



Bayesian Search for Missing Aircraft

Bayesian search theory provides a principled and successful method for planning searches for lost aircraft and other objects

Wednesday 28 August 2019

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*Royal Geographic Society-IBG Annual International Conference
London, England*

Outline

- What do we mean by Bayesian search?
- Example: Air France AF447 Search Planning
- Malaysia Airlines MH370

Bayesian Search Planning Process

Construct “Prior”
Probability
Distribution on
aircraft location

- Organize information into scenarios
- Quantify uncertainties
- Compute PDF for each scenario
- Weight each scenario
- Combine into a single PDF

Estimate search
effort
effectiveness

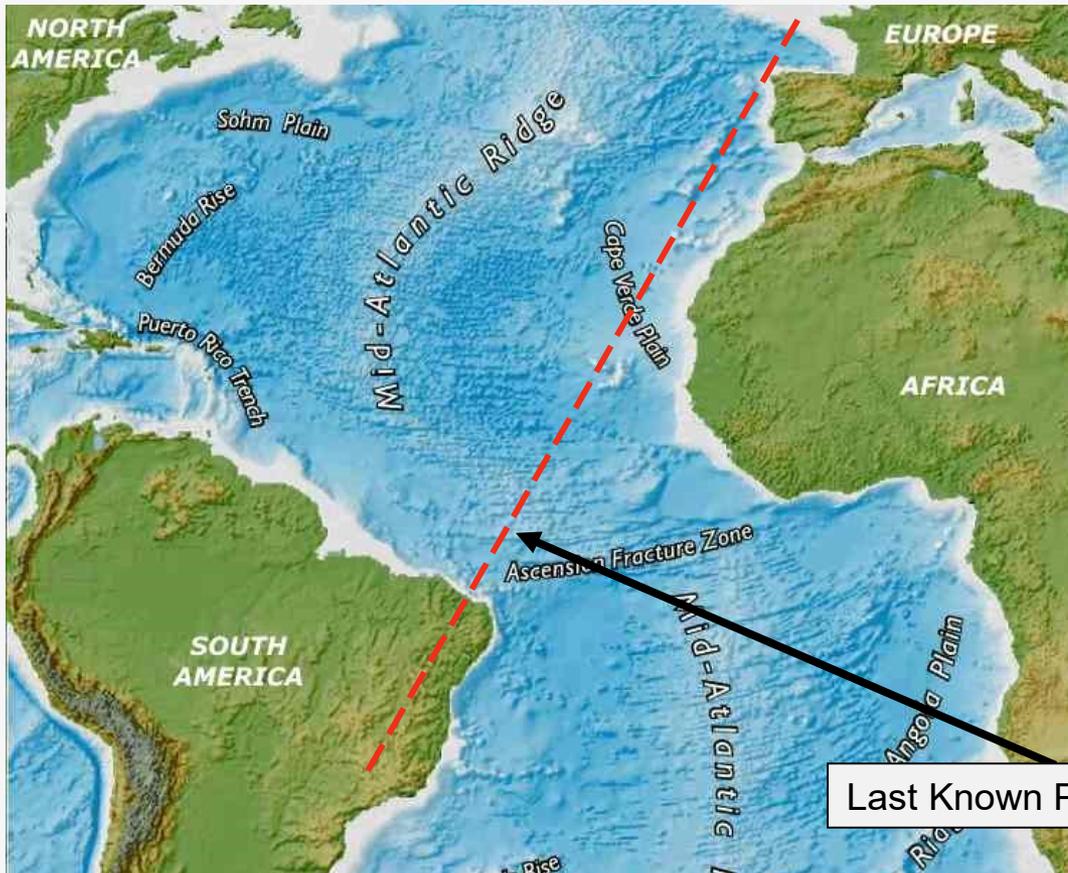
Update Prior with
search effort:
“Posterior” PDF

