Wake Turbulence Research Modeling

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Introduction

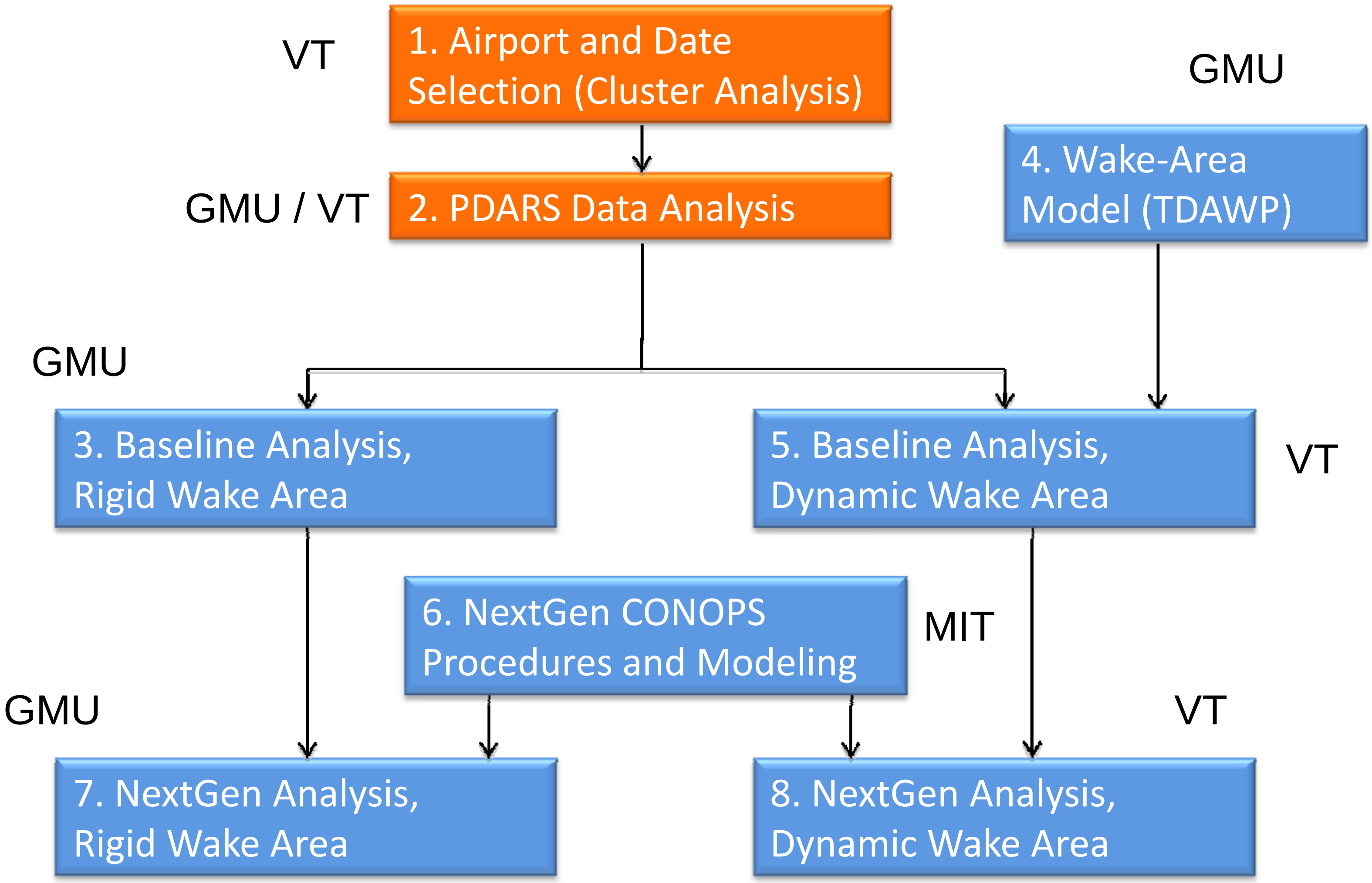
- This presentation and a companion presentation from MIT examine the NextGen Concept of Operations to determine what parts (if any) of the concept may cause an increased risk of an aircraft encountering a wake turbulence hazard over today's operations
- Identification of these potential risk areas will help the FAA focus efforts towards a more refined risk assessment and development of any necessary mitigation strategies
- The main focus of the research work presented is the development of tools (i.e., computer models) to study potential wake turbulence hazards in future NextGen procedures

- Our thanks to Ed Johnson, Tom Proeschel, Steve Lang and Jeff Tittsworth for supporting this project

NEXTOR Research Tasks

- **Task 1** – Examine the NextGen Concept of Operations and determine what parts (if any) of the concept may cause an increased risk of an aircraft encountering a wake turbulence hazard over today's operations
- **Task 2** - Research questions, mitigations, and prioritization of wake hazards
- **Task 3** – Develop model of current operations for use as a modeling baseline in studies of future NextGen era operations
- **Task 4** - Assessment of relative wake turbulence encounter probability associated with NextGen scenarios

Modeling Outline



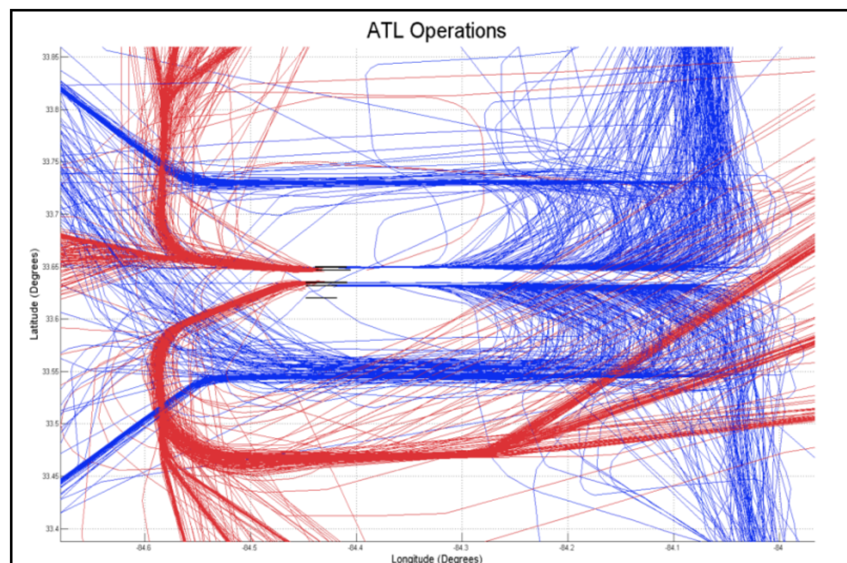
Radar Flight Track Data

- Airport Selection
  - Selected ATL, LAX and NYC
  - Busy terminal airspaces, diversity of aircraft types
  - Potential interaction between multiple airports in terminal area
- Cluster analysis to select representative days (2008 as baseline year)
  - Seven days of data for each airport
    - IMC/MMC/VMC days
- Performance Data Analysis & Reporting System (PDARS)
  - Aircraft position, velocity, altitude, heading
  - Required parsing and data scrubbing

