	cellsize	1						
6	NODATA_val	-9999						
7	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
8	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
9	0.0130402	0.0130402	0.0130402	0.0130402	0.0130402	0.0130402	0.0130402	0.0130402
10	0.01327612	0.01327612	0.01327612	0.01327612	0.01327612	0.01327612	0.01327612	0.02543353
11	0.01219205	0.01219205	0.01219205	0.01219205	0.01219205	0.01219205	0.01219205	0.01219205
12	0.02271069	0.02271069	0.02271069	0.02684607	0.02684607	0.02684607	0.02684607	0.02684607
13	0.01339994	0.01339994	0.01339994	0.01339994	0.009250722	0.009250722	0.02418792	0.02841876
14	0.004246004	0.004246004	0.01549587	0.03048659	0.03048659	0.0404804	0.0404804	0.02548968
15	0.02878893	0.02878893	0.02369645	0.01241634	0.01241634	0.01671483	0.006694146	0.006694146
16	0.004315878	0.009428957	0.009428957	0.01789578	0.0127827	0.0127827	0.008466819	0.008466819
17	-9999	0.009938363	0.01986292	0.02499774	0.02499774	0.01986292	0.01986292	0.01986292

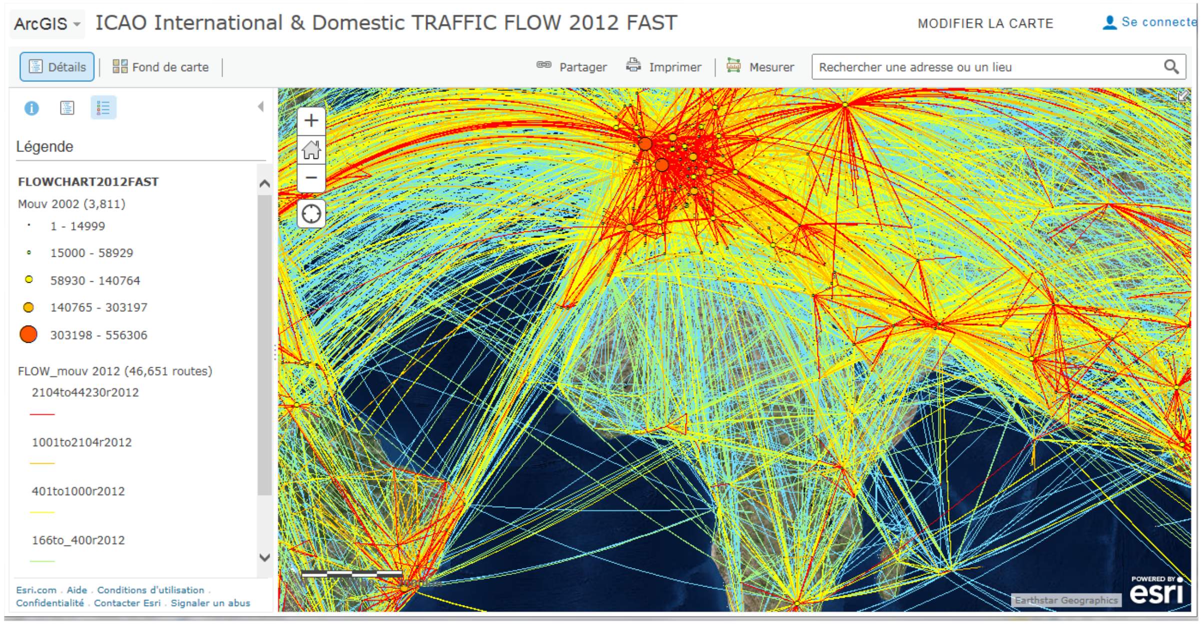
Table of global « Air occupation » global grid – 1 deg. arc

ASCII file of "air occupation" global grid offers the same format as "gridded population of the world" from CIESIN. This is the most practical format to create a calculation tool.

Construction of global grid of « air occupation » - GI sources (1)

To collect geo aeronautical data relevant to the issue, major producing organizations or users of aeronautical information, were contacted: DGAC-SIA (France), EUROCONTROL, ICAO, Eastview Geospatial Inc., Jeppesen, …

The first immediately available aeronautical Geo Information database for our purpose was the ICAO 2012 Global Traffic Flow : it gives in an ESRI shapefile the global flow of commercial air traffic between airports, processed from 2012 international and domestic data.



ICAO 2012 global traffic flow
Display of direct paths

The dataset is composed of 4,300 cities, 46,651 routes and 31,651,337 movements.

Each city pair is bidirectional, movements are given for each direction.