Use Posterior PDF
to make search
decisions

Repeat these steps for each
search phase

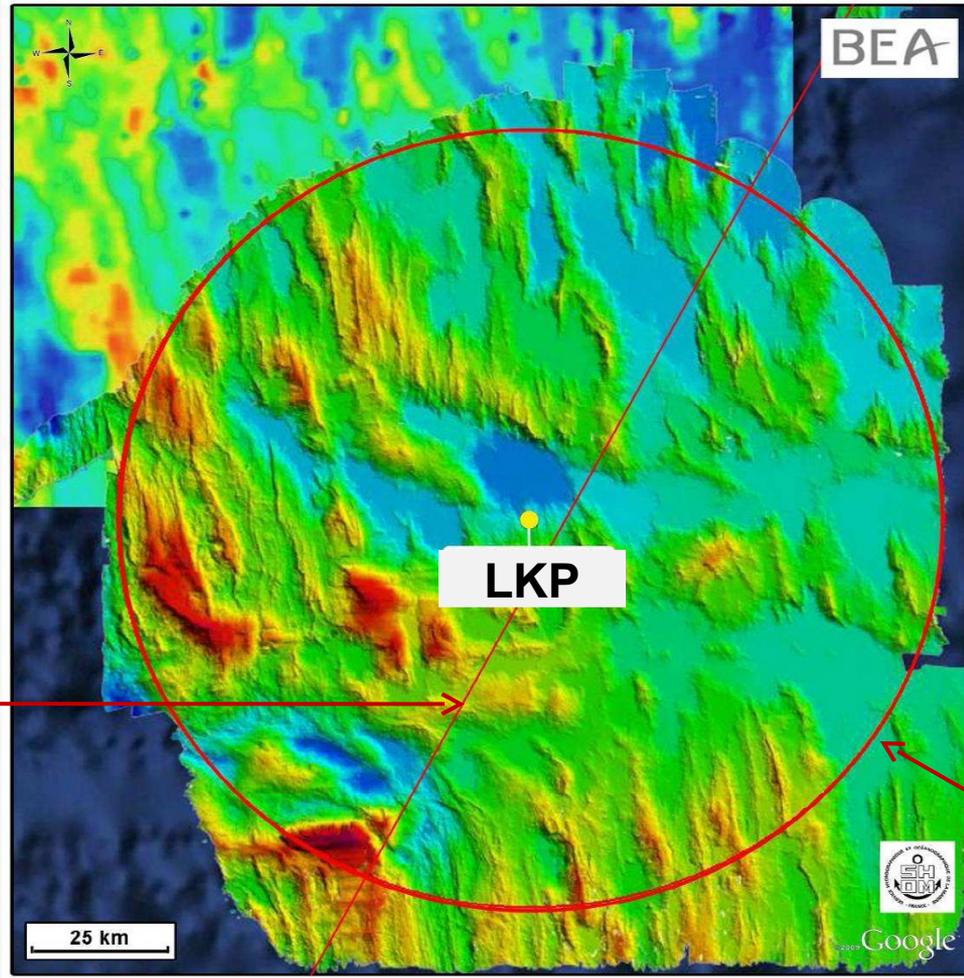
- Where should I search next?
- How much longer should I search?
- How many search assets will I need?

Air France Flight 447: Open Ocean Search for Wreckage



- In the early morning hours of 1 June 2009, Air France Flight 447, and Airbus 330 bound for Paris with 228 passengers and crew, disappeared during stormy weather over the South Atlantic
- The French Bureau of Enquiries and Analyses (BEA) took charge of the search.

Last Known Point and Search Containment Area



Satellite comms data determined that the plane could have flown no farther than 40 NM from the Last Known Point (LKP) before crashing.

40 NM search boundary

Three Initial Search Phases

1. **Surface search for floating debris:** It took 5 days before the first floating wreckage was found.
2. **Towed Pinger Locator (TPL) search:** limited by the 30-day battery life on the “black box” pingers.
3. **Sonar (active) searches for underwater wreckage:** side scan sonar towed behind ships.