Airport and Date Selection

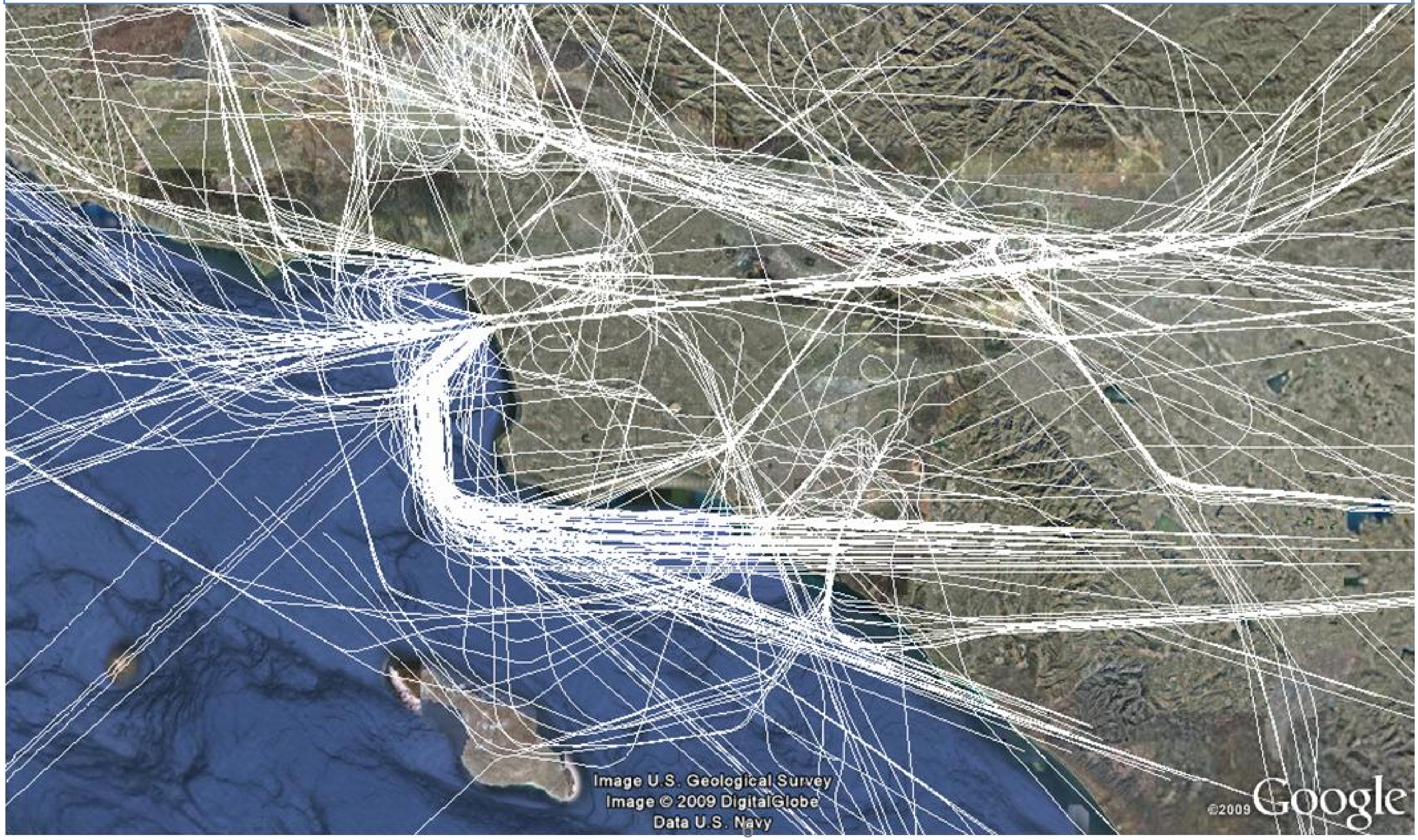
↓

Historic Flight Track Data

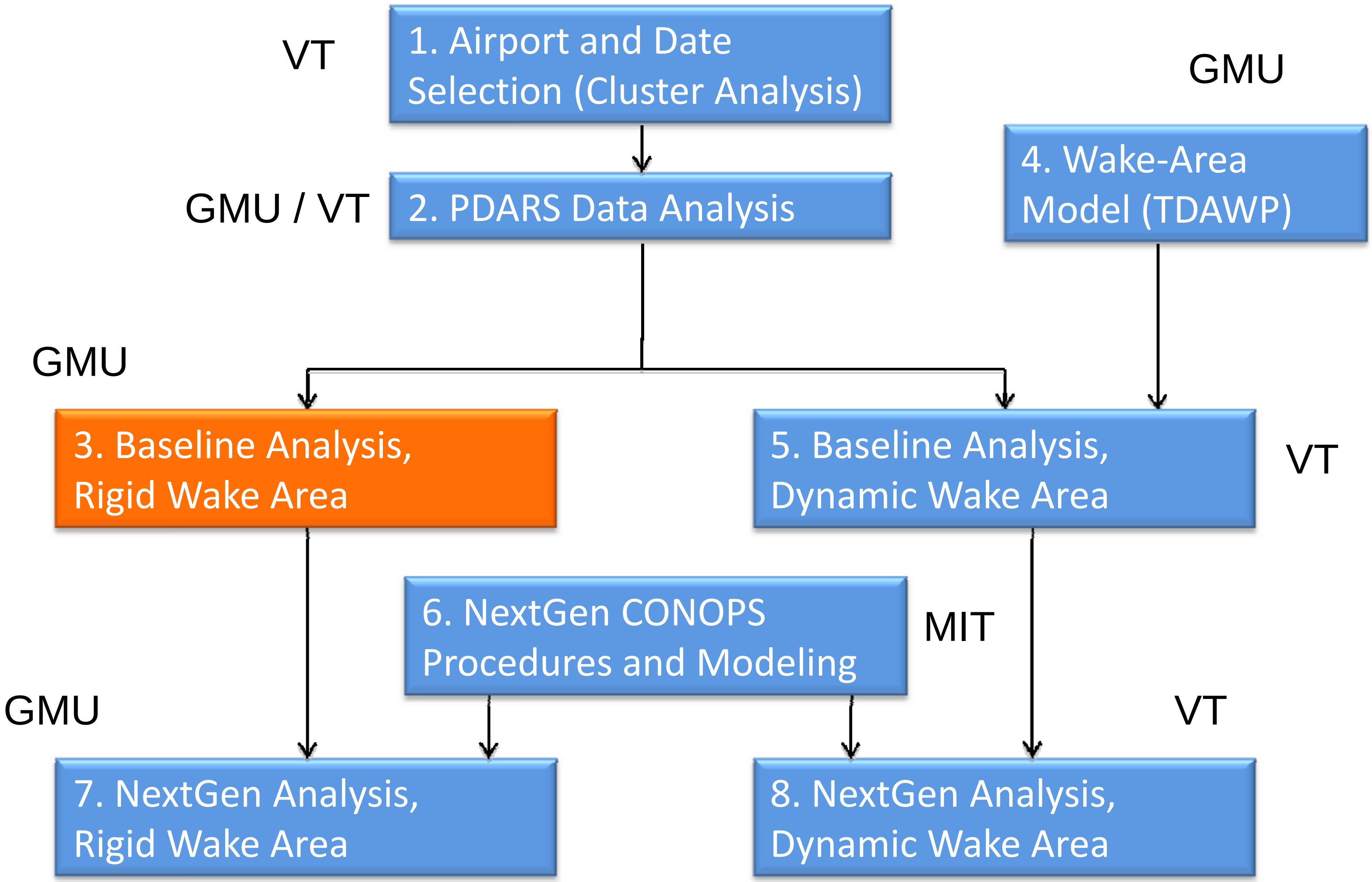


Sample Flight Tracks, LAX Area

Do these tracks contain clues for types of trajectory interactions that may lead to increased exposure to wake turbulence under NextGen?



