



CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)



# Analysis of OPD Benefits and Impact on Daytime Operations

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# Introduction

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- **Purpose for the Study**

- Rising fuel costs (Jet fuel ~ \$4.00 per gallon)
- Growing environmental awareness (Carbon trading)

- **Analysis Focus**

- **Optimized Profile Descent (OPD) operations are expected to reduce fuel usage and pollutant emissions**
- **Questions to ask:**
  - How will the proximity of arrival and departure flows change if OPDs are implemented?
  - Will OPD implementation require a compromise?
  - What will the overall benefit be assuming these compromises?



# Outline



- **Description of a typical flight**
  - Description of a baseline arrival
  - Description of an equivalent OPD trajectory
- **Baseline arrival vs. equivalent OPD arrival**
  - Track comparison
  - Flow stream comparison
  - Fuel burn and emissions comparison
- **Four OPD operational scenarios**
  - Unrestricted OPD
  - OPD with step down flexibility
  - OPD with low altitude vectoring
  - OPD with both step down flexibility and low altitude vectoring



# Description of a Typical Baseline Arrival B737-300



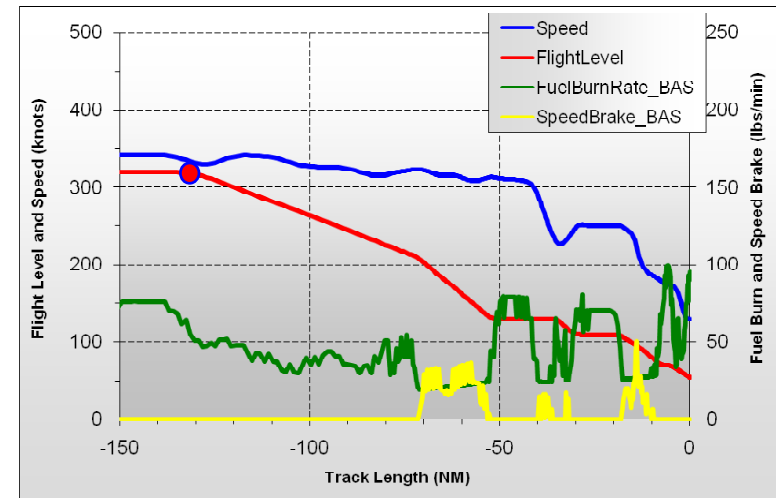
- **Trajectory and Fuel burn**

- **Left-hand side scale:**

- **Blue = Speed**
    - **Red = Flight level**

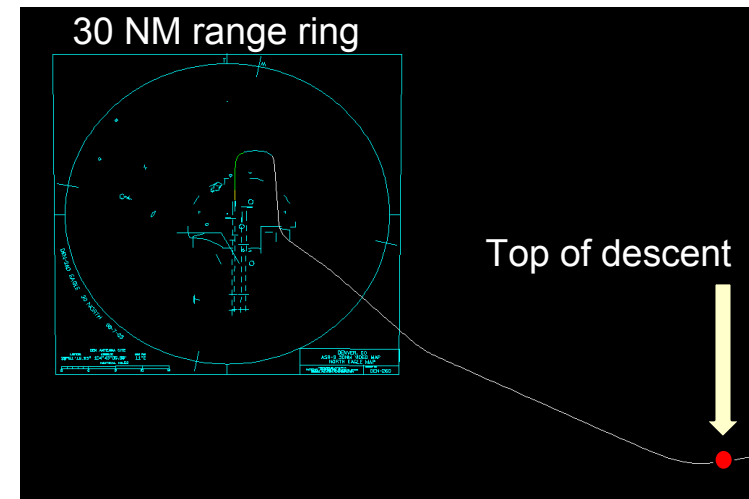
- **Right-hand side scale:**

- **Green = Fuel burn rate**
    - **Yellow = Speed brake**



- **Baseline flight**

- Trajectory derived from radar track data
  - Fuel burn and speed brake computed with iTRAEC trajectory model
  - Aircraft parameters from BADA







