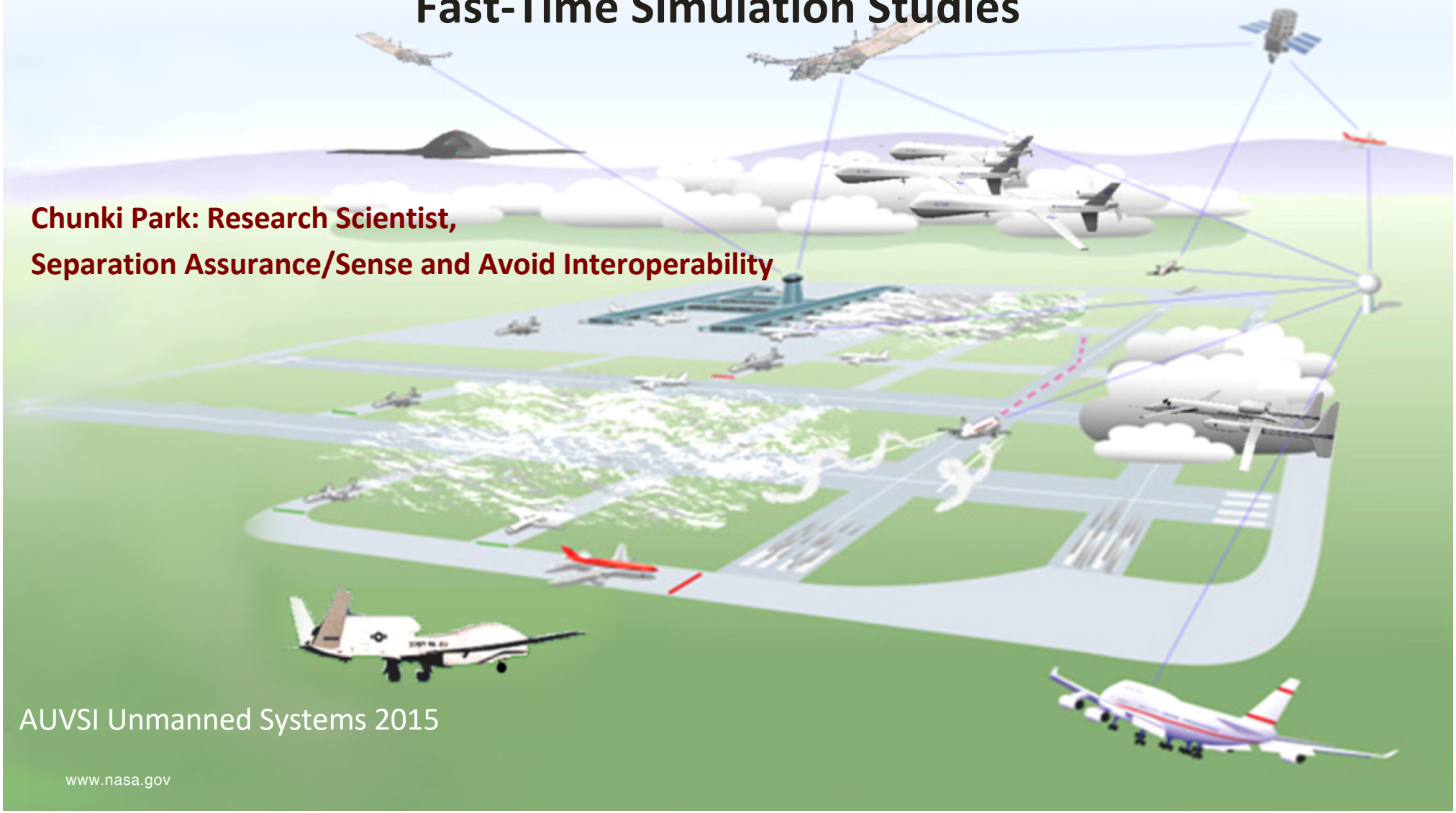
National Aeronautics and Space Administration

UAS Integration in the NAS Project
Fast-Time Simulation Studies

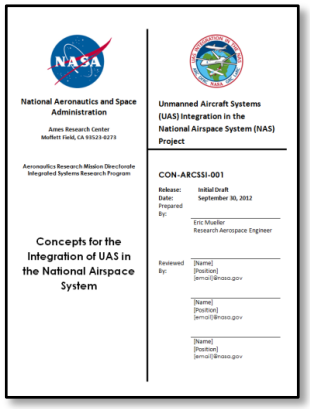


Chunki Park: Research Scientist,
Separation Assurance/Sense and Avoid Interoperability