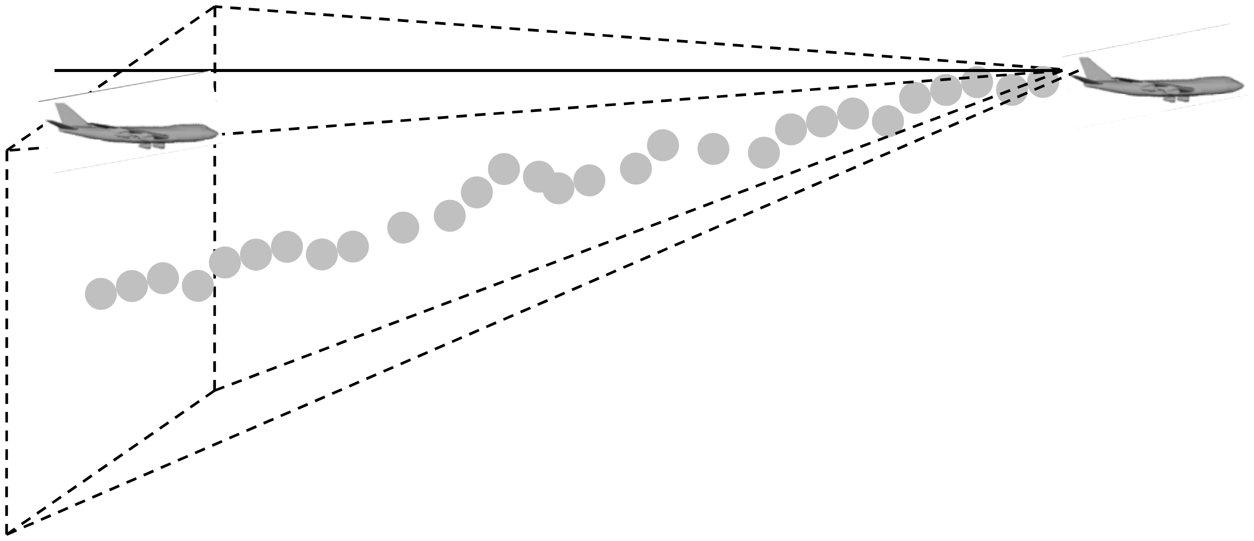
Modeling Outline



First-Order Analysis and Modeling

First-Order Approach

- Objective: Identify types of potential NextGen trajectories that may increase the potential for wake turbulence encounters from analysis of existing complex / interacting trajectories
- Define region of space that is likely to contain the wake
- Note: *Inside the region does not imply a wake encounter*
- Geometry of region is simple
  - Assumed to be rigid with fixed dimensions (parametric analysis)
  - Many factors ignored in first-order approach (wind, aircraft weight, etc.)
  - Size of the region is selected by the user based on appropriate wake characteristics



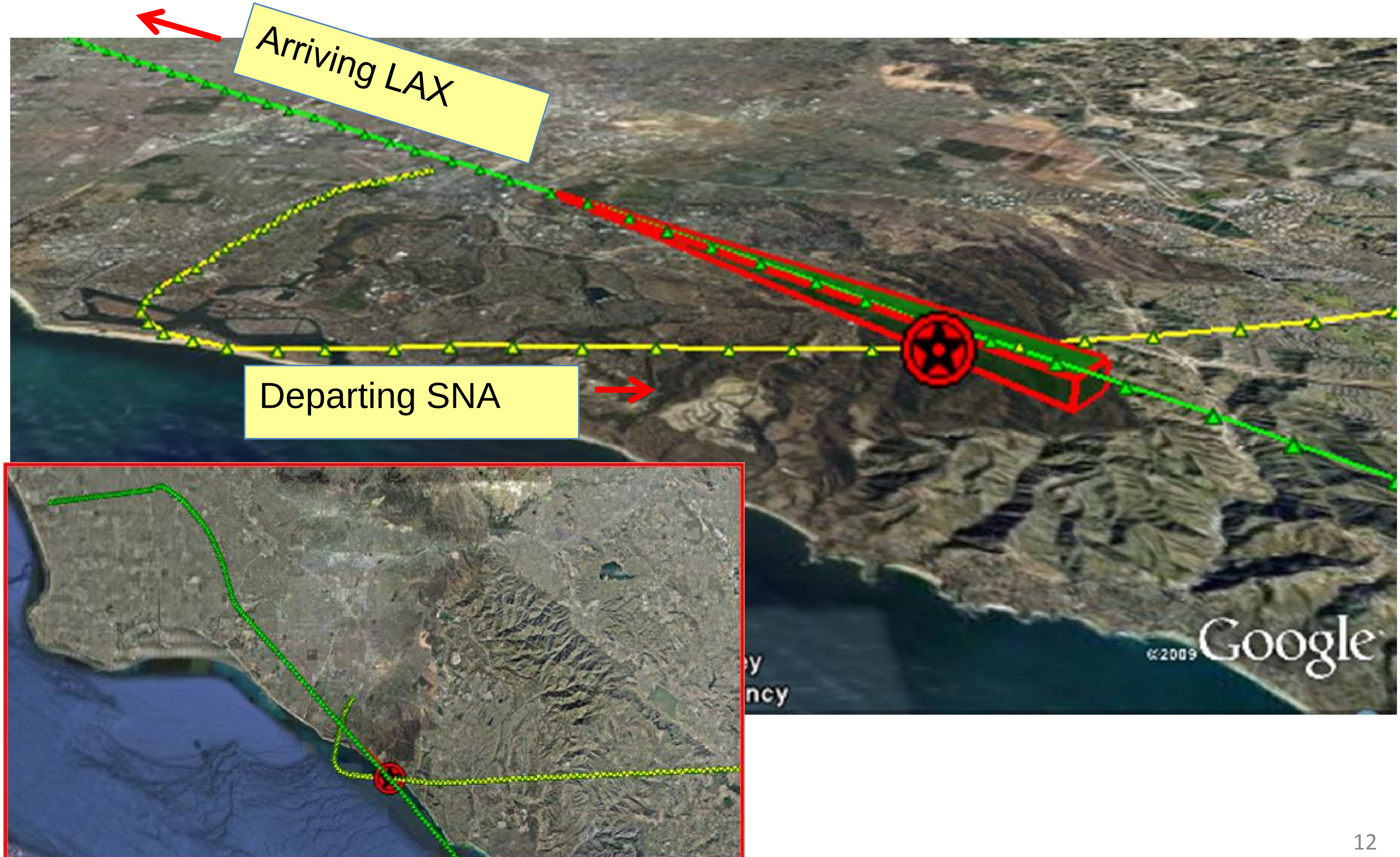
Approach Summary

- Identify scenarios where one airplane passes through the zone of another
  - Only consider cases in which the wake-generating aircraft is Large, B757, or Heavy (ignore small and unknown)
- Visually check each scenario using Google Earth
- Identify themes – determine if similar themes could be likely in NextGen era operations
- *Conclusions are qualitative*
- Approach is deliberately pessimistic
  - Identify a wide set of potential NextGen scenarios
  - Narrow set with more refined analysis
- Analyze narrowed set of scenarios for potential increased wake encounter probability assuming NextGen era separations and operational concepts