# Description of an Equivalent OPD

## B737-300



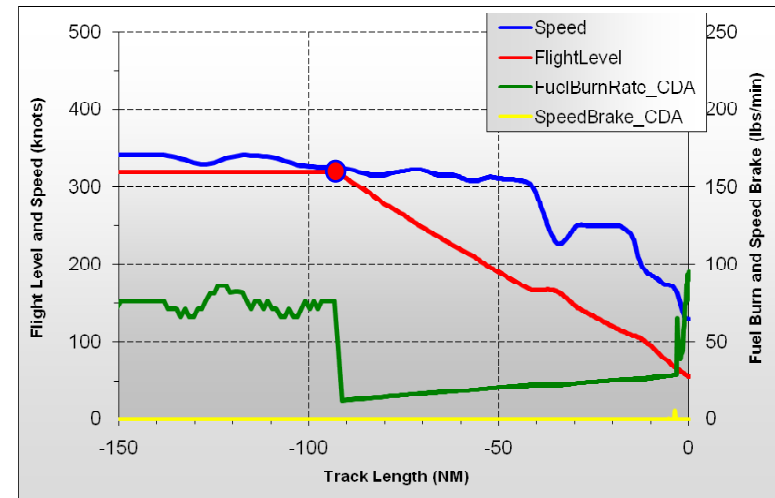
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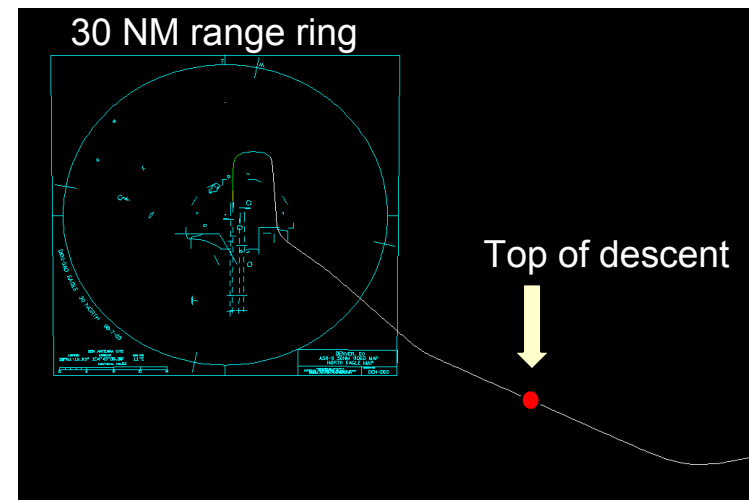
- **Right-hand side scale:**

- **Green = Fuel burn rate**
    - **Yellow = Speed brake**



- **Transform this flight to an equivalent OPD**

- Ground track is unchanged
  - Speed profile is unchanged
  - Descent profile is computed assuming idle thrust