AUVSI Unmanned Systems 2015

Research Capabilities

New UAS-related modeling and simulation capabilities



UAS-NAS integration concepts

18 UAS mission profiles



17 UAS types



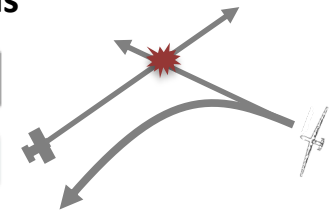


DAA sensor models

UAS models, comm. link models



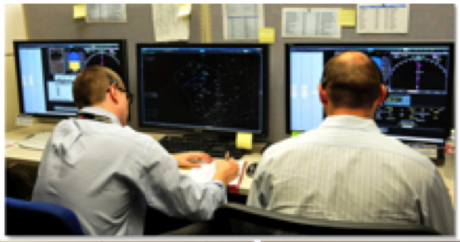
DAA algorithms



Human-in-the-Loop and Flight Test Evaluation



Pseudo-pilot stations





Air Traffic Control Stations



Vigilant Spirit Control Station

Traffic displays, DAA algorithms, ATC, Ground Control Station

NAS-wide Simulation

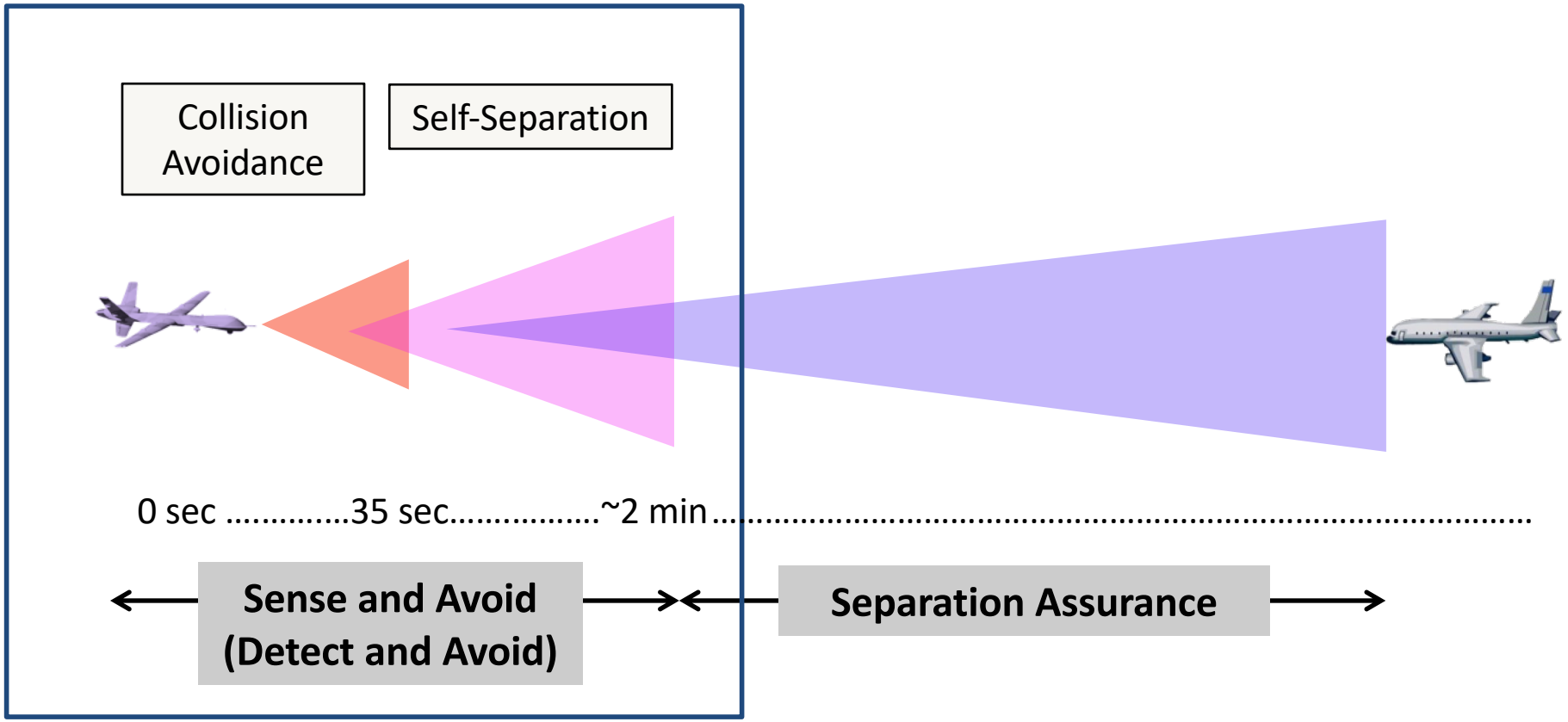


ACES: Flight plan and NAS-agent modeling system

Airspace Separation Mitigation for UAS

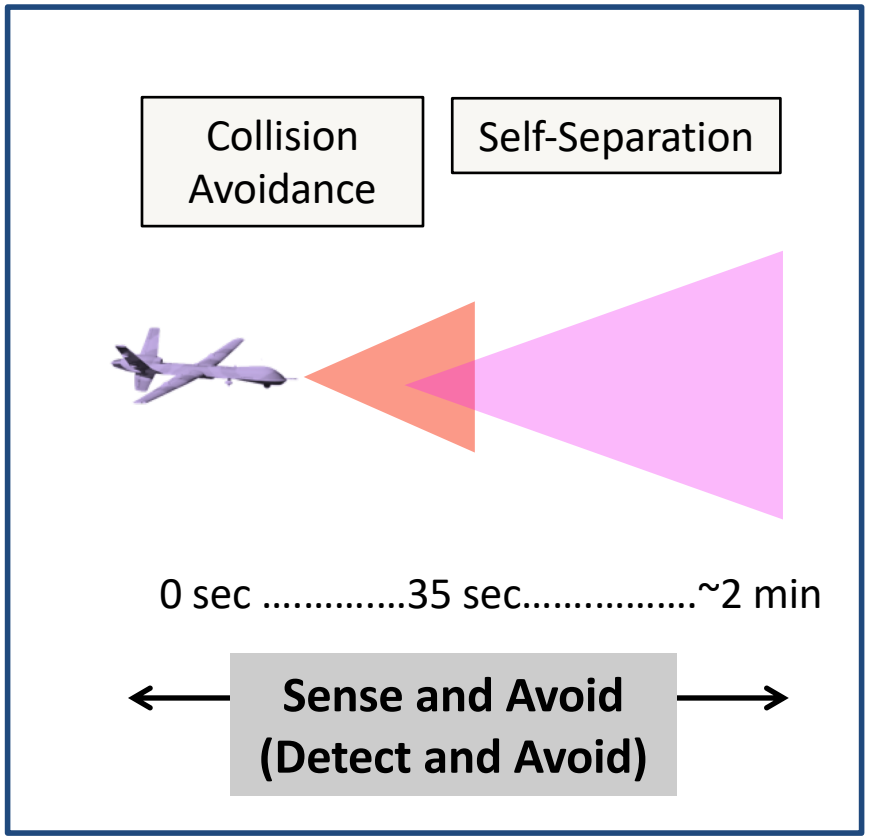
- The lack of an onboard pilot leads to the problem of how to deal with the legal requirement identified in the US Code of Federal Regulations (CFR) that pilots “see and avoid” other aircraft (specifically 14 CFR 91.113)

Sense and Avoid (SAA) was defined by the FAA sponsored SAA for UAS Workshop Final Report published in October 9, 2009 as “the combination of UAS Self-Separation (SS) plus Collision Avoidance (CA) as a means of compliance with 14CFR Part 91, §91.111 and §91.113”



Key Measure of Safety: Risk Ratio

- Risk Ratio
  - The net improvement in safety arising from a given mitigation
  - Risk Ratio is an experimental measure of projected performance
  - Risk Ratio was used in TCAS II safety analysis



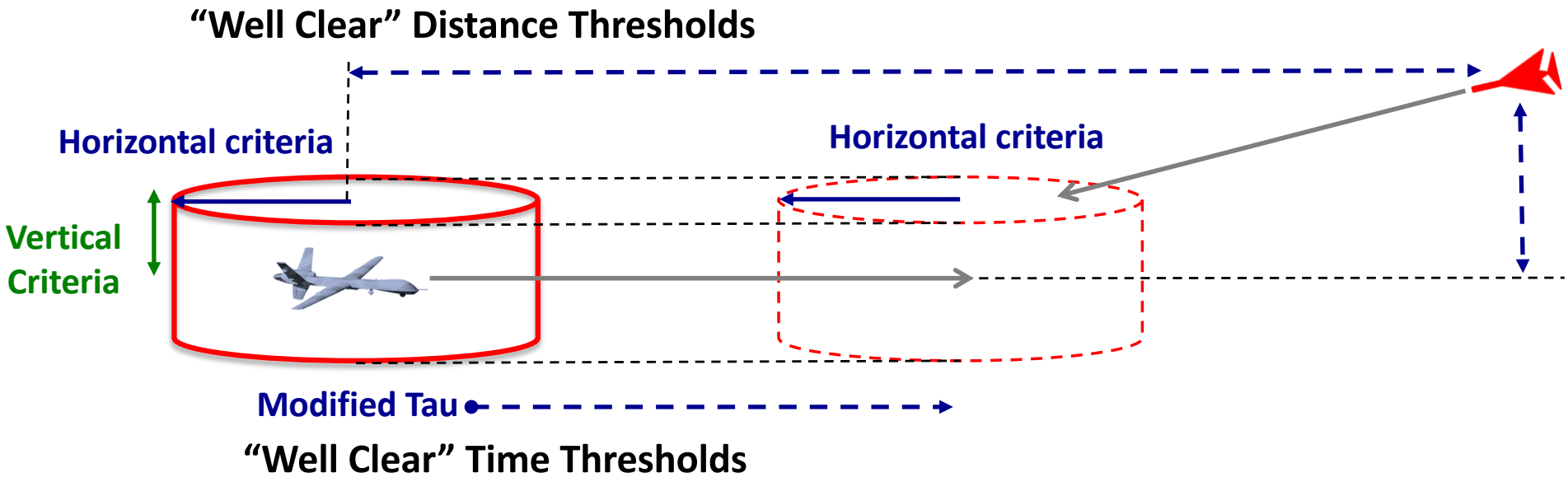
Risk Ratio for Self Separation =

$$\frac{\text{Mid air collision rate with self separation}}{\text{Mid air collision rate without self separation}}$$

Concept of Loss of Well Clear

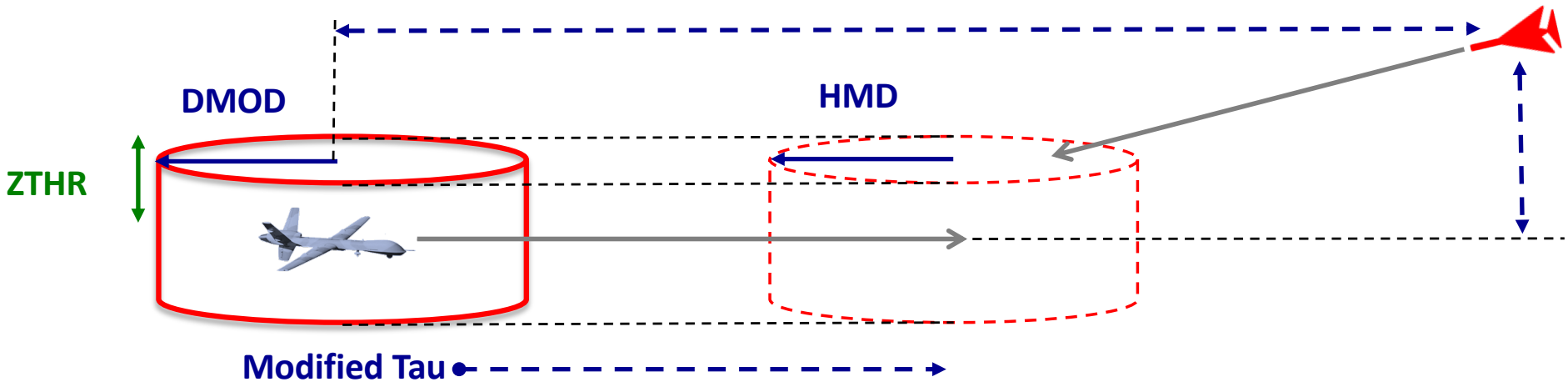
- A well clear separation standard should be large enough to
  - Avoid collision avoidance maneuvers by intruders,
  - Minimize traffic alert issuances by air traffic control,
  - Avoid excessive concern for pilots of proximate piloted aircraft.