Development of Tools & Methods

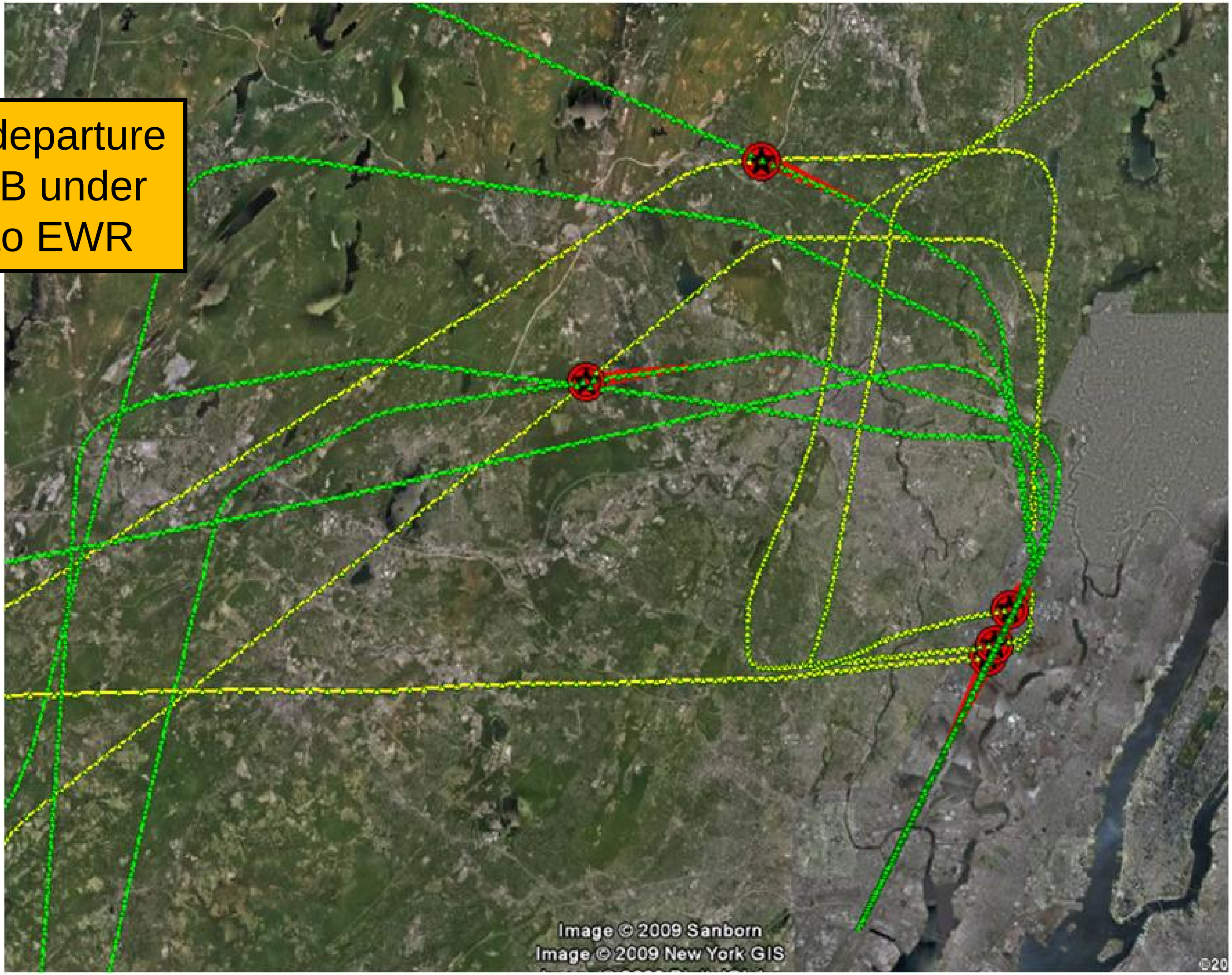
- The following examples illustrate development of analysis tools & methods using existing radar tracks
  - NextGen aircraft trajectories will be synthesized based on capabilities likely to be operational in a time period of interest
  - A positive result indicates the potential for a wake encounter based on parameters chosen by the modeler
  - A potential encounter may be nearly indistinguishable from background turbulence
  - Both the track data and the preliminary wake models contain known uncertainties
  - Identifying potential for wake encounters under NextGen operations rather than analyzing specific events in detail
- There are:
  - NO known wake encounters in any of these cases
  - NO known deviations from required separations in any of these cases
- These examples do not indicate any areas of concern in the NAS