# Baseline to OPD Comparison

## B737-300

- **Summary**

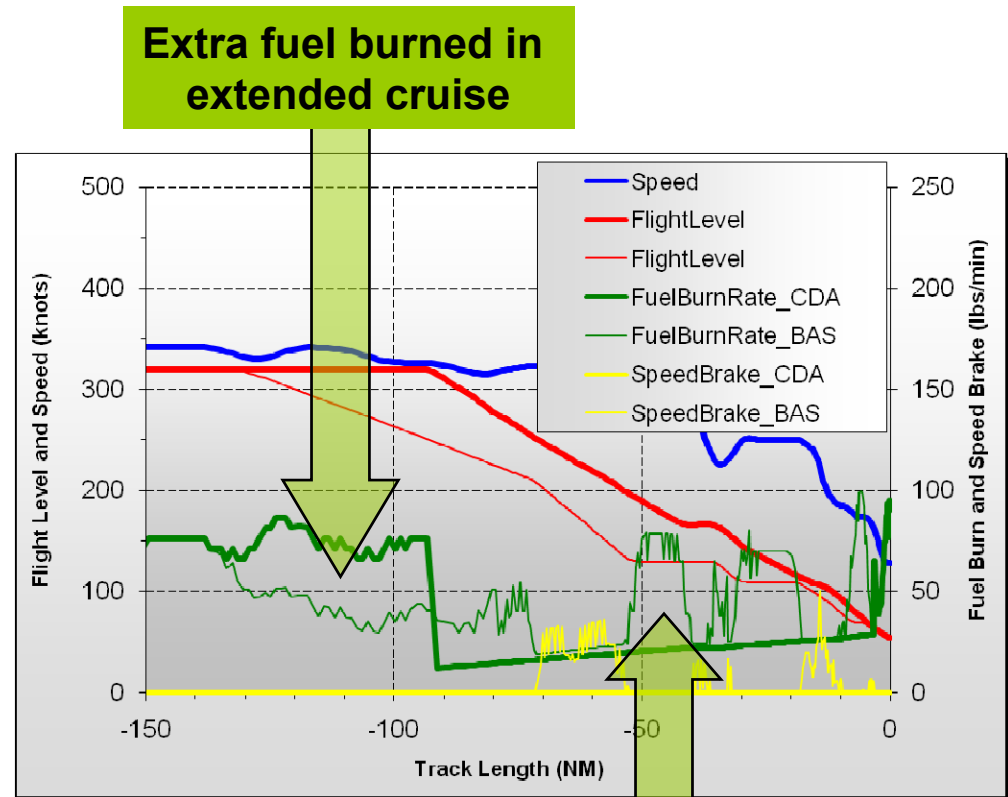
- **Comparison plot**

- Bold lines = OPD
    - Thin lines = Baseline

- **Total fuel savings is computable from comparison of fuel burn (6 lbs/gallon):**