Construction of global grid of « air occupation » - GI sources (2)

FLOWmouv2012all

FID	Shape *	NM	ORIGIN	DESTINATIO	STATE_ORIG	STATE_DEST	ROUTE	_FLIGHTS_	FLIGHTS_20	SERIE	pourc	FLY_2012	pourc10_12	Kind
0	Polyline	235.460678	ANAA	PAPEETE	French Polynesia (Fr.)	French Polynesia (Fr.)	ANAA/PAPEETE	82	52	0	57.692308	57	-43.859649	DOM
1	Polyline	548.105077	ANNABA	LYON	Algeria	France	ANNABA/LYON	117	81	0	44.444444	117	0	INT
2	Polyline	413.529556	ANNABA	ORAN	Algeria	Algeria	ANNABA/ORAN	110	58	0	89.655172	157	29.936306	DOM
3	Polyline	766.379125	ANNABA	PARIS	Algeria	France	ANNABA/PARIS	324	134	0	141.791045	341	4.985337	INT
4	Polyline	596.99626	AALBORG	FAROE ISLANDS	Denmark	Faroe Islands (Den.)	AALBORG/FAROE ISLANDS	23	1	0	2200	17	-35.294118	INT
5	Polyline	1129.625261	AL AIN	AMMAN	United Arab Emirates	Jordan	AL AIN/AMMAN	83	21	0	295.238095	38	-118.421053	INT
6	Polyline	1459.867481	AL AIN	COCHIN	United Arab Emirates	India	AL AIN/COCHIN	52	2	0	2500	52	0	INT
7	Polyline	1014.760626	AL AIN	PESHAWAR	United Arab Emirates	Pakistan	AL AIN/PESHAWAR	208	49	0	324.489796	70	-197.142857	INT
8	Polyline	1184.662024	ANAPA	ARKHANGELSK	Venezuela	Russian Federation	ANAPA/ARKHANGELSK	32	21	0	52.380952	31	-3.225806	INT
9	Polyline	422.785176	ANAPA	YEREVAN	Venezuela	Armenia	ANAPA/YEREVAN	24	70	0	-65.714286	13	-84.615385	INT
10	Polyline	706.397398	ANAPA	SAMARA	Venezuela	Russian Federation	ANAPA/SAMARA	27	59	0	-54.237288	6	-350	INT
11	Polyline	930.159989	ANAPA	ST-PETERSBURG	Venezuela	Russian Federation	ANAPA/ST-PETERSBURG	239	85	0	181.176471	146	-63.69863	INT
12	Polyline	1678.743476	ANAPA	NIZHNEVARTOVSK	Venezuela	Russian Federation	ANAPA/NIZHNEVARTOVSK	44	24	0	83.333333	34	-29.411765	INT
13	Polyline	1813.154872	ANAPA	NOVOSIBIRSK	Venezuela	Russian Federation	ANAPA/NOVOSIBIRSK	13	15	0	-13.333333	47	72.340426	INT
14	Polyline	1109.462195	ANAPA	SYKTYVKAR	Venezuela	Russian Federation	ANAPA/SYKTYVKAR	32	25	0	28	47	31.914894	INT
15	Polyline	1277.737205	ANAPA	TYUMEN	Venezuela	Russian Federation	ANAPA/TYUMEN	198	26	0	661.538462	105	-88.571429	INT
16	Polyline	169.435253	ARAXA	BELO HORIZONTE	Brazil	Brazil	ARAXA/BELO HORIZONTE	523	50	0	946	618	15.372168	DOM
17	Polyline	460.688347	AL GHAYDAH	SANA'A	Yemen	Yemen	AL GHAYDAH/SANA'A	106	35	0	202.857143	69	-53.623188	DOM
18	Polyline	942.828714	ABAKAN	NORILSK	Russian Federation	Russian Federation	ABAKAN/NORILSK	55	53	0	3.773585	47	-17.021277	DOM
19	Polyline	486.943641	ABADAN	DUBAI	Islamic Republic of Iran	United Arab Emirates	ABADAN/DUBAI	33	55	0	-40	86	61.627907	INT
20	Polyline	234.371092	ABADAN	ISFAHAN	Islamic Republic of Iran	Islamic Republic of Iran	ABADAN/ISFAHAN	156	157	0	-0.636943	130	-20	DOM
21	Polyline	231.99312	ABADAN	SHIRAZ	Islamic Republic of Iran	Islamic Republic of Iran	ABADAN/SHIRAZ	195	53	0	267.924528	163	-19.631902	DOM
22	Polyline	758.576585	ABILENE, TX	BULLHEAD CTY, AZ	United States	United States	ABILENE, TX/BULLHEAD CTY, AZ	7	5	0	40	2	-250	DOM

ICAO 2012 global traffic flow
Shapefile Table view

The dataset is composed of 4,300 cities, 46,651 routes and 31,651,337 movements.

Each city pair is bidirectional, movements are given for each direction.

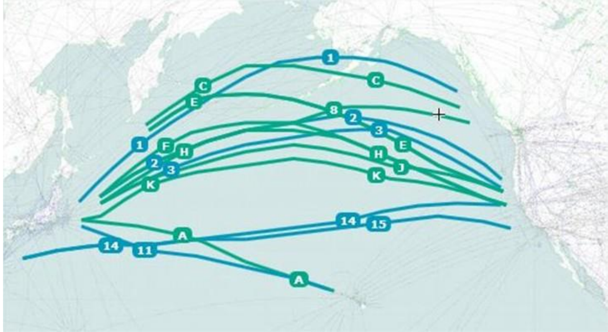
FLIGHTS: movements nb 2010; FLIGHTS_20: movements nb 2002;
pourc : a2002-2010 augmentation; pourc10_12: 2010-2012 augmentation