Example

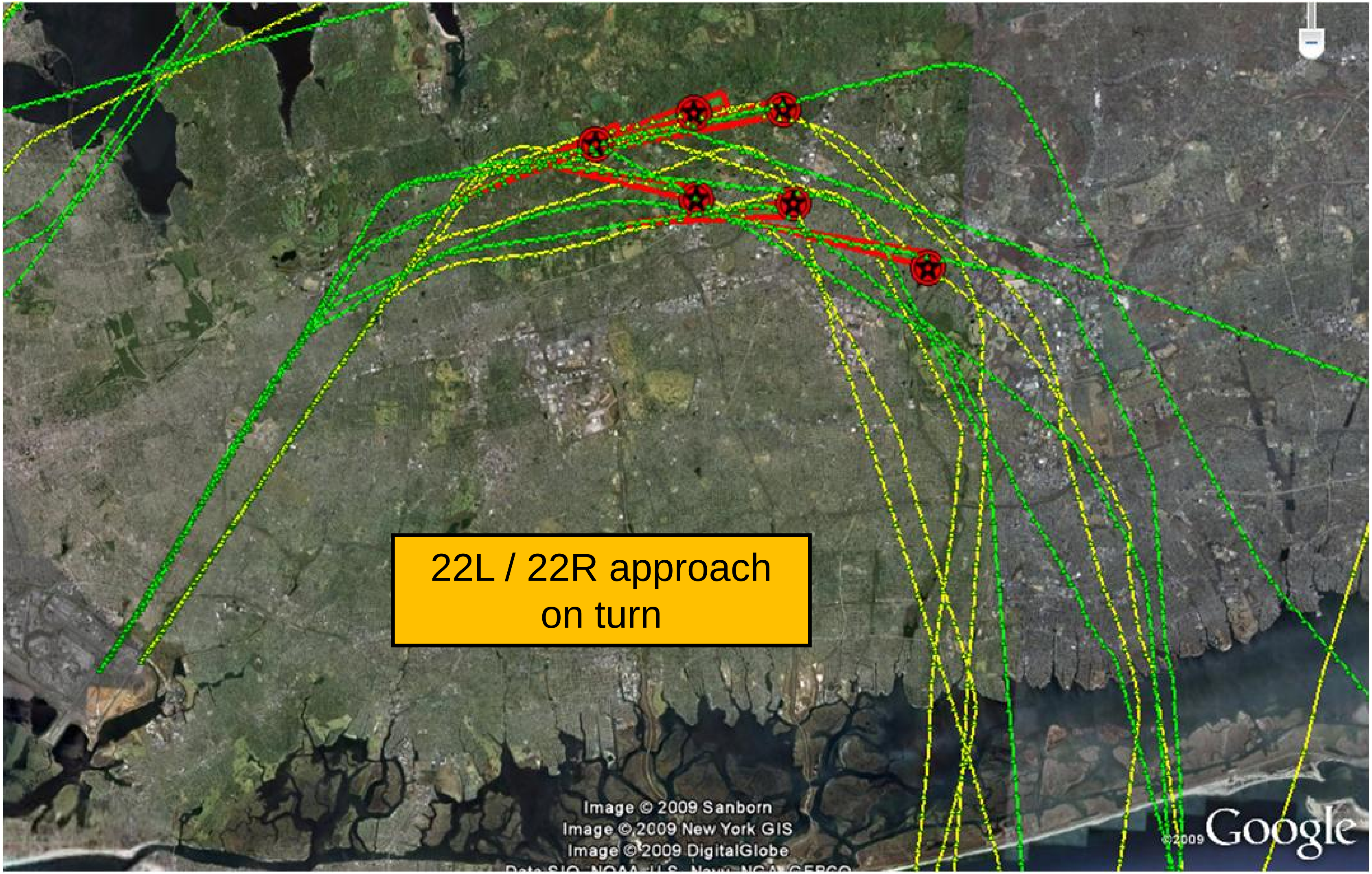


EWR Arrivals / TEB Operations

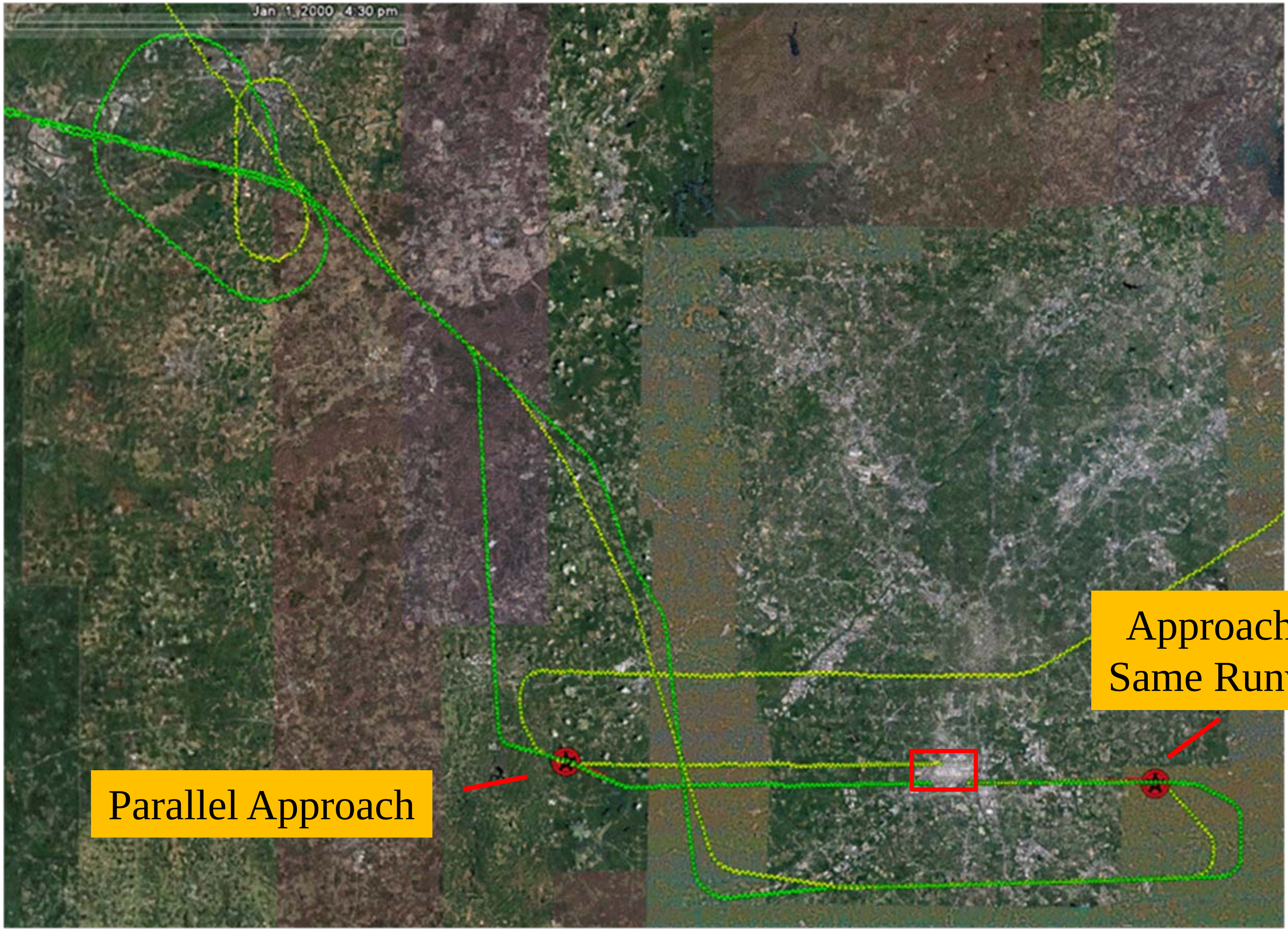
Arrival / departure from TEB under arrival to EWR



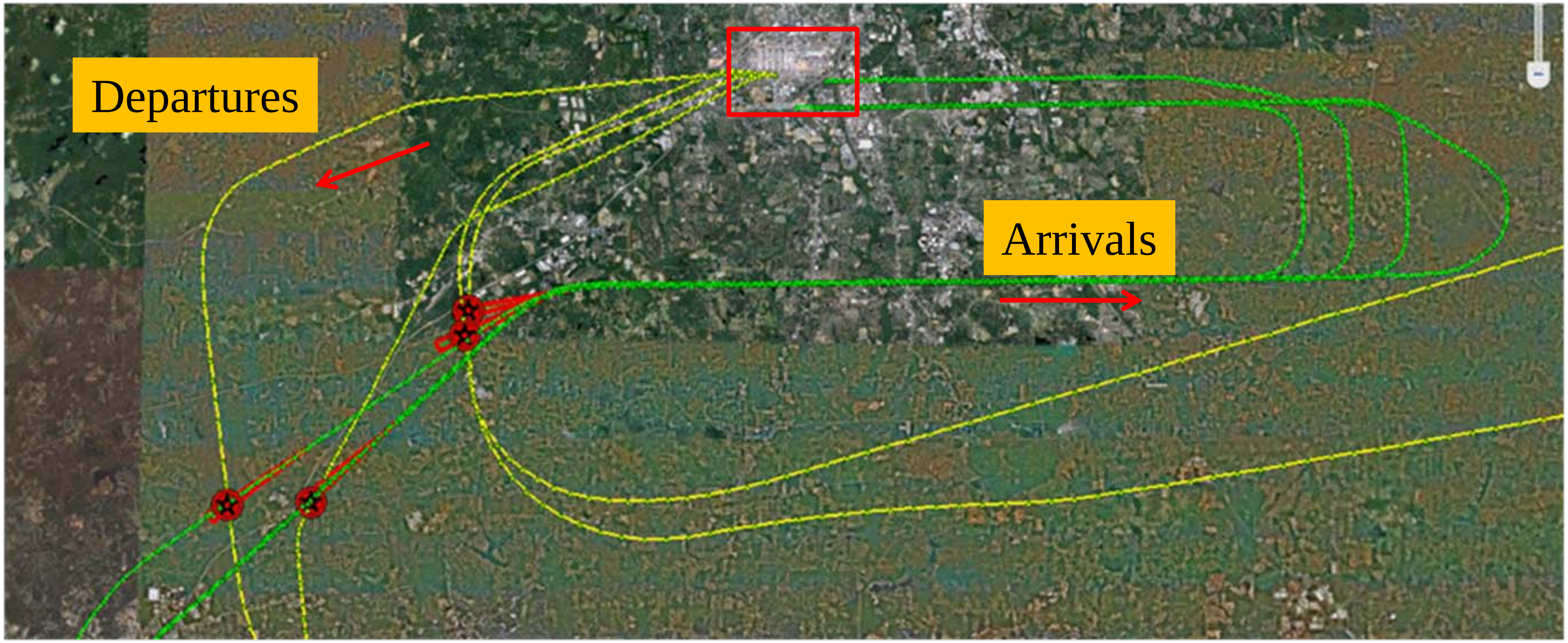
JFK Parallel Turns



Turns on Approach (ATL)