Recovered floating wreckage

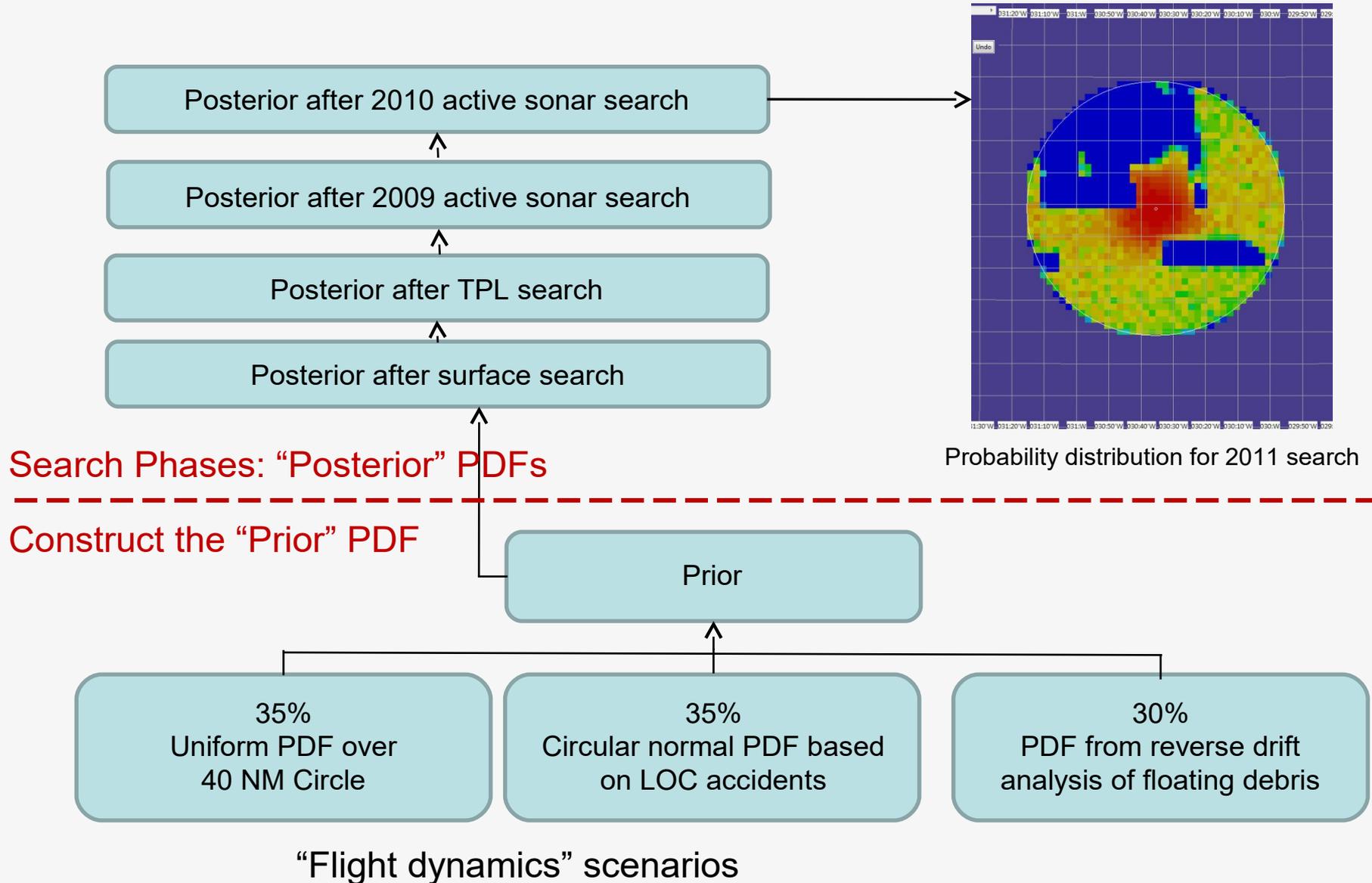


Tail Section

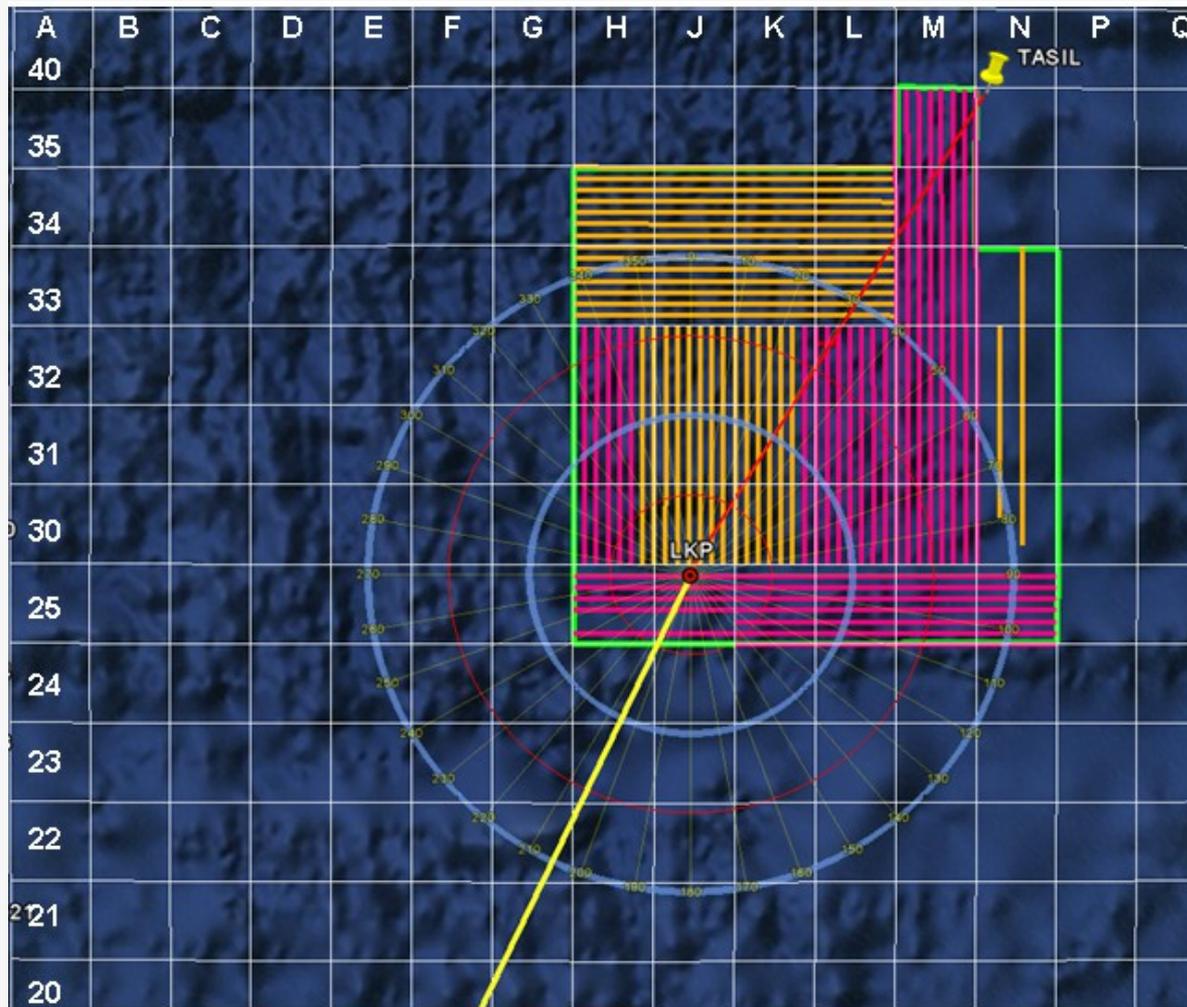


Galley