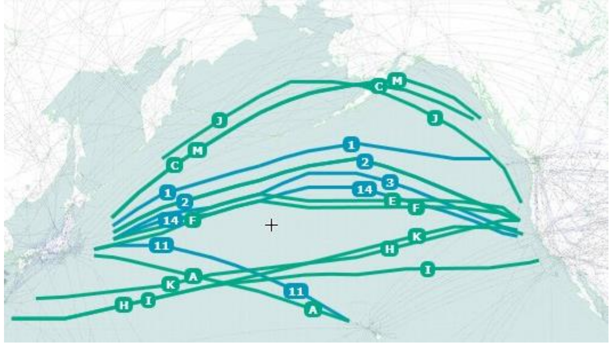
ICAO 2012 global traffic flow has the advantage of providing global air flow data directly in a geographical format. Some limits were nevertheless highlighted:

The impossibility to know the temporal distribution of the flights: during the year or according to day and night. No indication is given on the dates and times of flights.

The difficulty to interface the traffic flow data with the airways provided by other databases, because :

- These data are from various origin and format
- the airways are not known early enough exhaustively: for example, North Atlantic and Pacific tracks are modified every day depending on meteorological conditions to reduce flight time and fuel





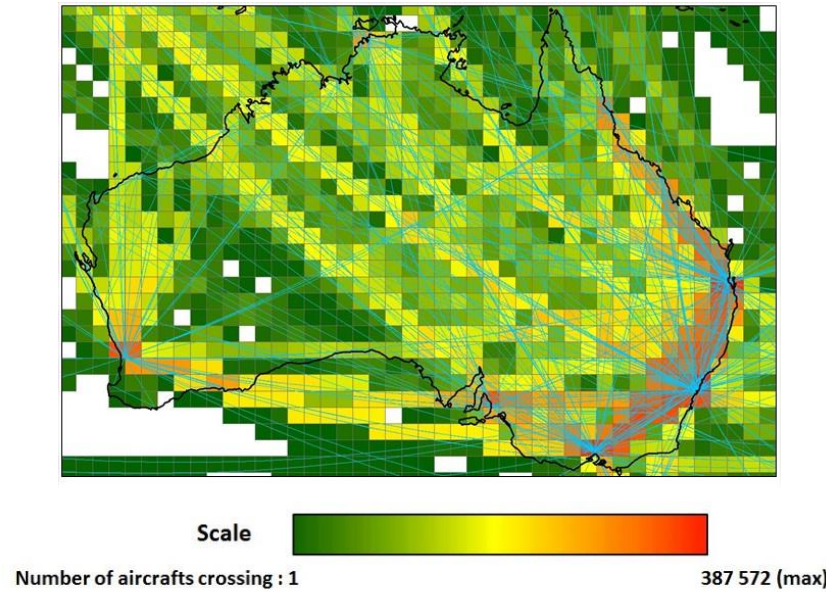
Pacific tracks different each day
Views on 09/12/2013
and 25/09/2014
(http://skyvector.com/)

Use of ICAO global traffic flow 2012 for the construction of an average global grid of “air occupation”

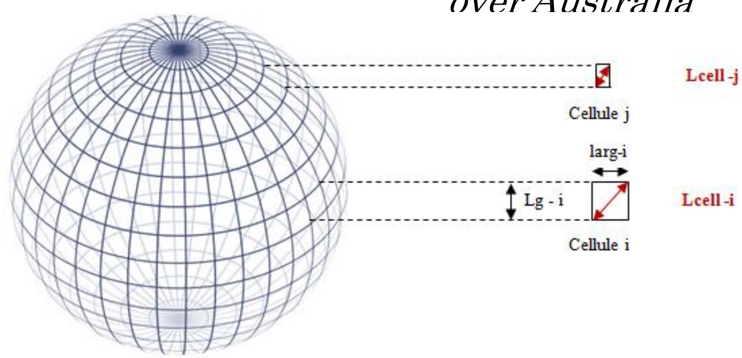
The idea is as follows: for each air link between two airports, we can plot geographically the most direct path and ICAO database can give the number of flights per year for each of these path.

The principle of a geographical grid is to divide the Earth in regular cells with a given resolution on latitude and longitude and to assign to each unit cell a value of the measured variable considered: for our purpose, we computed

- air traffic flow: number of aircrafts crossing the cell in one year
- mean number of aircrafts occupying the cell,
- density of aircrafts.



Air traffic flow grid
- 1° of arc -
over Australia



Computing average aircrafts occupation and density on each cell:

If you are an observer in the cell, it corresponds to the number of aircrafts you see on your vertical, averaged over time. It depends on :