**Net Fuel Savings = 220 lbs**

\* compare to Boeing & LVNL estimate of 240 lbs for B737-800

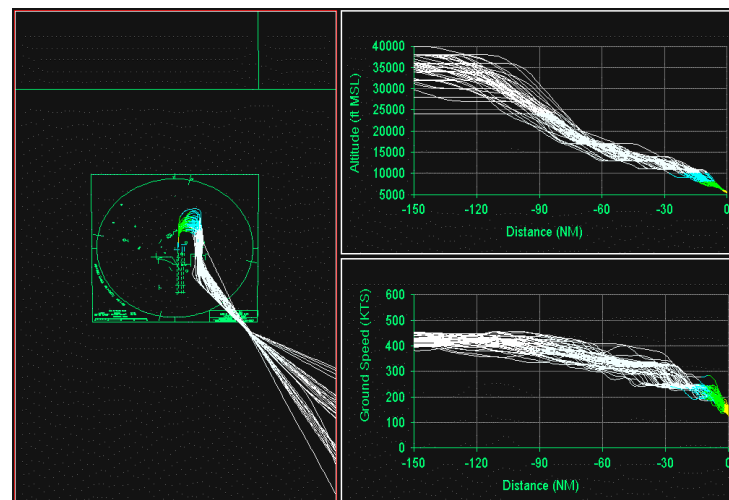
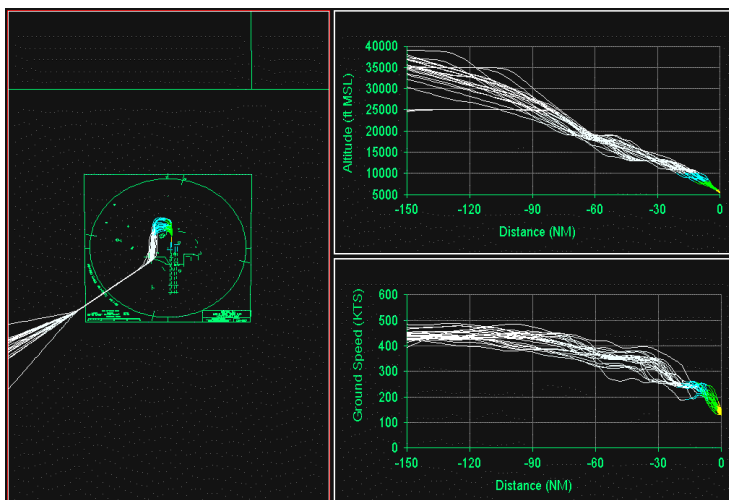
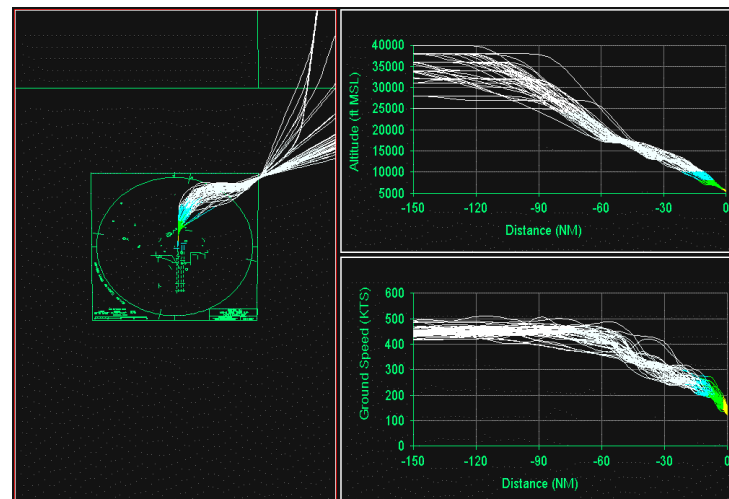
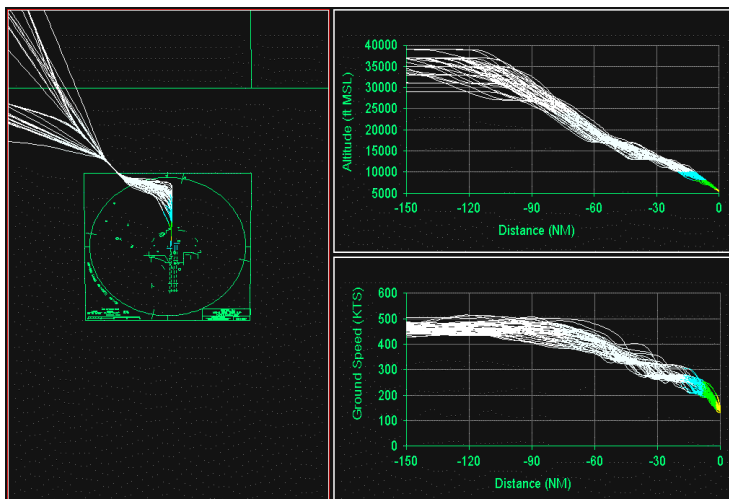