Bayesian Analysis Process



Towed Pinger Locator Search Paths

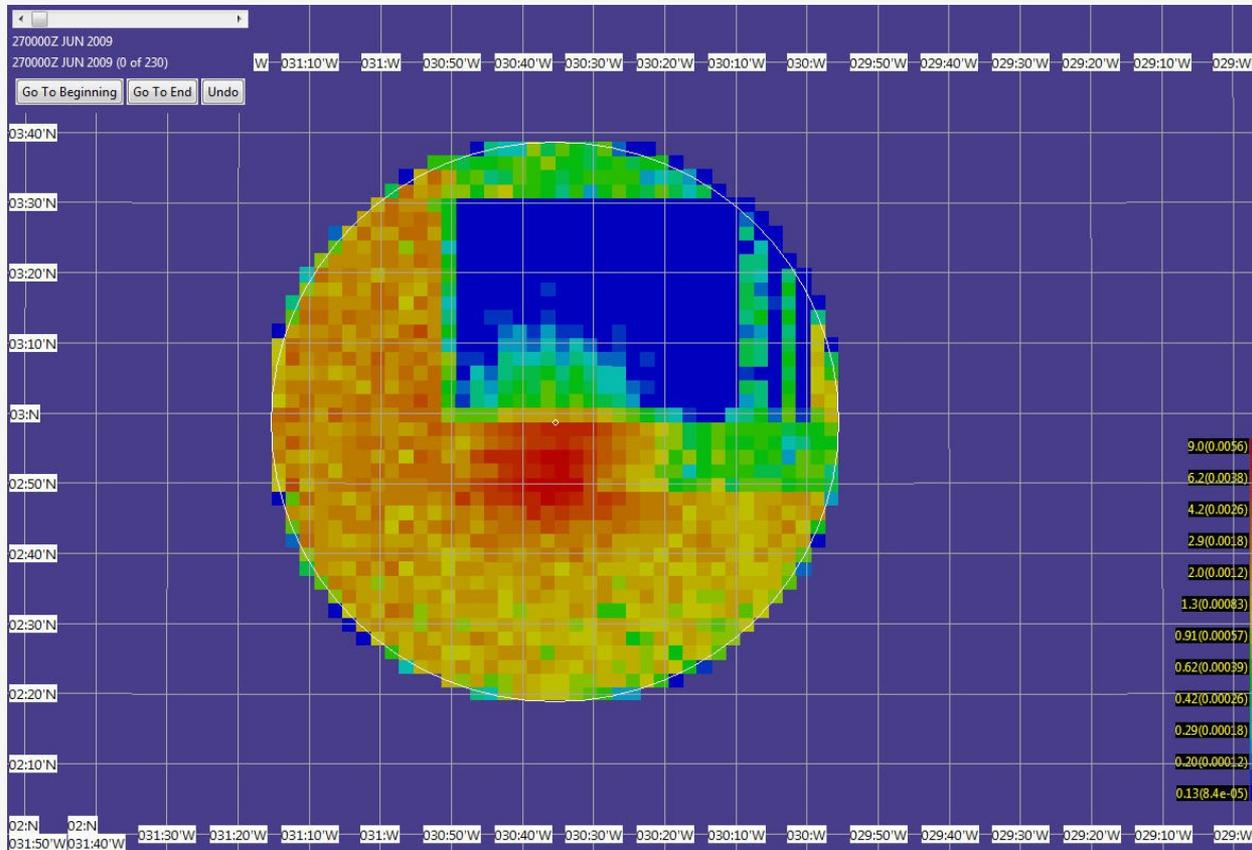


Fairmount Glacier (orange) and