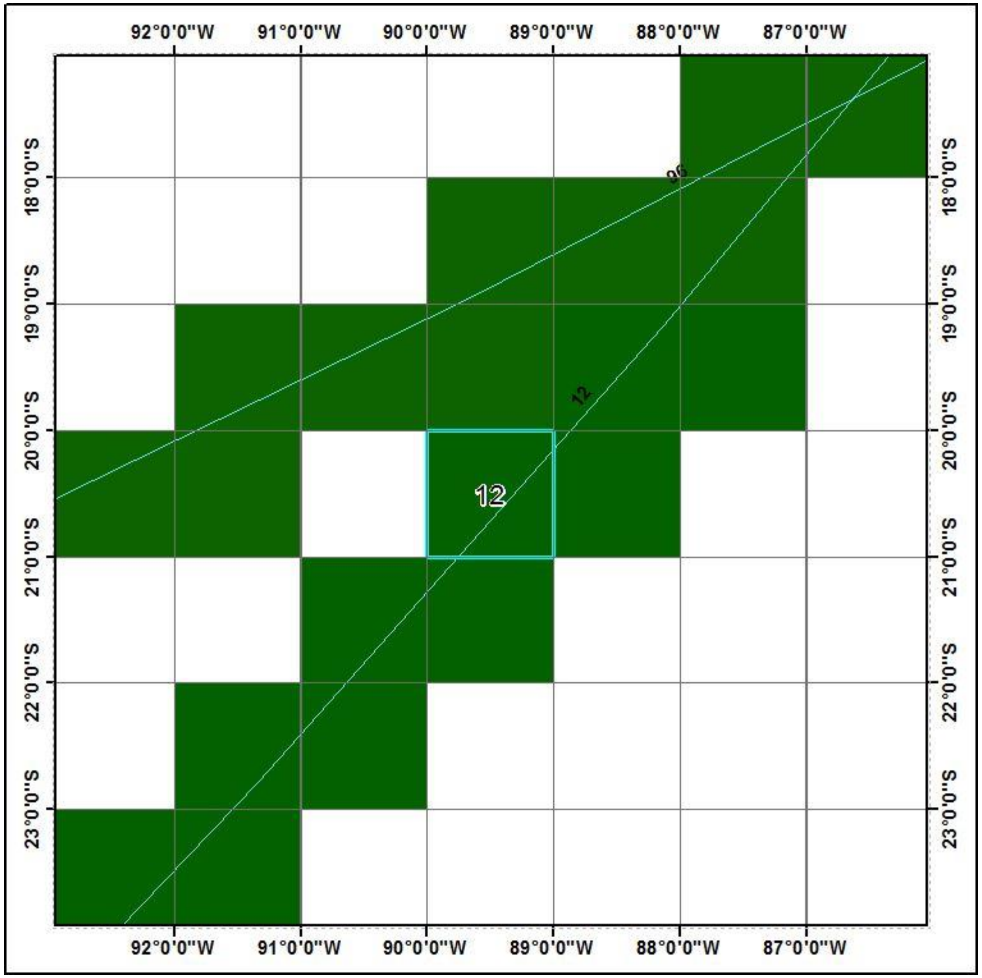
- the number of aircrafts crossing the cell
- the time they need to cross, so their speed.

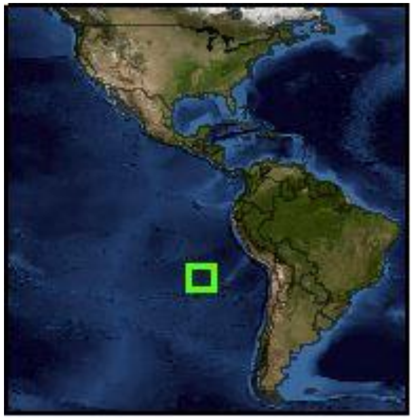
Flow-year : number of flights crossing the cell per year = Sum of ICAO movements crossing the cell per year, based on direct paths.
Year-sec : Year duration in sec (31 556 952 s).
Cell-length : Length of cell cross, assimilated to the diagonal of the rectangle defined by length and width of the cell (worst case)
Cell-surface : Surface of cell
Aircraft-speed : mean cruising speed of a flight : choice is 266m/s at 35 000 feet
Nb-aircrafts : Mean number of aircrafts occupying the cell
D-aircrafts : Density of aircrafts occupying the cell

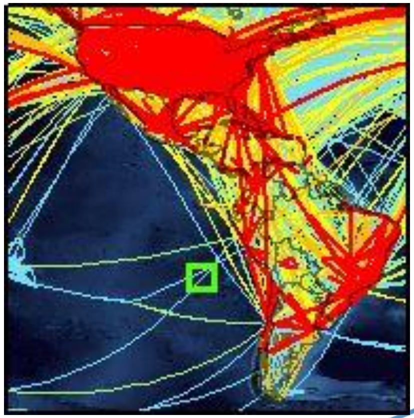
Nb-aircrafts = (Flow-year/Year-sec)x(Cell-length/Aircraft-speed)

D-aircrafts= Nb-aircrafts/Cell-surface

Construction of global grid of « air occupation » - Illustration (1)