Crossing Arrivals and Departures



Summary

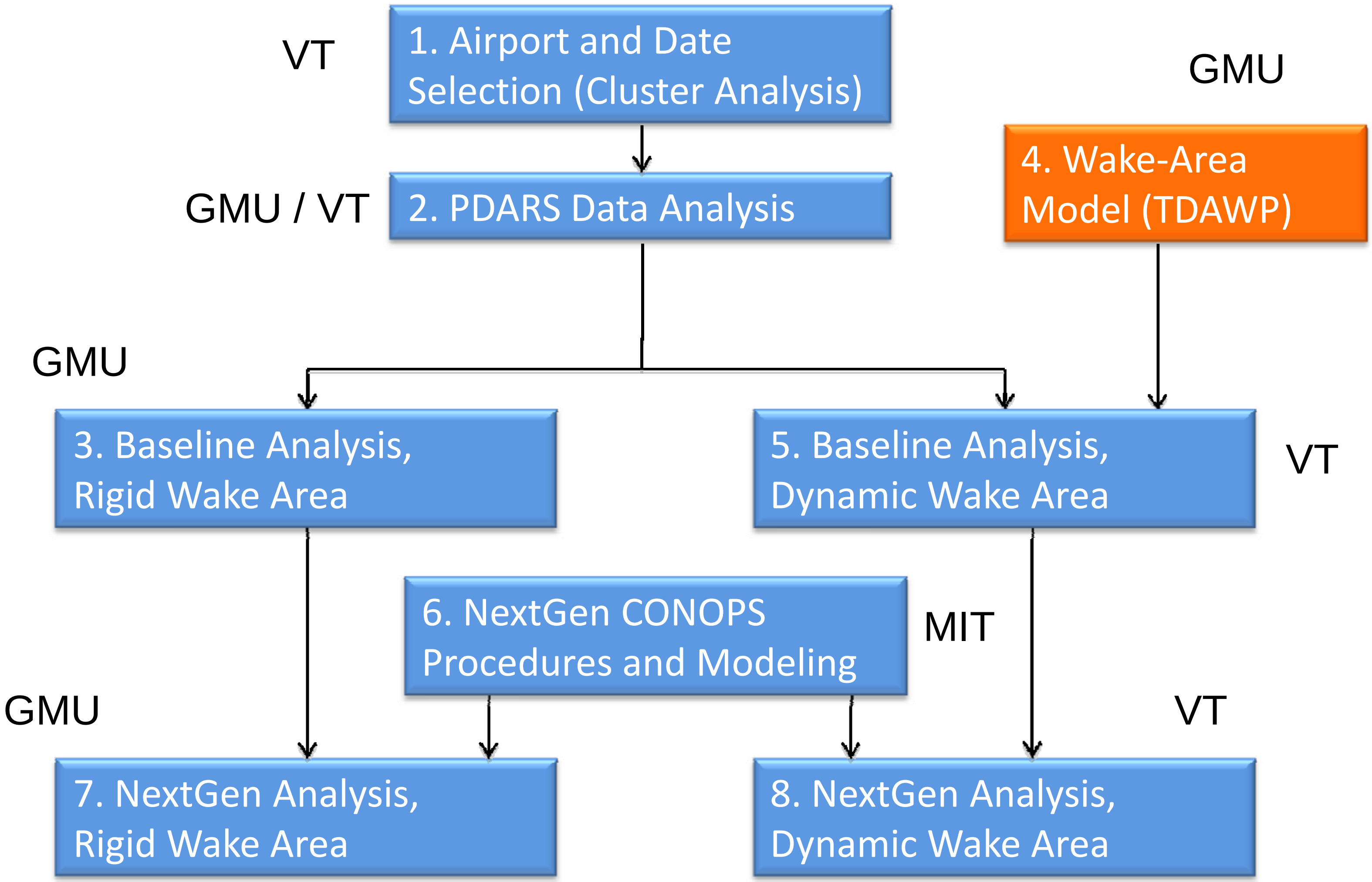
Scenarios from Original Brainstorm Session

Scenario
Arrivals
Same runway
Merging of arrival streams
Turns to parallel approaches
Crossing arrivals and departures
Departures

Other Potential Wake Turbulence Scenarios Identified

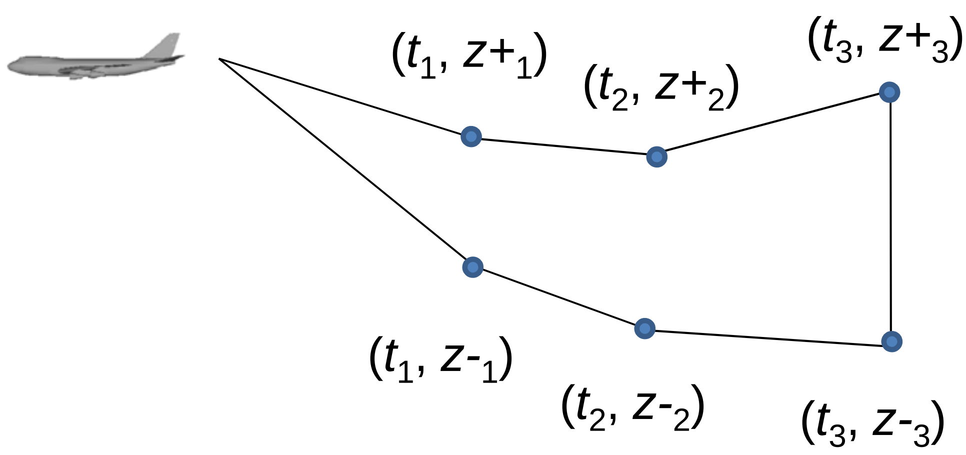
GA aircraft flying under arrivals
Holding patterns
Irregular operations

Modeling Outline

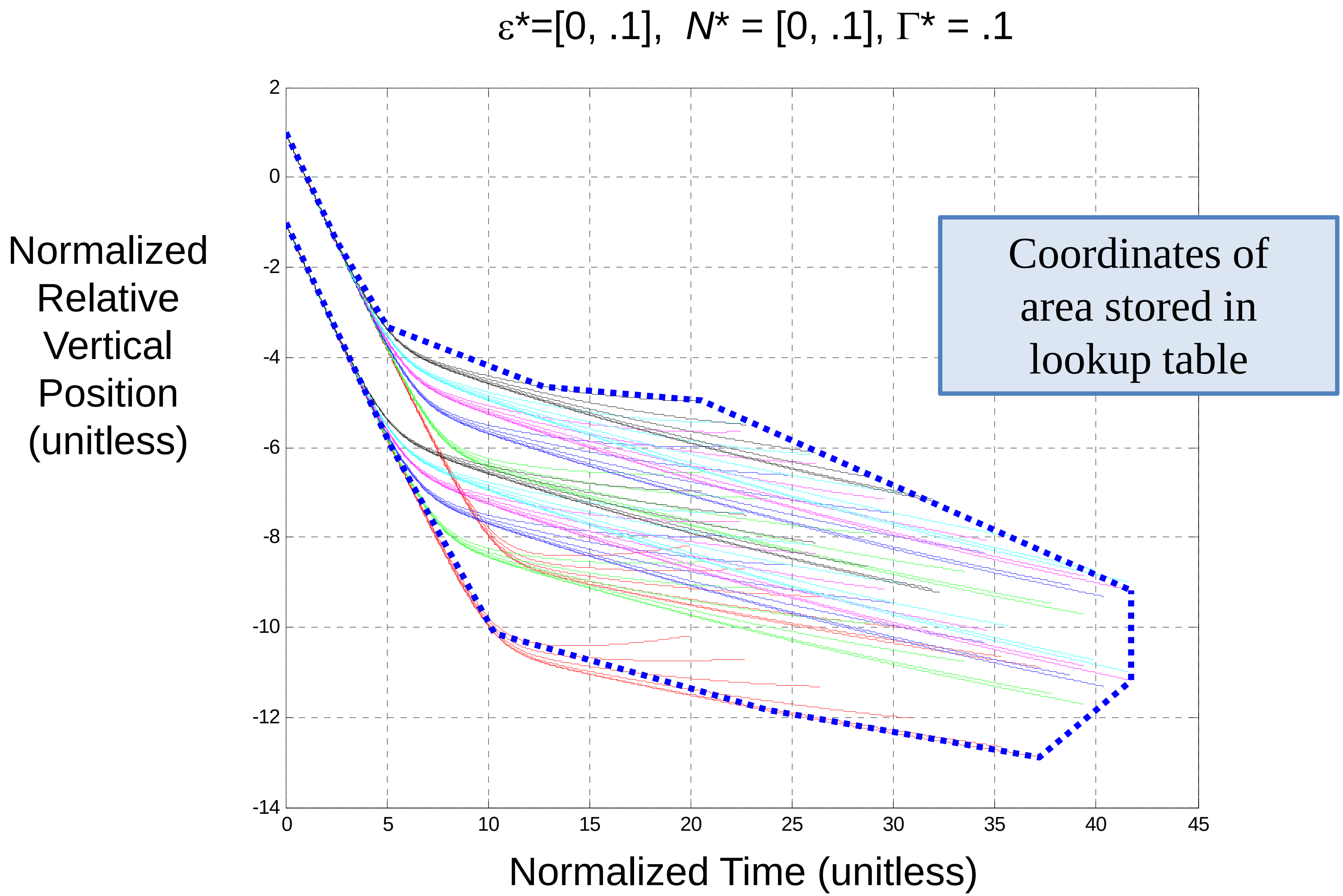


Wake Area Model

- Describe wake area as 3D polyhedron (currently 2D)
- Polyhedron is a function of:
  - Aircraft: Velocity, mass, wingspan, altitude
  - Atmosphere: Eddy dissipation rate, Brunt-Vaisala frequency, air density, wind speed/direction
  - Circulation threshold