- Time and distance-based definition of "Loss of Well Clear (LoWC)"
  - When two aircraft are within distance thresholds
  - When the projected horizontal closest point of approach (CPA) of two aircraft is within a distance-based volume in particular time thresholds



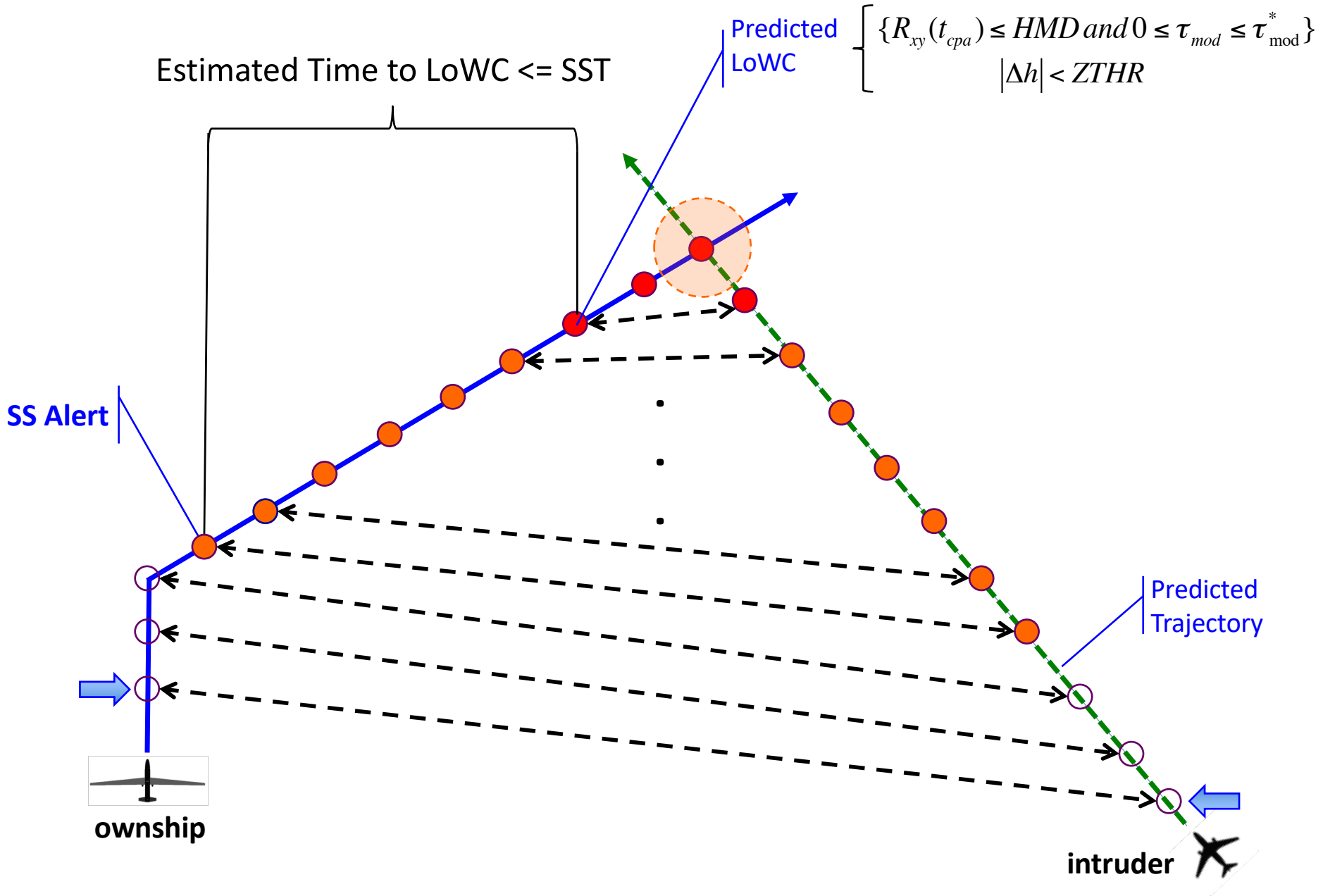
Definition of Loss of Well Clear

Parameters	Values	Descriptions
Modified Tau	35 sec	Ratio of range to range rate with DMOD
DMOD	4,000 ft	Distance modification that represents a minimum desirable range between two aircraft
HMD	4,000 ft	Horizontal distance at the predicted horizontal CPA
ZTHR	450 ft	Current altitude separation



Self-Separation Alerting

- Self-Separation Threshold (SST): Time to predicted LoWC





Fast-Time Simulation Environment

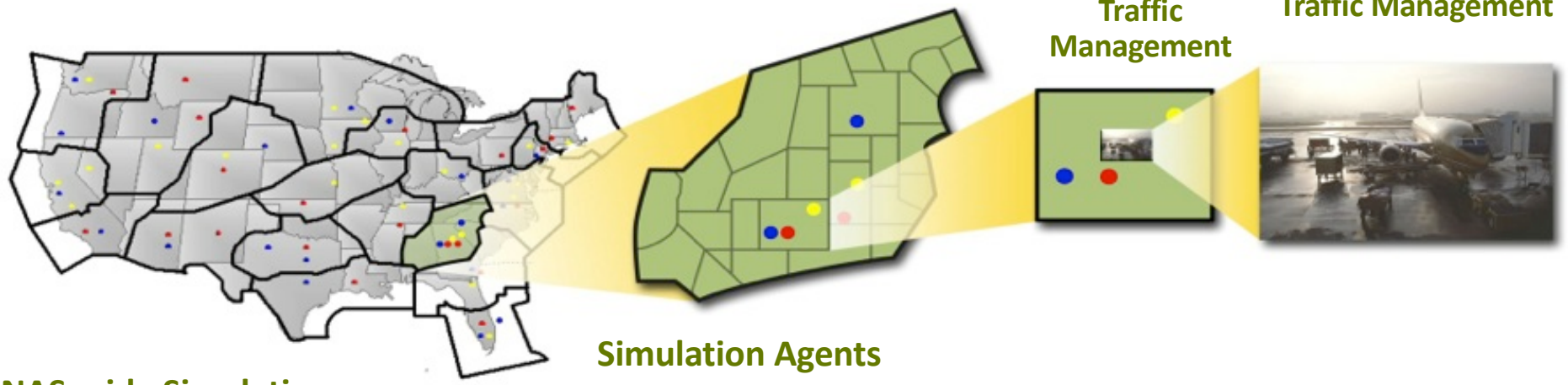
Modeling and Simulation: ACES

National Traffic Management

Regional Traffic Management

Local Approach and Departure Traffic Management

Airport and Surface Traffic Management



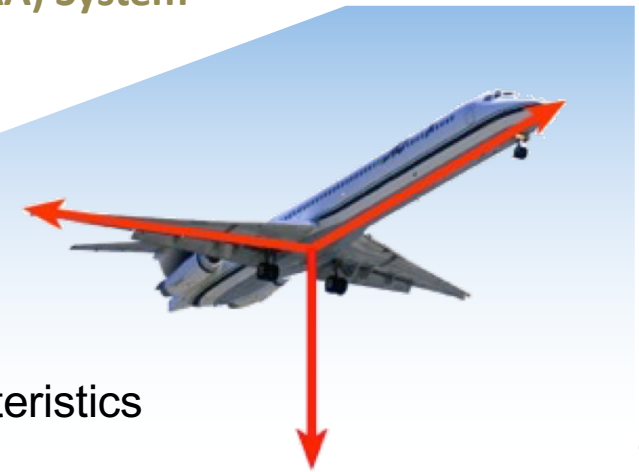
NAS-wide Simulation

- Gate-to-gate simulation of ATM operations
- Full flight schedule with flight plans
- Sector and center models with some airspace procedures

Simulation Agents

- Air traffic controller decision making
- Traffic flow management models
- Individual aircraft characteristics
- UAS Detect-and-Avoid (DAA) System [JADEM]

4-DOF Trajectory Model
- Aerodynamic models of aircraft
- Models replicate pilot behavior
- User-definable uncertainty characteristics



UAS Missions Overview

- Developed under contract with IAI Inc.