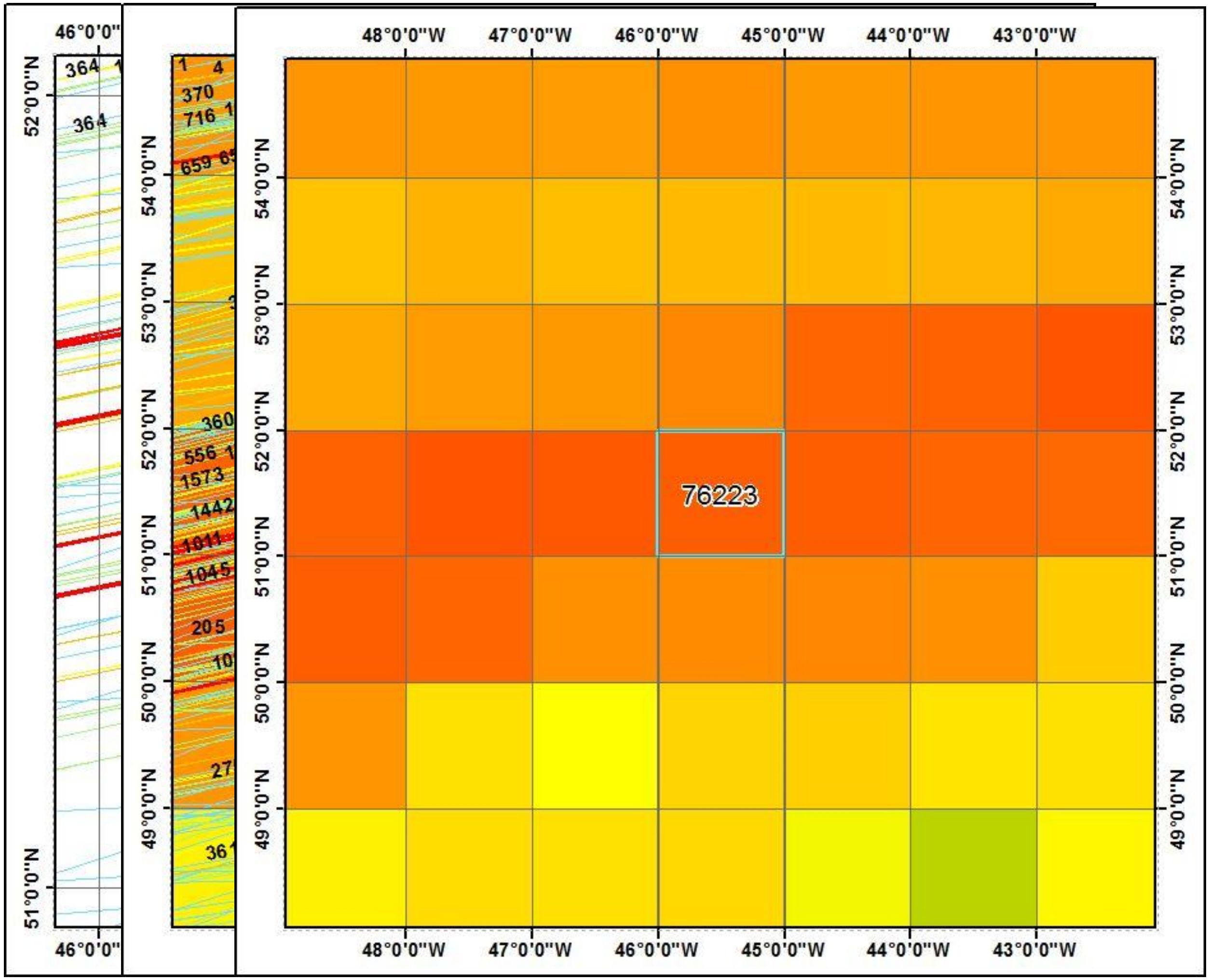


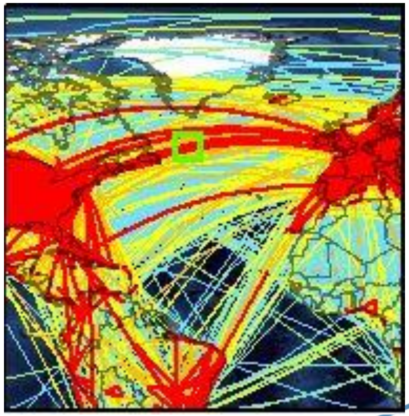


cell (21°S, 90°W) : 12 flights crossing/year

Mean number of aircrafts on the cell: 2,18.10^{-4}
Density of aircrafts : 1,89.10^{-8}

Construction of global grid of « air occupation » - Illustration (1)





cell (51°N, 46°W) : 76223 flights crossing/year

Mean number of aircrafts on the cell: 1,19
Density of aircrafts : 1,55.10^{-4}

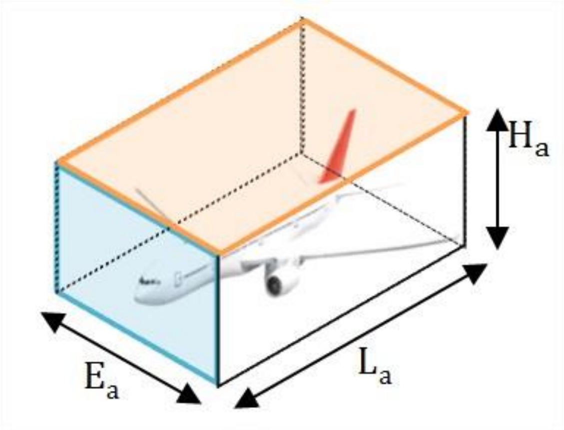
The air traffic risk model could be based on two indicators:

1st indicator - Probability of critical crossing

The critical crossing corresponds to the intersection of the debris with the top or the front of the box bounding the aircraft.