Fairmount Expedition (pink) Search Tracks.

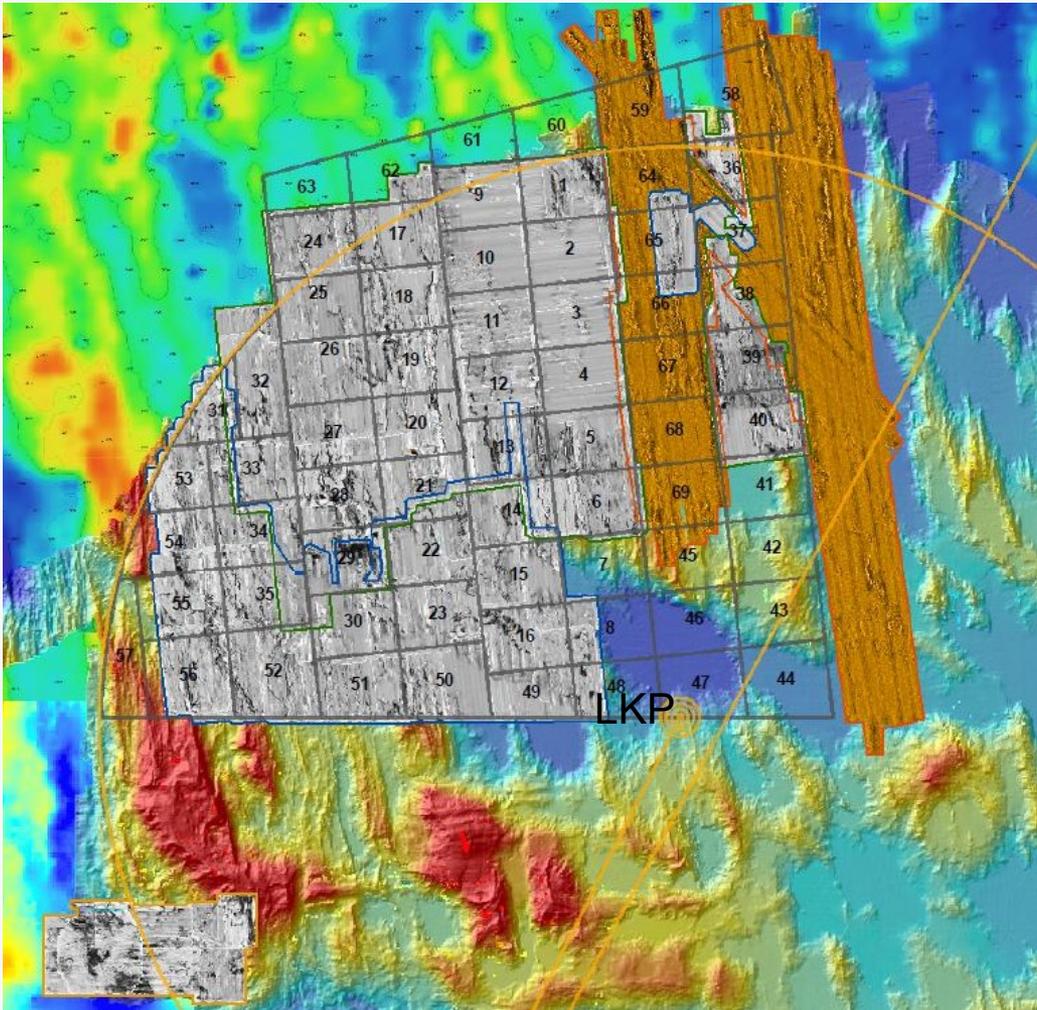
Blue circles are 20 NM and 40 NM circles about the LKP