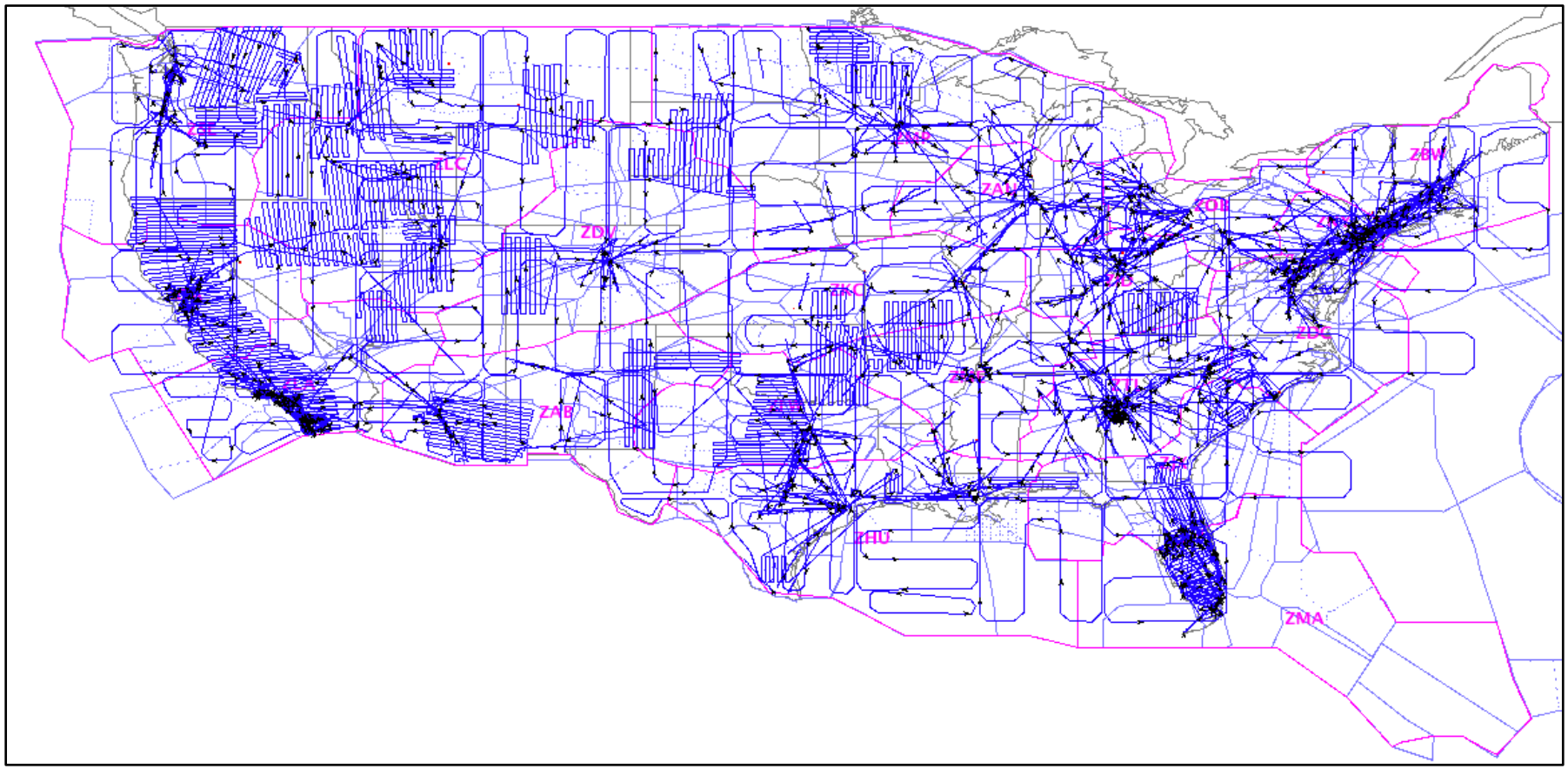
	UAS Mission	Total Number of Flights	Total Flight Time (hr)
1	Aerial Imaging and Mapping	295	182.60
2	Air Qualtiy Monitoring	1044	2393.49
3	On-Demand Air Taxi Cirrus	8720	6240.12
4	On-Demand Air Taxi Mustang	3180	1107.76
5	Airborne Pathogen Tracking	1308	3002.24
6	Border Patrol	867	3357.90
7	Cargo Delivery	1317	1966.07
8	Flood Inund. Mapping	127	275.02
9	Flood Stream Flow	200	368.51
10	Law Enforcement	300	859.11
11	Maritime Patrol	1512	11267.74
12	Point Source Emission Monitoring	432	648.05
13	Spill Monitoring	836	2078.07
14	Strategic Fire Monitoring	312	4959.85
15	Tactical Fire Monitoring	2496	3373.88
16	Traffic Monitoring	1043	1953.05
17	Weather Data Collection	2401	13324.86
18	Wildlife Monitoring	308	189.34
	Total	26698	57547.66

Mission Characteristics

	UAS group	Duration (per flight)	Flights per day	Cruise Alt.	Flight Pattern
Air Quality Monitoring	Shadow-B	1-4 hrs.	104-1044	4k,5k, and 6k ft AGL	Radiator Grid Pattern
Cargo Transport	Cessna 208	varies	1.4k	2k-16k	Point to Point
Atmospheric Sampling	Global Hawk	1.5-13 hrs.	2352	5k-35k ft AGL	Radiator Grid Pattern
On-demand Remote Air Taxi -Cirrus	Cirrus SR22T	varies	8k	6k-11k	Point to Point
On-demand Remote Air Taxi - Mustang	Cessna Mustang	varies	2k-4k	9k-20k	Point to Point
Strategic Fire Monitoring	Predator-B	20 hrs.	74-324	31k ft MSL	Radiator Grid Pattern
Tactical Fire Monitoring	Shadow-B	1-1.5 hrs.	varies	varies	Circular Loitering Orbit
Flood Inundation Mapping	Aerosonde	1-4 hrs.	varies	4k ft AGL	Radiator Grid Pattern Point to Point
Flow Stream Monitoring	Aerosonde	1-4 hrs.	20-200	4k	Radiator Grid Pattern Point to Point

NAS-wide UAS Mission Profile

- A snapshot of mission profiles: UAS tracks in blue



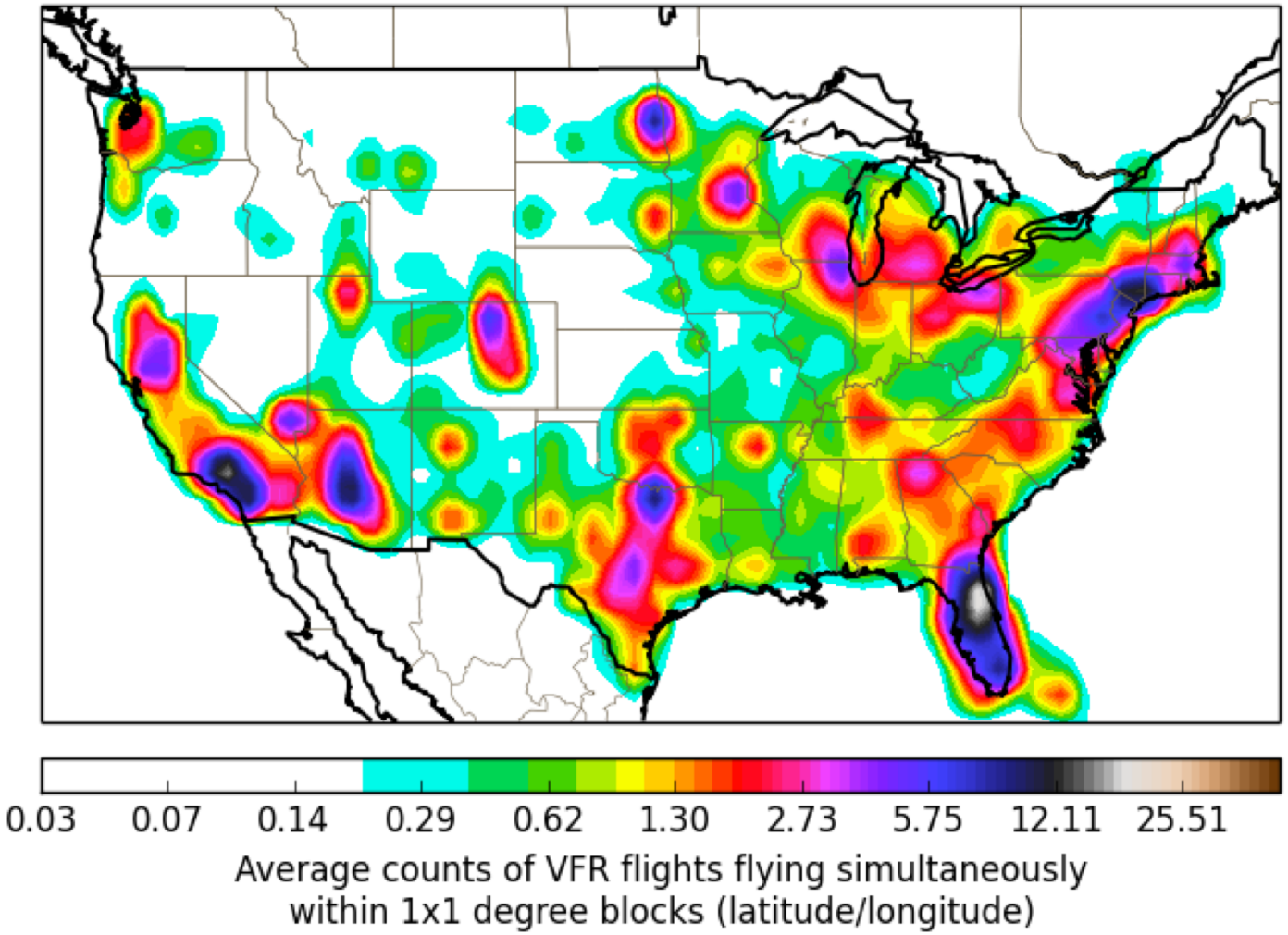
VFR Traffic (courtesy of 84th RADES)

- The 84th Radar Evaluation Squadron (RADES) data were used.
  - The data contain the radar hits collected from hundreds of radar sites in U.S, and each hit provide timestamp, latitude, longitude and others but does not always provide Mode 3 code, Mode C code.
  - There is no explicit information that could be used to determine whether radar hits come from IFR flights or VFR flights.
  - All cooperative VFR has the same Mode 3 code, 1200.
  - A single aircraft could be detected from multiple radar sites.