Probability of critical crossing would depend on the average dimensions and speed of aircrafts, and speed of debris.

Casualty area would take into account the orientation of velocity vectors – aircraft and debris –, the aircraft front and top surface, and also the debris surface.



Bounding box for critical crossing

Average commercial airliner: Front surface of about 500m^2 and top surface around 1600m^2 (estimates from manufacturers' databases)

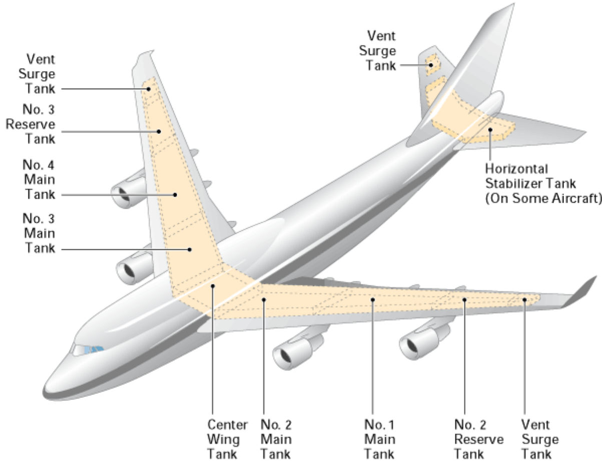
The air traffic risk model could be based on two indicators:

2nd indicator - Risk of catastrophic event

The risk of catastrophic event would add on critical crossing calculation a coefficient of vulnerability of the aircraft.

The coefficient of vulnerability would correspond to the fraction of vulnerable surface of a plane relative to the surface of top and front of the bounding box: it would be depending on the kinetic energy of the debris and the shock tolerance of the surface considered.

The weak elements for the device would include especially the windshield of the cockpit and the wings with the tanks inside.



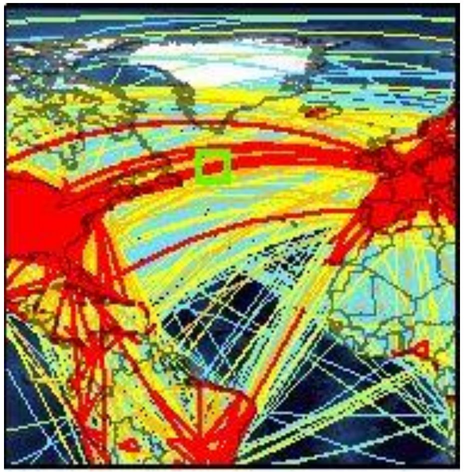
Identification of weak elements of the top surface of aircrafts

For the following basic example, we choose the falling of a titane sphere of mass 50 kg and collision surface 1m^2.

Considering the kinetic energy of this debris, the fraction of vulnerable surface of planes relative to the surface of top and front of the bounding box is estimated at **4%**.

Supposing that re-entry area is on the air tracks of north Atlantic, meaning :
- flow has the characteristics of Cell 1° (51°N, 46°W)
  ➔ Mean number of aircrafts per cell 1° of arc : **1,19**
- planes are international flights only (big dimensions)

Probability of critical crossing: 5.07E10^{-7}
Risk of catastrophic event: 2.06 E10^{-8}



Reentry area

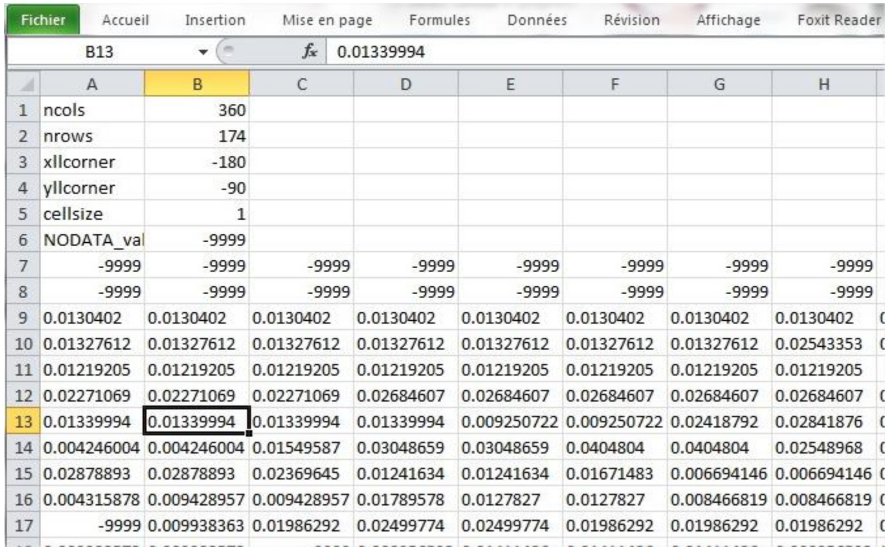
CNES has now a numerical representation of the world air distribution. The first air traffic grids produced are based on recent ICAO global traffic flow data: they provide average aircrafts presence and average density in an ASCII format for risks calculation.

They are based as a first approach on the most direct trajectories.