**What happens if this is applied to all arrivals?**



# DEN Example Flows

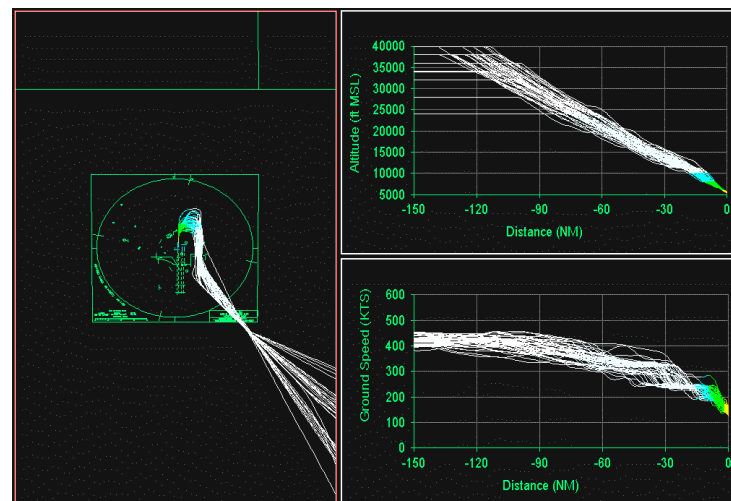
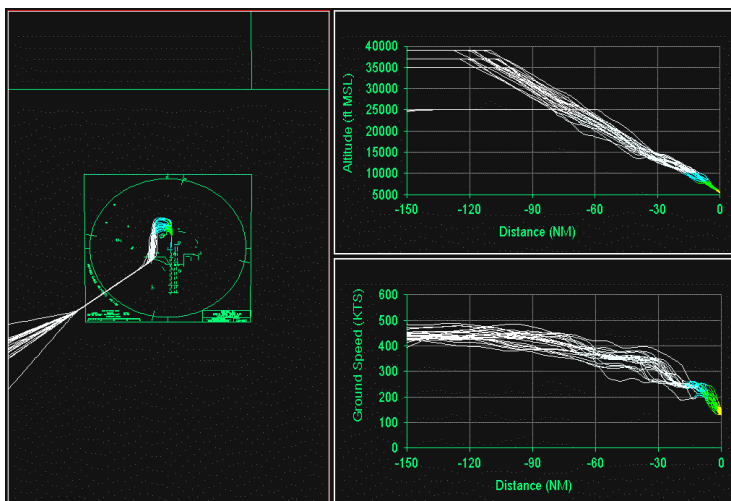
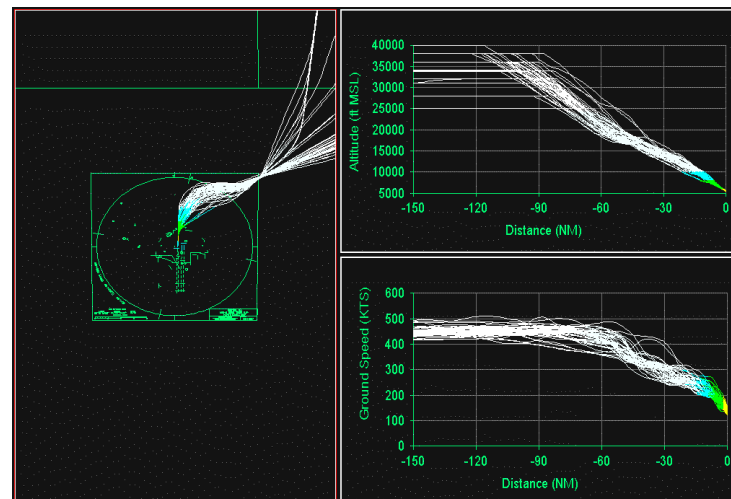
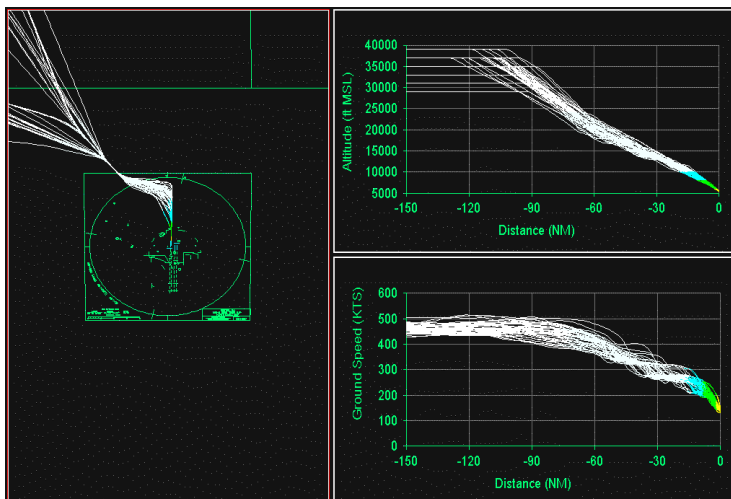
## Baseline Arrival Tracks





# DEN Example Flows

## Equivalent OPD Tracks with Modeled Vertical Profiles





# Discussion of Equivalent OPD

- **Existing baseline arrivals are transformed into OPDs**
    - Cruise is extended
    - Thrust on descent is set to idle
    - Ground tracks are left unchanged
    - Speed profiles are left unchanged
- Spacing and separations are left unchanged
- **Additional OPD operational considerations**
    - Implementing OPD operations will require decision and automation support
    - Transformed tracks lose all vertical separation
  - **Answers the question:** If we design and implement OPDs during all operating hours, where would we need to address operational conflicts and what level of benefit would be derived?