- Cooperative VFR tracks were processed using
  - A clustering method based on a modified minimum spanning tree algorithm,
  - The quadratic regression to estimate the aircraft position within a time window,
  - A Kalman filter to generate smooth trajectories,
  - Filters to categorize each track into IFR or VFR: altitude, speed, and Mode 3 code.

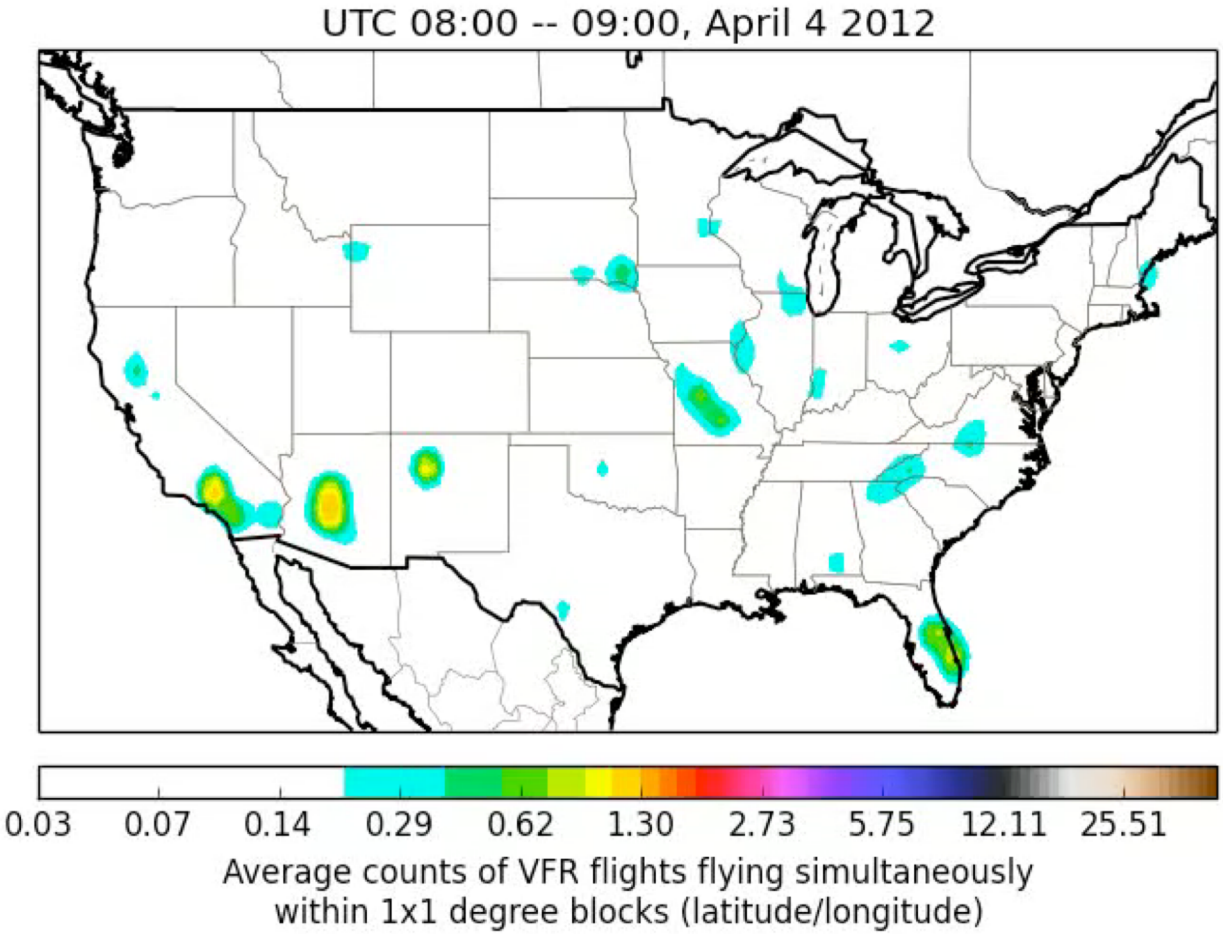
- Non-cooperative VFR tracks were processed
  - Using algorithm developed by Honeywell to process non-cooperative VFR tracks and estimates altitude measurements