Computed air occupation is limited to commercial activities

It is averaged over day and night and over the year.

For maxima of risks ➔ need of a specific grid to identify concentrations of air traffic (airports areas, daytime).



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4	yllcorner	-90						
5	cellsize	1						
6	NODATA_val	-9999						
7	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
8	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
9	0.0130402	0.0130402	0.0130402	0.0130402	0.0130402	0.0130402	0.0130402	0.0130402
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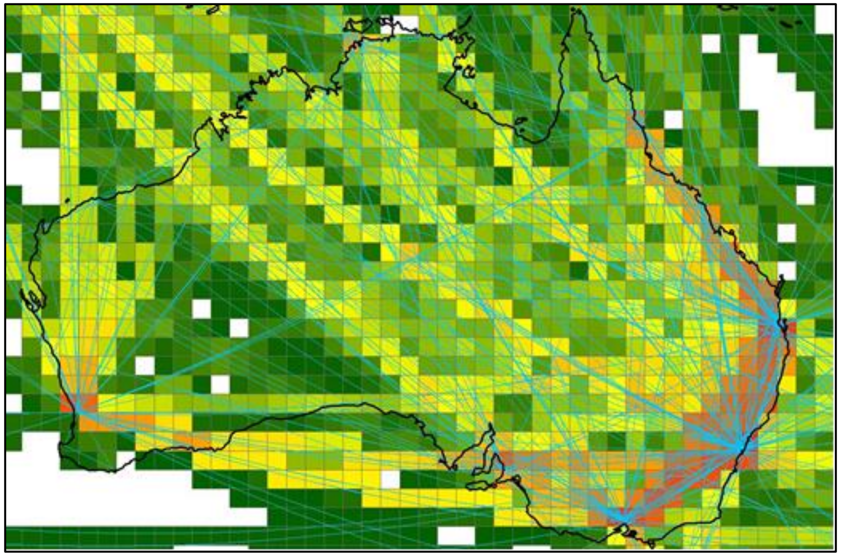
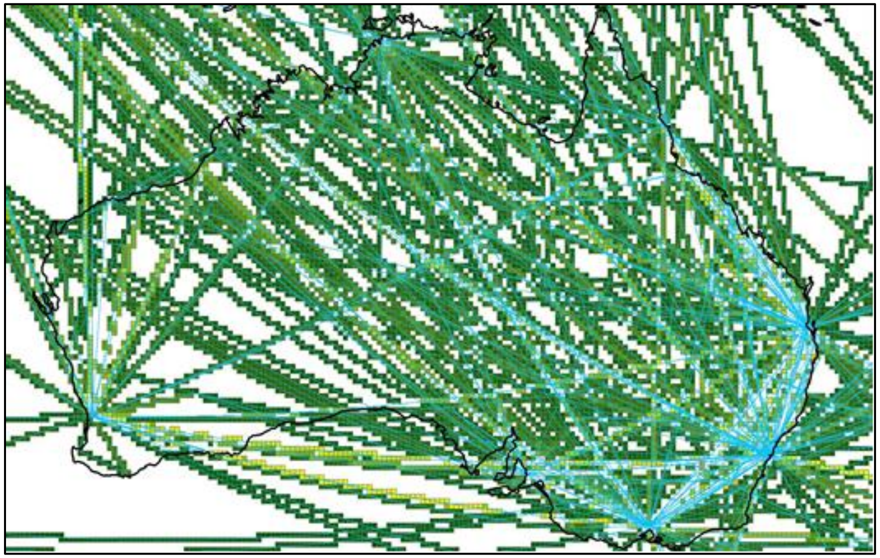
17	-9999	0.009938363	0.01986292	0.02499774	0.02499774	0.01986292	0.01986292	0.01986292

Table of global « Air occupation » global grid 1 deg. arc

These grids were processed with two resolutions: 1° and 15' of arc.