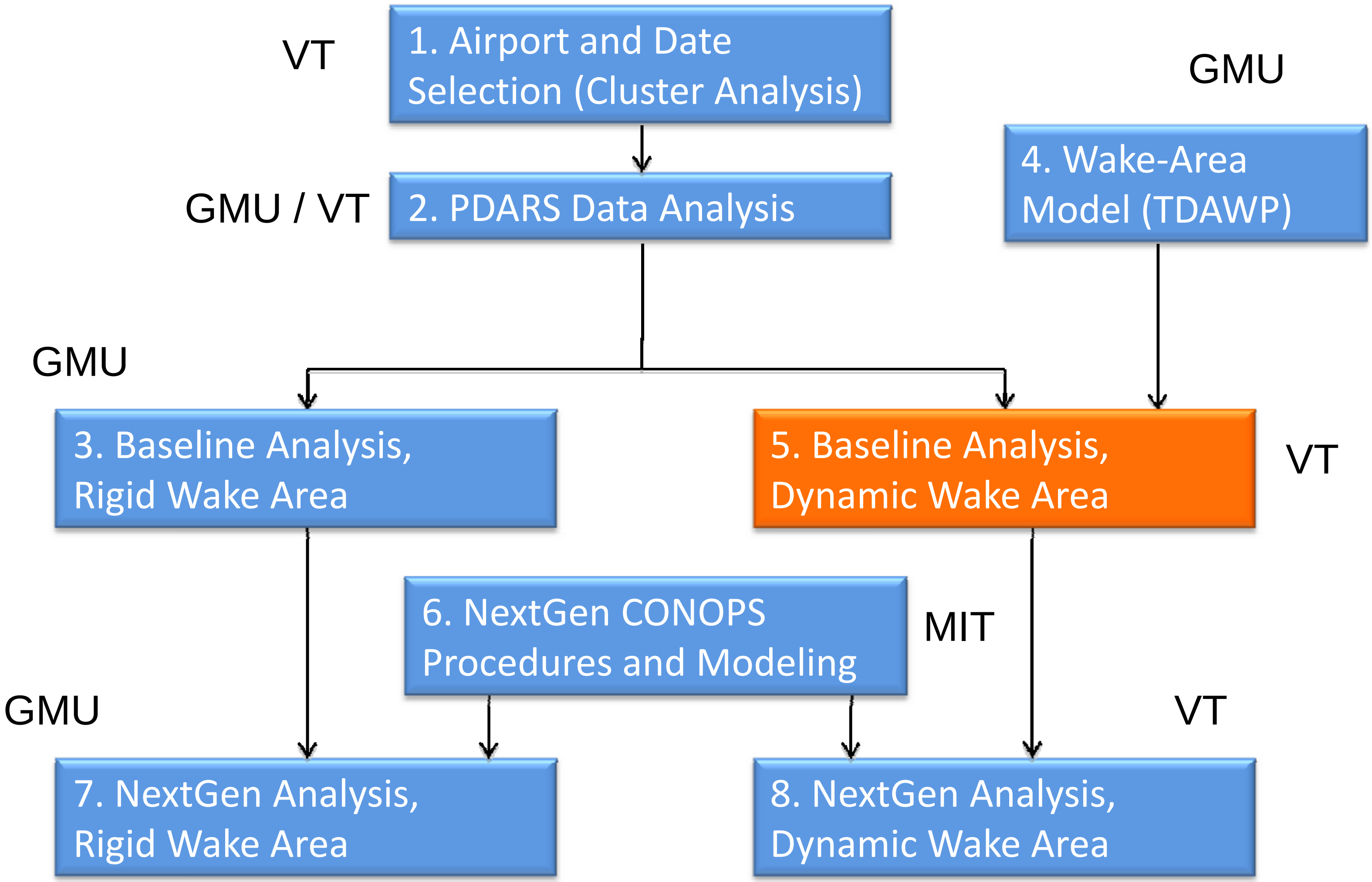
Example Wake Area



TDAWP model, GMU implementation based on Proctor, Hamilton, Switzer, 2006, TASS driven algorithms for wake prediction.

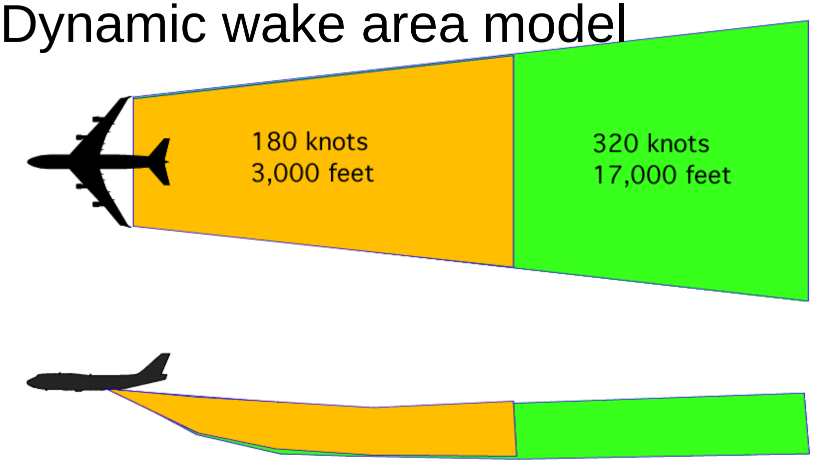
Dynamic Wake Envelope Modeling

Modeling Outline



Wake Encounter Model (WEM)
A Model to Identify Potential Wake Encounters with Dynamic Wake Area

Dynamic wake area model



- WEM "flies" each aircraft along its radar (or prescribed) track using a step size of 5 seconds
- WEM tests whether aircraft has the potential to encounter a wake envelope of surrounding aircraft

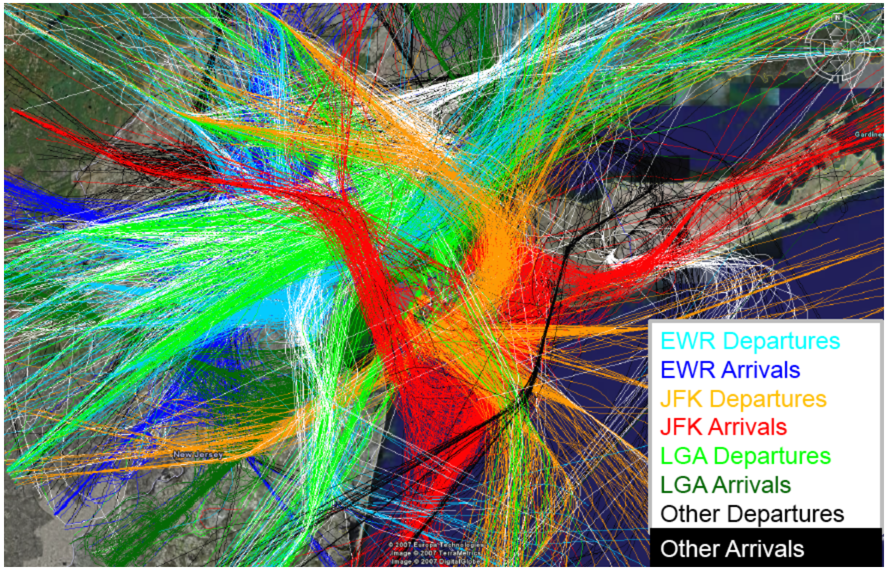
- WEM produces a series of outputs:
  - Potential wake encounters for given day/terminal area
  - Potential encounters by aircraft type
  - Potential encounters by location
  - Potential encounters under differing atmospheric conditions
- Aggregate counts of potential encounters (compared to today) will be used to identify NextGen operational concepts requiring further research