Processed VFR Traffic: Geographic Flight Density

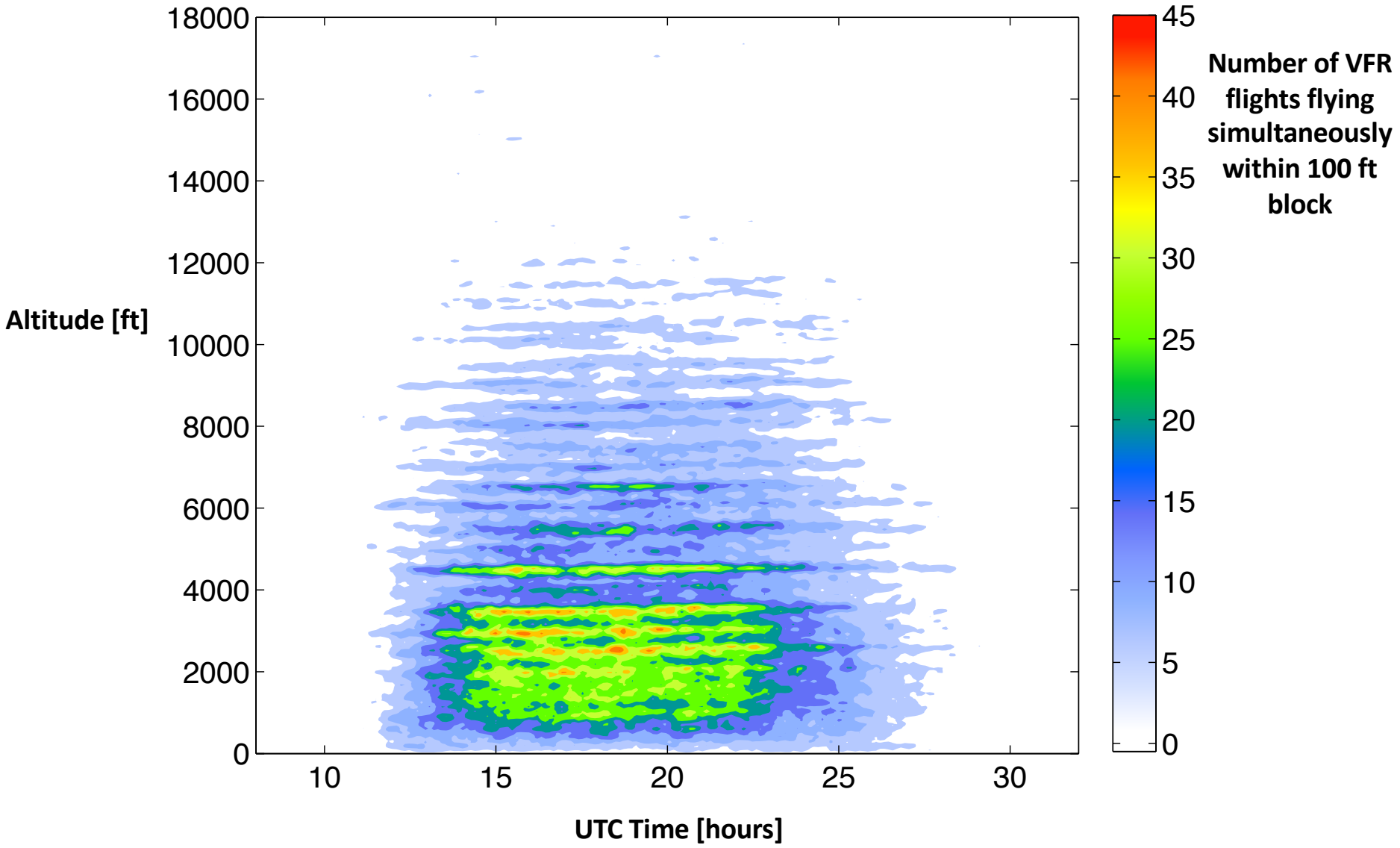


* Cooperative VFR Flight Profiles from April 4th, 2012

VFR Traffic: Geographic Flight Density – Video Clip



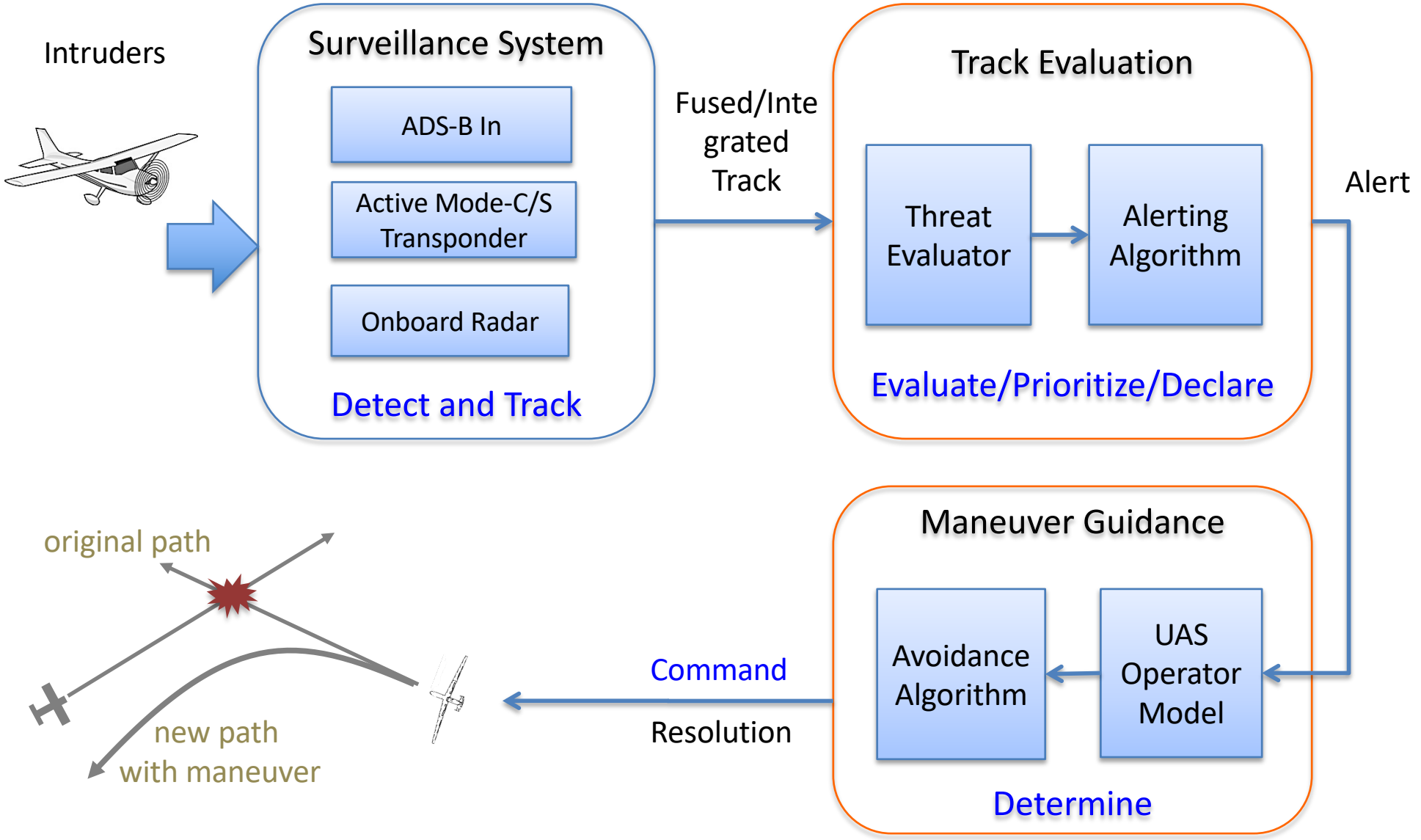
VFR Traffic: Density by Altitude



* Cooperative VFR Flight Profiles from April 4th, 2012

DAA Model

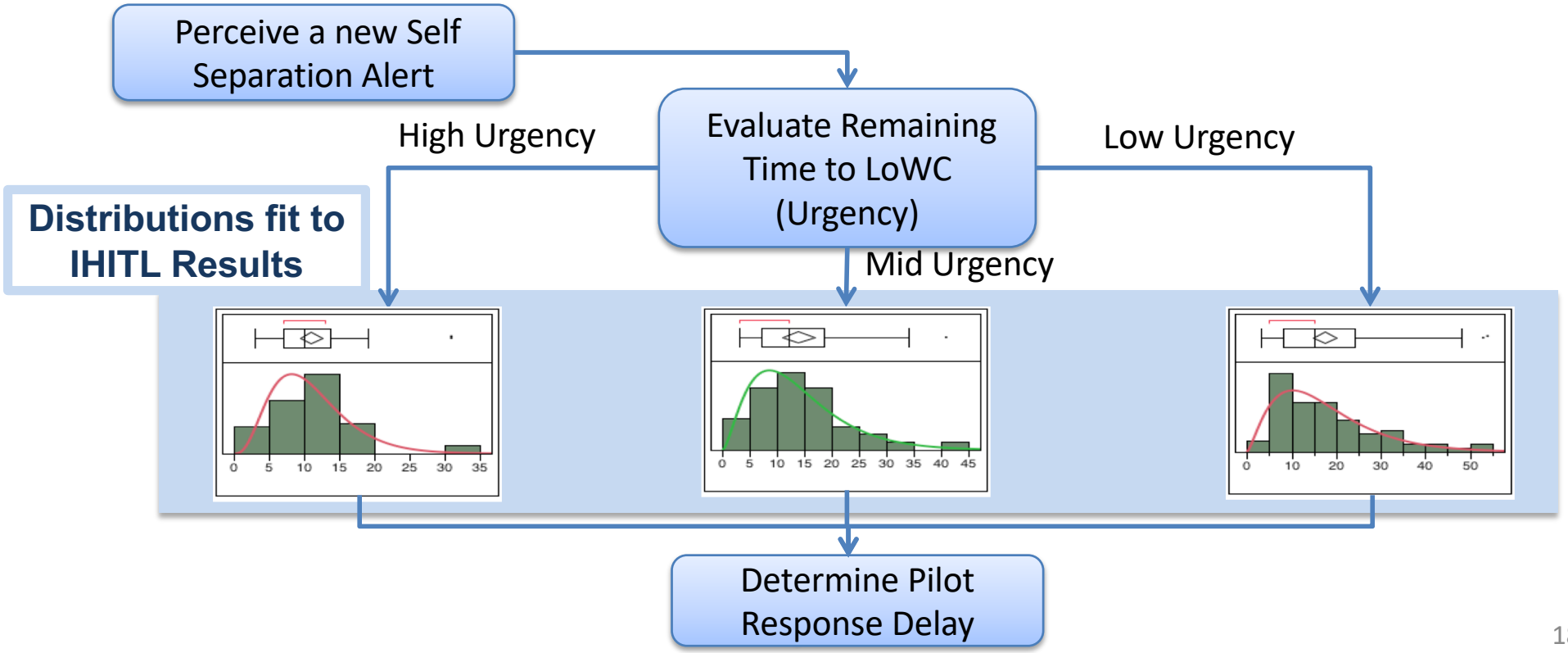
- JAVA architecture (JADEM)



A Stochastic Pilot Response Model

- Pilot total response time is the time from the first self-separation alert to the time pilot uploads maneuver to prevent loss of well clear.
  - *NASA HSI team breaks this down by different measures*

- Use total pilot response time data from IHITL to build a pilot response time model, so there are realistic responses to SS alerts in ACES simulations
  - Sample for a distribution, and "wait" that amount of time before commanding maneuver



Accomplished ACES Simulation Studies and On-going Studies

Accomplished ACES Fast-Time Simulation Studies

- DAA Surveillance Performance Study
  - To evaluate potential safety by investigating geometric characteristics of intruders that caused LoWC
  - To propose and investigate performance metrics for evaluating the performance of surveillance system, such as the ratio of undetected and late-detected LoWC, and the time to LoWC at first detection for given surveillance parameters