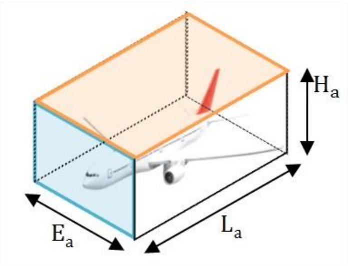
Flow count : 1° of arc

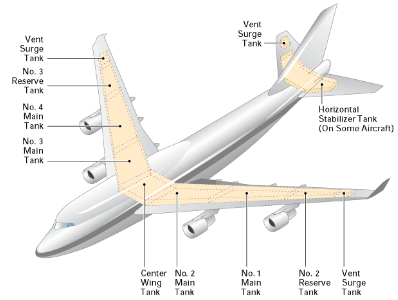


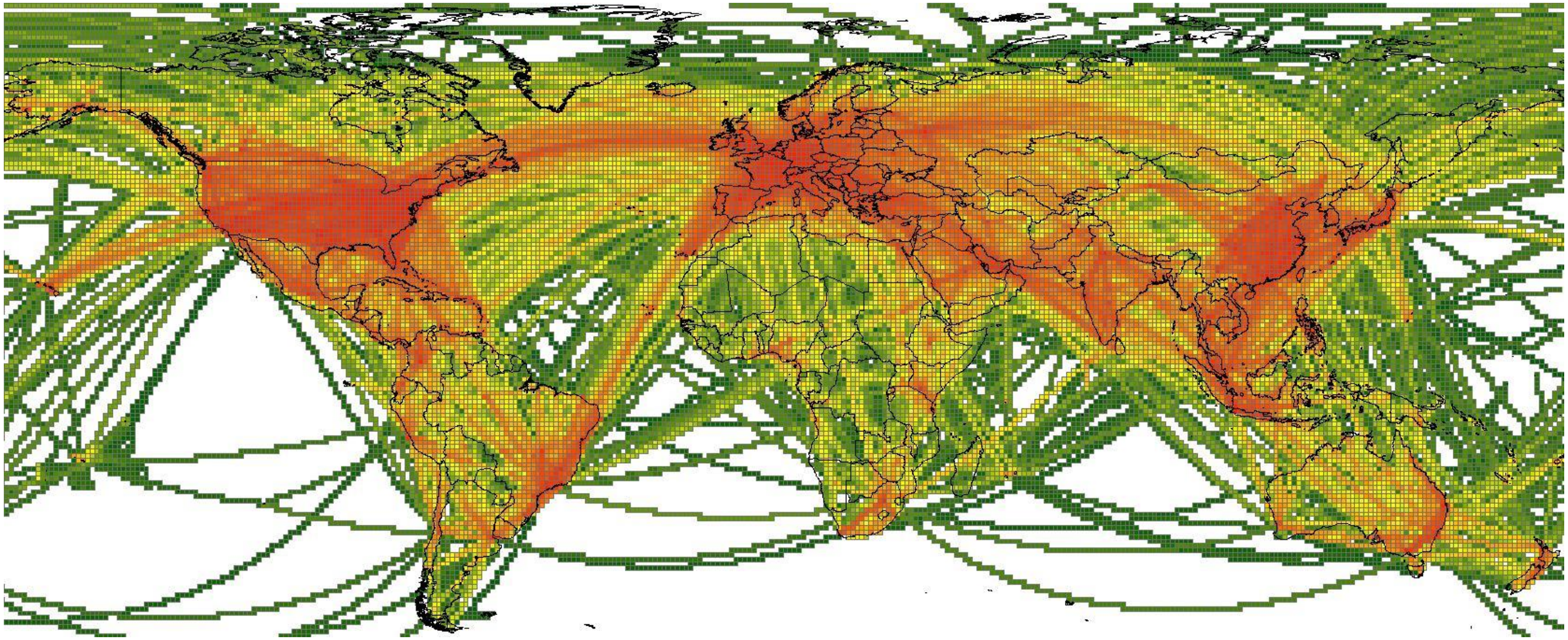
Flow count : 15' of arc

Air flow global grids over Australia : 1° and 15' of arc

Next step will be to develop more precisely the air traffic risk model :
- probability of critical crossing
- risk of catastrophic event







Display of « Air occupation » global grid – 1 deg. arc

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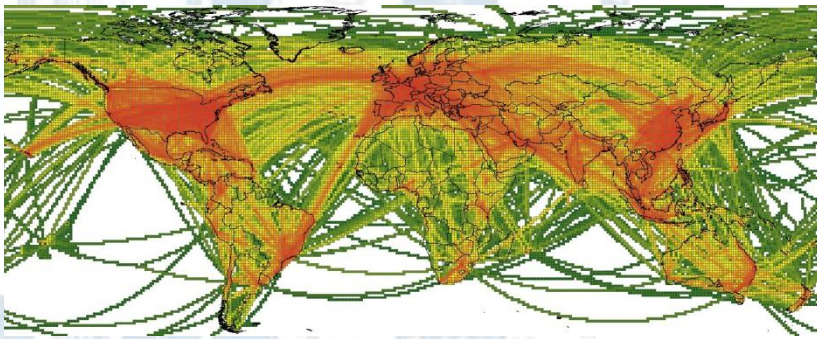
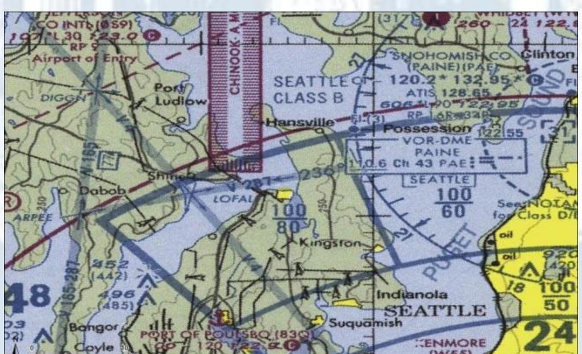
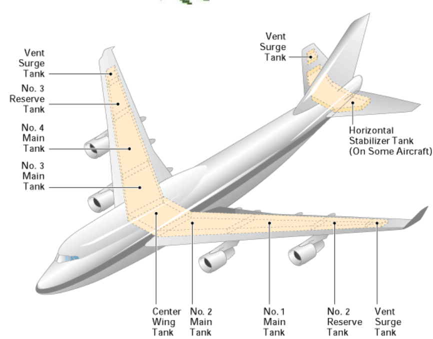
CNES PROGRESS ON STUDIES







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IAASS 20-23 october 2014