Posterior after TPL Search

- Assumed 0.8 probability of survival of underwater locator beacon.
 - If survival is independent then 0.92 detection prob within 1730m lateral range
 - If survival is dependent = 0.72 detection prob.
 - We used $0.77 = (.25)(.92) + (.75)(.72)$



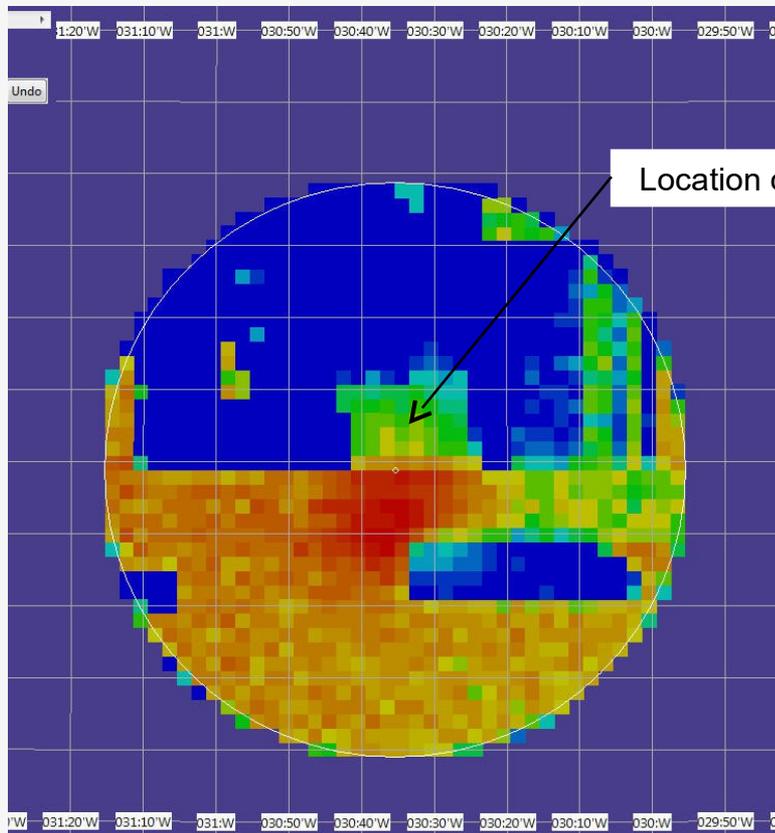
2009-10 Sonar Searches



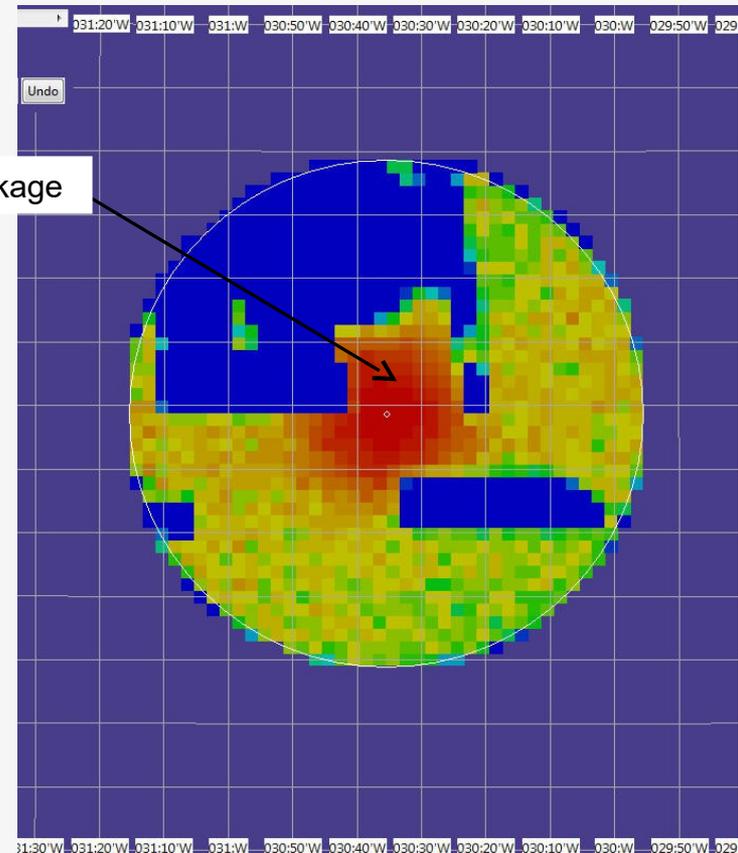
- Woods Hole Oceanographic Institute (WHOI) deployed 3 REMUS 6000 AUVs to search the grey area.
- US Navy/Phoenix International performed search in orange area using ORION towed side-looking sonar
- Both searches rated highly effective, $P_d > 0.9$

Posterior PDF, Spring 2011

- Metron was asked to assess all previous search efforts and update the PDF to show “where we stand”
- Generated two PDFs:



Posterior Assuming ULBs Worked



Posterior Assuming ULBs Failed

FDR and CVR Recovered

The Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) provided valuable information on the accident.



Flight Data Recorder (FDR) being recovered by a mechanical arm on the Remora 6000 Remotely Operated Vehicle; it was found *without* the Underwater Locator Beacon (ULB) chassis.



Cockpit Voice Recorder (CVR) capsule with the ULB still attached, but antenna broken off.