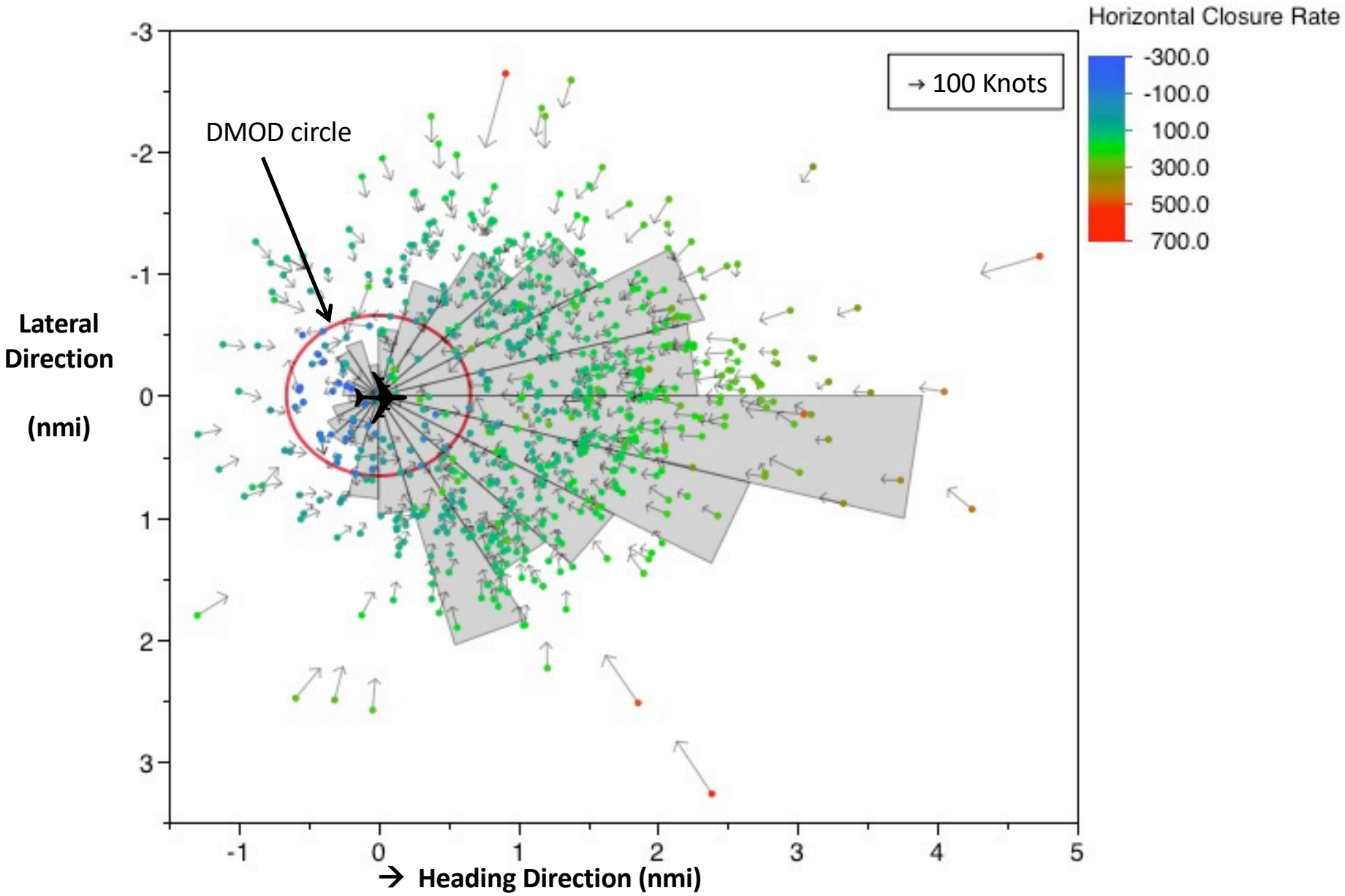
- Encounter Rate Simulation Study
  - To evaluate the effect of LoWC parameters on LoWC rates by measuring the LoWC rates per UAS flight hour as a function of time or distance thresholds
  - To characterize encounters at the LoWC boundary and evaluate the alerting threshold definition that includes Time to CPA, horizontal and vertical miss distance

- Airspace Safety Threshold Study
  - To determine encounter rates based on historical radar data
  - To determine encounter rates based on simulated UAS missions with/without ATC separation provision services

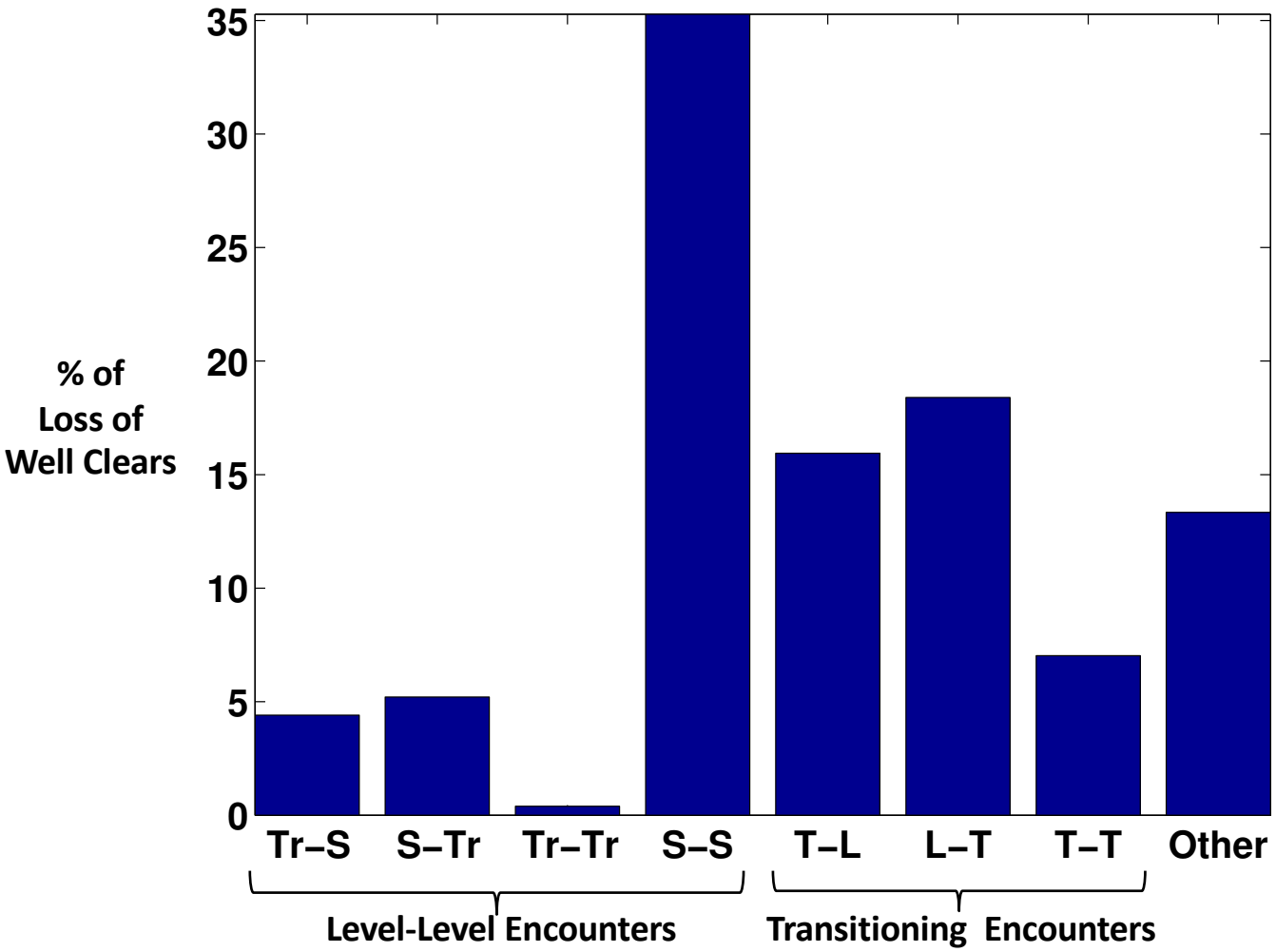
* All accomplished studies were unmitigated studies in which no UAS or VFR flights were maneuvered to avoid potential Loss of Well Clear.