Important Points About the Analysis

- A potential wake vortex encounter as determined from these models does not represent a real wake vortex encounter (e.g., unsafe conditions in the system)
  - The assumed values of circulation strength, BVF and EDR parameters are set to very low values and were not present in the atmosphere during the days of analysis
  - The potential wake vortex interactions were not reported in the NASA ASRS database
- A potential wake vortex encounter merely implies that under optimal atmospheric conditions, an aircraft generating a wake could produce a wake that could impinge on another aircraft

NYC Results: IMC

- Five potential wake encounters during an IMC day
- Arriving EWR flights create potential wake vortex interactions with departing TEB flights



Date	Weather Condition	Circulation Threshold	EDR	BVF	Potential Wake Encounters	Flights
3/19/2008	IMC	75	0.0001	0.0005	5	4,765
		75	0.0020	0.0100	2	4,765
		75	0.0040	0.0200	1	4,765
		125	0.0001	0.0005	4	4,765
		125	0.0020	0.0100	1	4,765
		125	0.0040	0.0200	0	4,765
		175	0.0001	0.0005	3	4,765
		175	0.0020	0.0100	0	4,765
		175	0.0040	0.0200	0	4,765

Circulation strength threshold expressed in m^2/s, EDR in m^2/s^3 and BVF in 1/s

New York Results: IMC

WEM Model Results (LAX) IMC

- LAX had two potential wake encounters (1 IMC, 1 VMC)
- Both were departure interactions

- IMC encounter details:
  - Wake produced by Embraer 190 (Large)
  - Potential wake encountered by Embraer 120 (Small)

Date	Weather Condition	Circulation Threshold	EDR	BVF	Potential Wake Encounters	Flights
7/18/2008	IMC	75	0.0001	0.0005	1	5,453
		75	0.0020	0.0100	0	5,453
		75	0.0040	0.0200	0	5,453
		125	0.0001	0.0005	0	5,453
		125	0.0020	0.0100	0	5,453
		125	0.0040	0.0200	0	5,453
		175	0.0001	0.0005	0	5,453
		175	0.0020	0.0100	0	5,453
		175	0.0040	0.0200	0	5,453

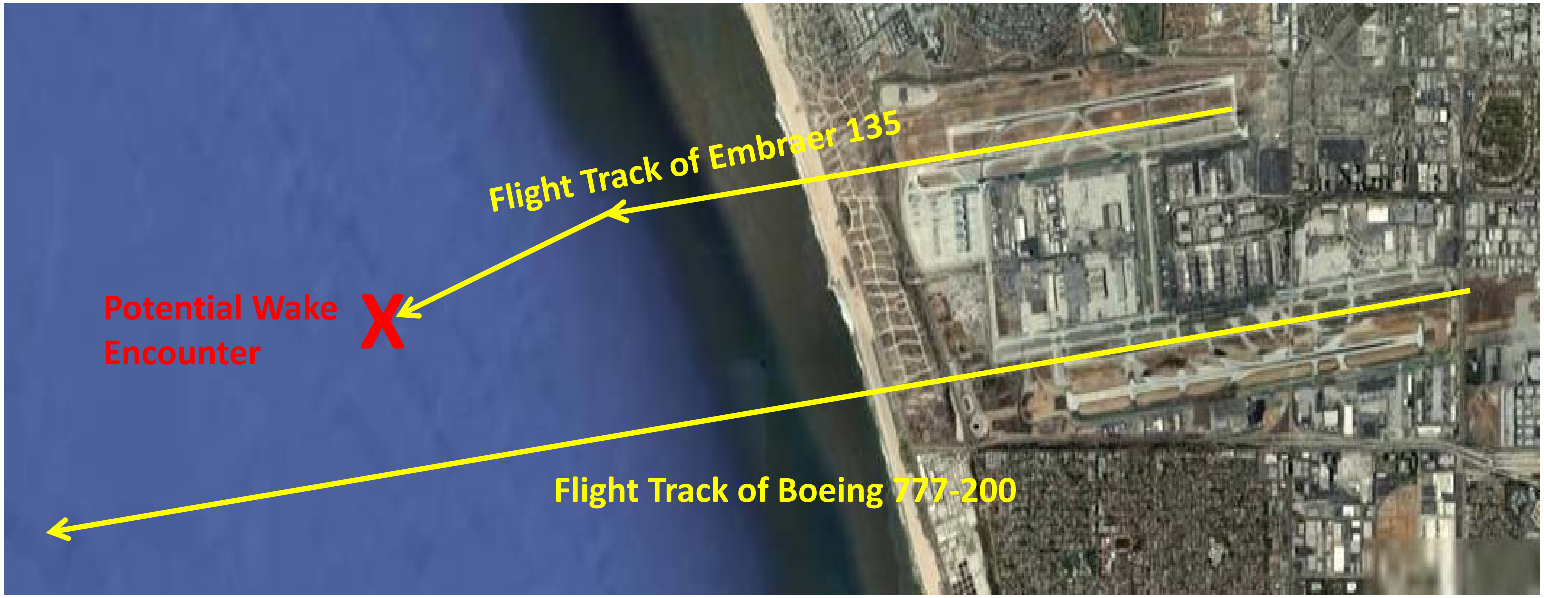
Circulation strength threshold expressed in m^2/s, EDR in m^2/s^3 and BVF in 1/s

LAX Results: VMC

- Wake Produced by Boeing 777-200 (Heavy)
- Affected aircraft: Embraer 135 (Large)
- Aircraft taking off from parallel runway

Date	Weather Condition	Circulation Threshold	EDR	BVF	Potential Wake Encounters	Flights
6/18/2008	VMC	75	0.0001	0.0005	1	5,380
		75	0.002	0.01	0	5,380
		75	0.004	0.02	0	5,380
		125	0.0001	0.0005	1	5,380
		125	0.002	0.01	0	5,380
		125	0.004	0.02	0	5,380
		175	0.0001	0.0005	1	5,380
		175	0.002	0.01	0	5,380
		175	0.004	0.02	0	5,380

Circulation strength threshold expressed in m^2/s, EDR in m^2/s^3 and BVF in 1/s



Potential Encounters by Wake Category and Weather Conditions

- Most potential wake encounters produced by large aircraft
  - Large aircraft are more common than heavy aircraft at the airports studied

Wake Generator	Wake Encounterer	Potential Number of Encounters
Heavy	Large	2
757	Small	1
Large	Large	1
Large	Small	6

- Most potential encounters occurred during IMC which was surprising
- Skewed result since most IMC potential encounters associated with EWR/TEB scenario

Weather Condition	Potential Number of Encounters
IMC	6
MMC	2
VMC	2

Preliminary Conclusions

- Two modeling approaches to identify potential wake issues in NextGen have been presented:
  - First-order model (fixed wake area)
  - Dynamic wake model
- Models are sensitive to input variables (EDR, BVF, circulation strength, aircraft state, etc.)
- Models can study thousands of flights to identify areas of potential wake encounters or interactions
- Models will offer insight to assess the relative wake turbulence encounter probability associated with NextGen scenarios

Future Research

- Analyze more data (ATL, DCA, other)
  - Continue analysis of NYC data
  - Conclusions likely qualitative with only single days of data
- Improvements to wake-area models
  - Lateral component of wake profiles (wind and turning effects
  - Non-uniform spacing of parameter intervals
  - Inclusion of uncertainty
- Continue development of wake-encounter point-model
- Moving from using baseline to validate proper operation of the tool to NextGen analysis