Malaysia Air Flight 370



Comparison of MH 370 and AF 447

- **AF 447**

- LKP GPS coordinates reported 2m40s before crash
- Surface debris recovered 5 days after crash.
- Multiple system alerts point to a likely failure scenario (LOC)
- 40 nm circle area of uncertainty: 17,240 km²

- **MH 370**

- Last radar fix 6 hrs before crash
 - Only satellite log-on interrogations and requests after that
- Floating wreckage washed up one year after crash on the east coast of Africa
- No warning of problems
- Area of Uncertainty
 - 60,000 km² – priority area (~ half of England)
 - 240,000 km² – medium area (~2x England)
 - 1,120,000 km² – wide area (~2x state of Texas!)

Status of the Search

- The Australian Transportation Safety Board (ATSB) oversaw an exhaustive search of the South Indian Ocean.
- No wreckage was ever located on the ocean bottom.
- Wreckage washed up in Eastern Africa
 - Reverse drift analysis was inconclusive (too long a time period)
- In January 2017 the ATSB suspended the search.
- In January 2018, US-based Ocean Infinity conducted a no-cure/no-pay search using unmanned underwater vehicles/sonar covering 120,000 km². It was unsuccessful.
- Ocean Infinity intends to re-analyze the data and return to search in the winter of 2019/20.

...Stay Tuned!