Encounter Characteristics of Intruders at LoWCs

- Relative position, Bearing distribution, and Horizontal Closure Rate



Type of Loss of Well Clear



[Ownship-Intruder]

Tr - Turning
S- Straight
T- Climbing/Descending
L - Level

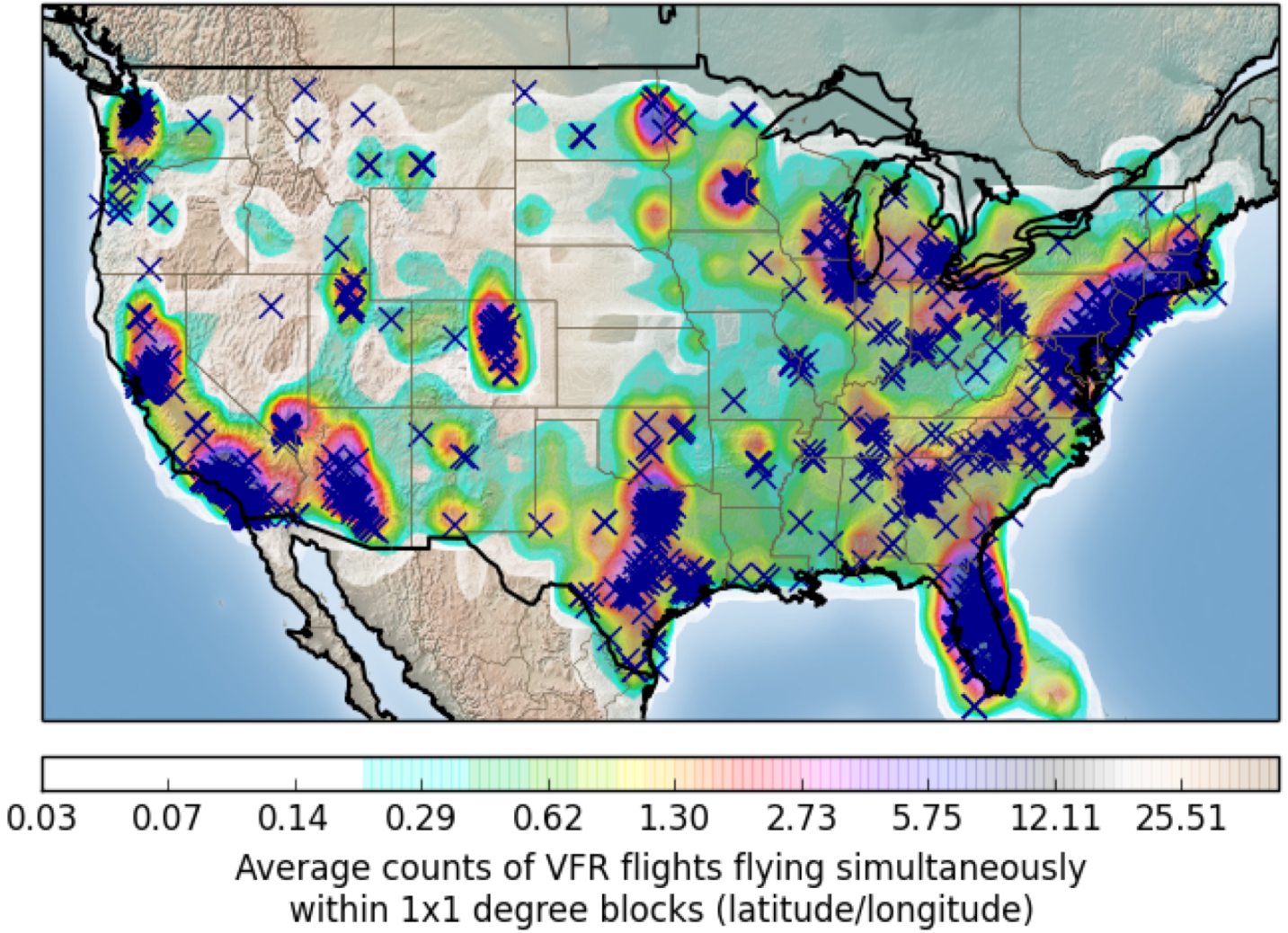
On-going ACES Fast-Time Simulation Studies

- DAA Alert and Resolution Performance Study
  - To investigate the effects of different SST setting on the DAA SS system performance by measuring metrics such as correct/nuisance/late/missed alerts, time to LoWC at first alerts, alerting duration, and resolution success rates
  - To analyze the effect of a distance buffer on the definition of LoWC
  - To investigate the number of concurrent intruders detected within a surveillance volume during the flight and at alerts

- PT5 Encounter Threshold Study
  - To calculate the frequency of PT5 alerts levels and investigate encounter characteristics at alerts (e.g. range, relative speed, relative heading, and vertical closure rate)
  - To analyze the sequence and duration of PT5 alert levels during an encounter and the underlying causes of transitions between alert levels (e.g., by analyzing the conflict geometries)
  - To calculate the risk ratio that the PT5 alerting scheme can provide

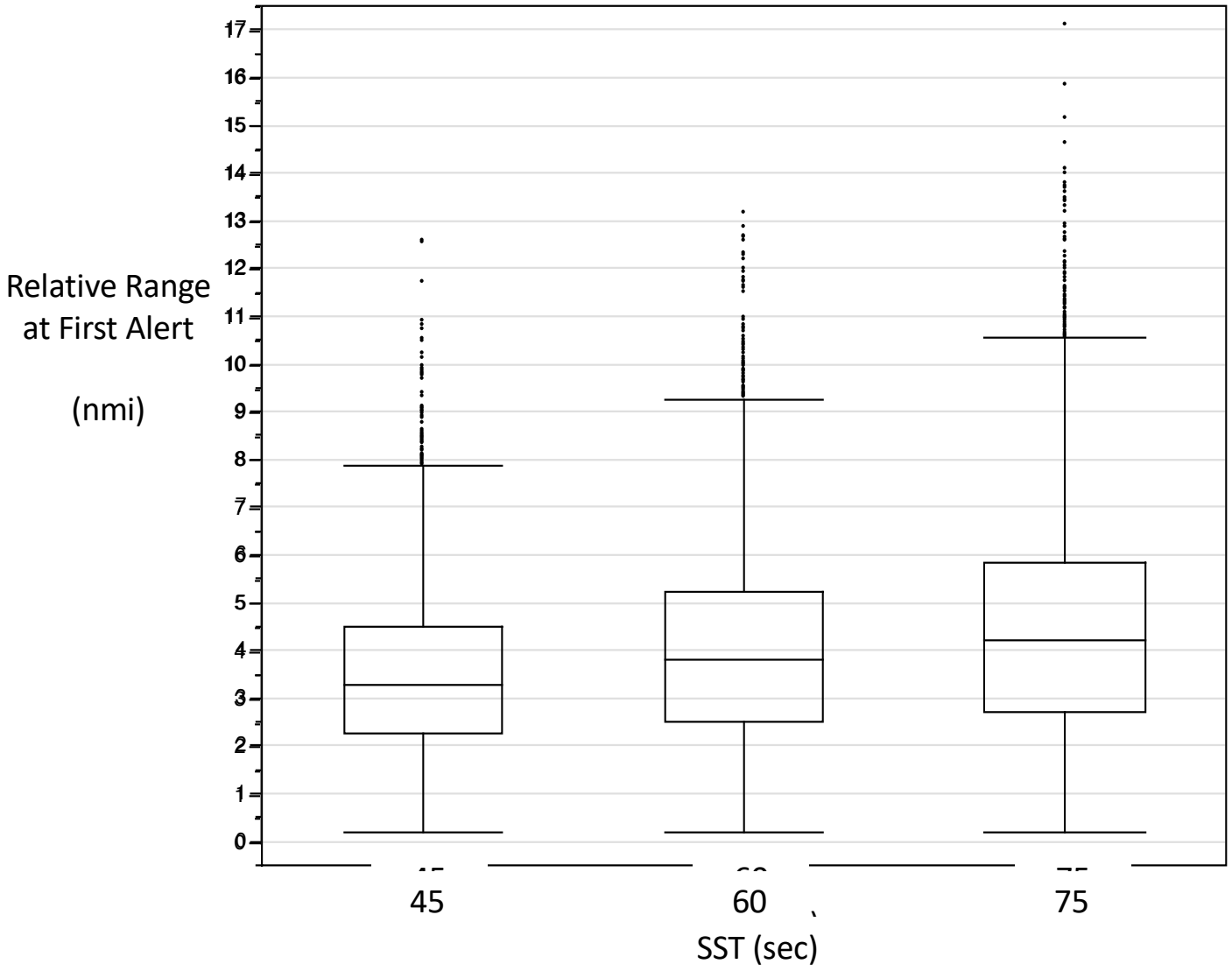
Sample Result 1: Loss of Well Clear on CONUS

- Simulating UAS missions without DAA systems and ATC separation provision services on cooperative VFR traffic on April 4, 2012,
  - The UAS missions (26,698 flights, 57,547 total flight hrs) cause 2,664 Loss of Well Clears.
  - LoWCs occurred mostly in the regions that have high VFR density.



Sample Result 2: Distribution of Relative Range at SS Alerts

- Relative range distribution when SS alerts were issued
  - Self-Separation Threshold: Time to estimated LoWC
  - For three Self-Separation Threshold: 45 sec, 60 sec, and 75 sec



Summary

- ACES is used to simulate NAS-wide operations of UAS and VFR flights
  - UAS missions and background VFR traffic
  - JADEM, a Java architecture for DAA model
  - Pilot response model

- Fast-time simulation studies have been accomplished
  - Airborne encounter characteristics, preliminary surveillance performance, and airspace safety have been investigated and follow-on studies are in progress
  - The simulation results help RTCA SC-228 to develop minimum operational performance standard (MOPS) for DAA systems

- Future ACES fast-time simulation studies
  - DAA surveillance performance study with high-fidelity sensor model
  - Risk ratio study
  - And more…

Questions?

Contact Information

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