# Evaluation Scenarios

- **Scenario 1: Unrestricted OPD**
  - Begins at the maximum cruise altitude
  - Ends as the aircraft transitions to a landing configuration
- **Scenario 2: Delayed initiation**
  - Begins at an altitude lower than the maximum cruise altitude
    - Normal setting of the top of descent above the OPD initiation altitude
    - Allows step-downs before descent
  - Ends after transition to landing configuration
- **Scenario 3: Early termination**
  - Begins at the maximum cruise altitude
  - Ends at a specified lower altitude
    - Normal operations below the OPD termination altitude
    - Allows arrival shelf level-offs
- **Scenario 4: Combination of Scenarios 2 and 3**





# Scenario 0: Baseline Arrival Operations

South runway configuration, Jets only  
Departures from 17L and less used flows omitted for clarity  
Flow tubes encompass ~90% of tracks for each flow stream

cyan = departures

purple = arrivals

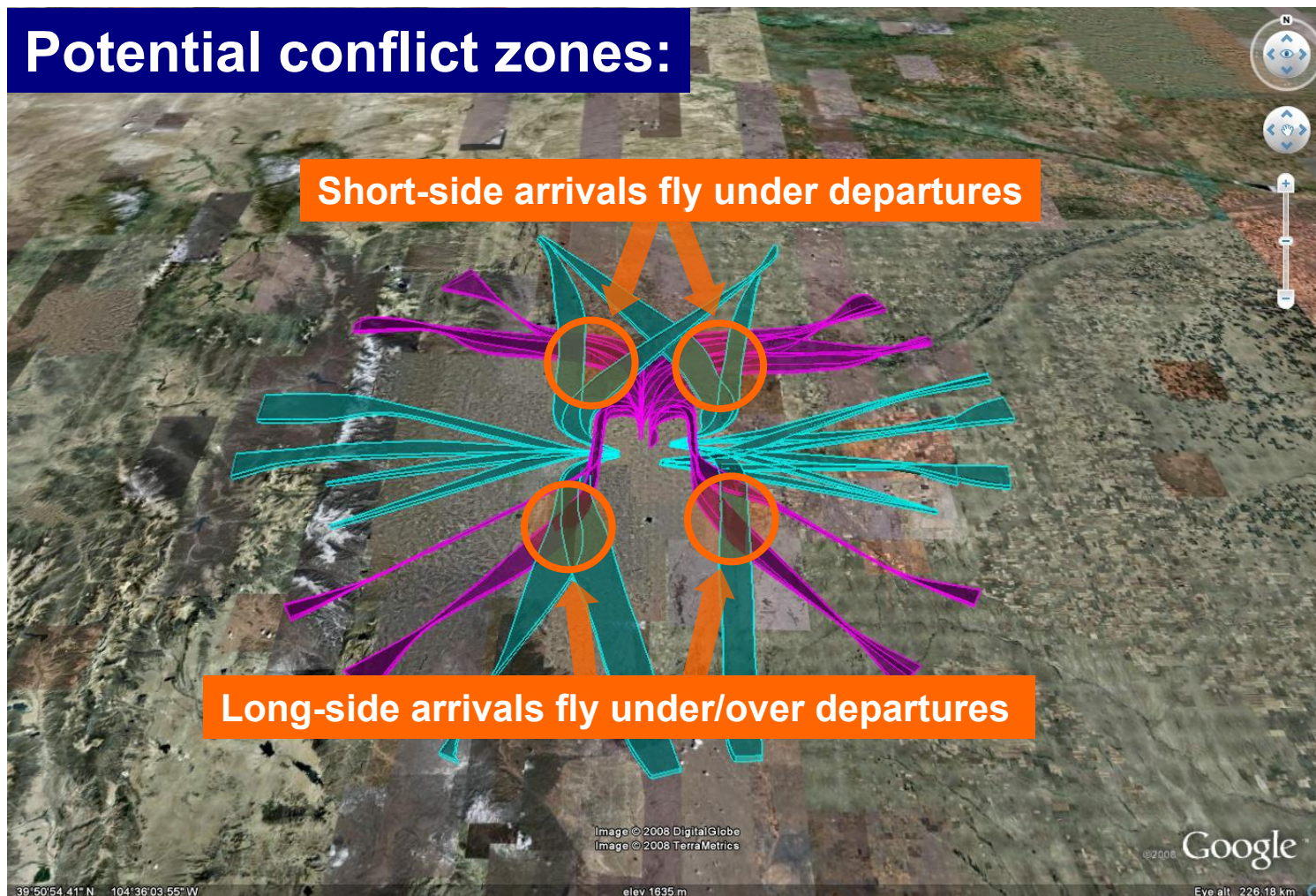






# Scenario 0: Baseline Arrival Operations

## Potential conflict zones:







# Scenario 0: Baseline Arrival Operations







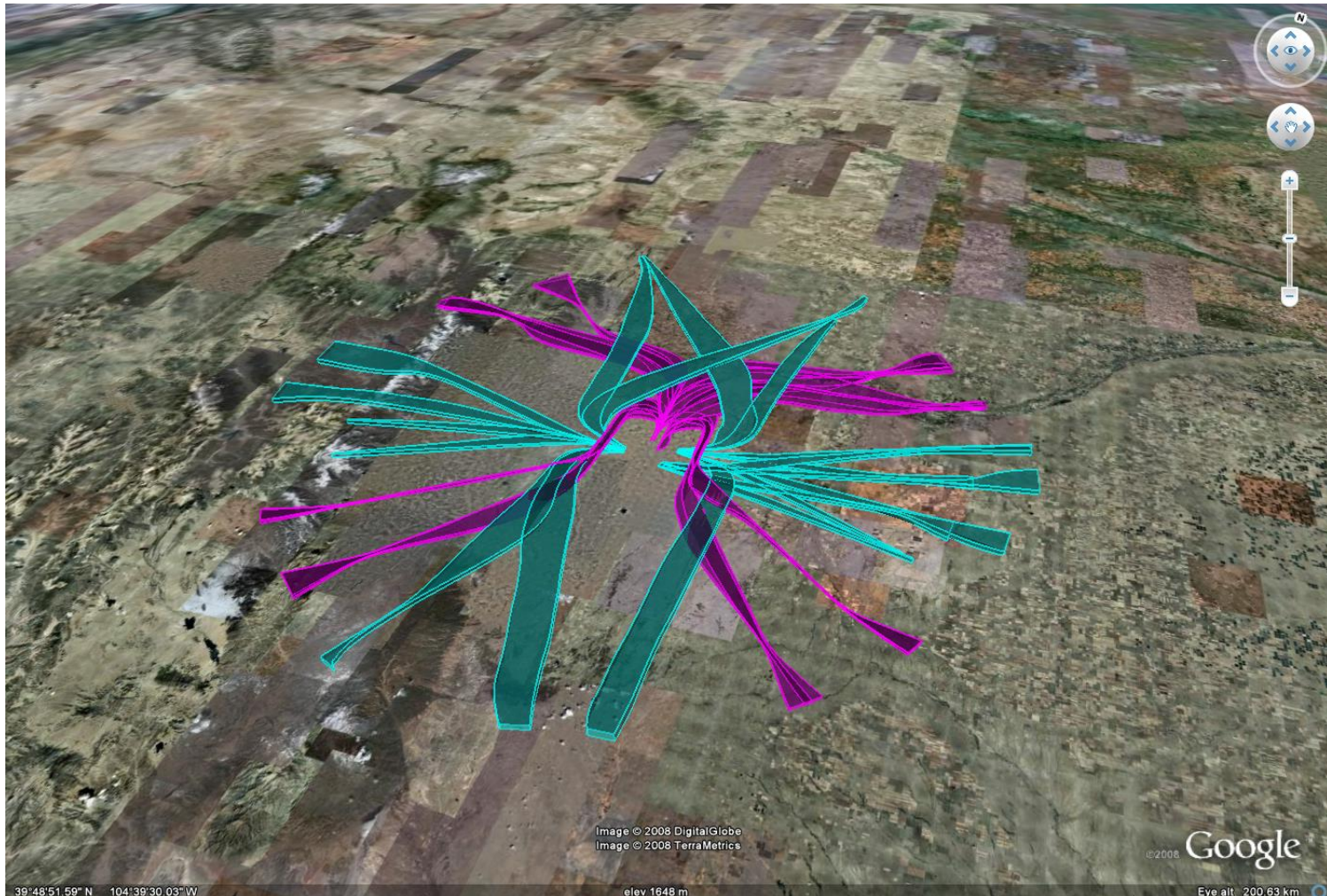
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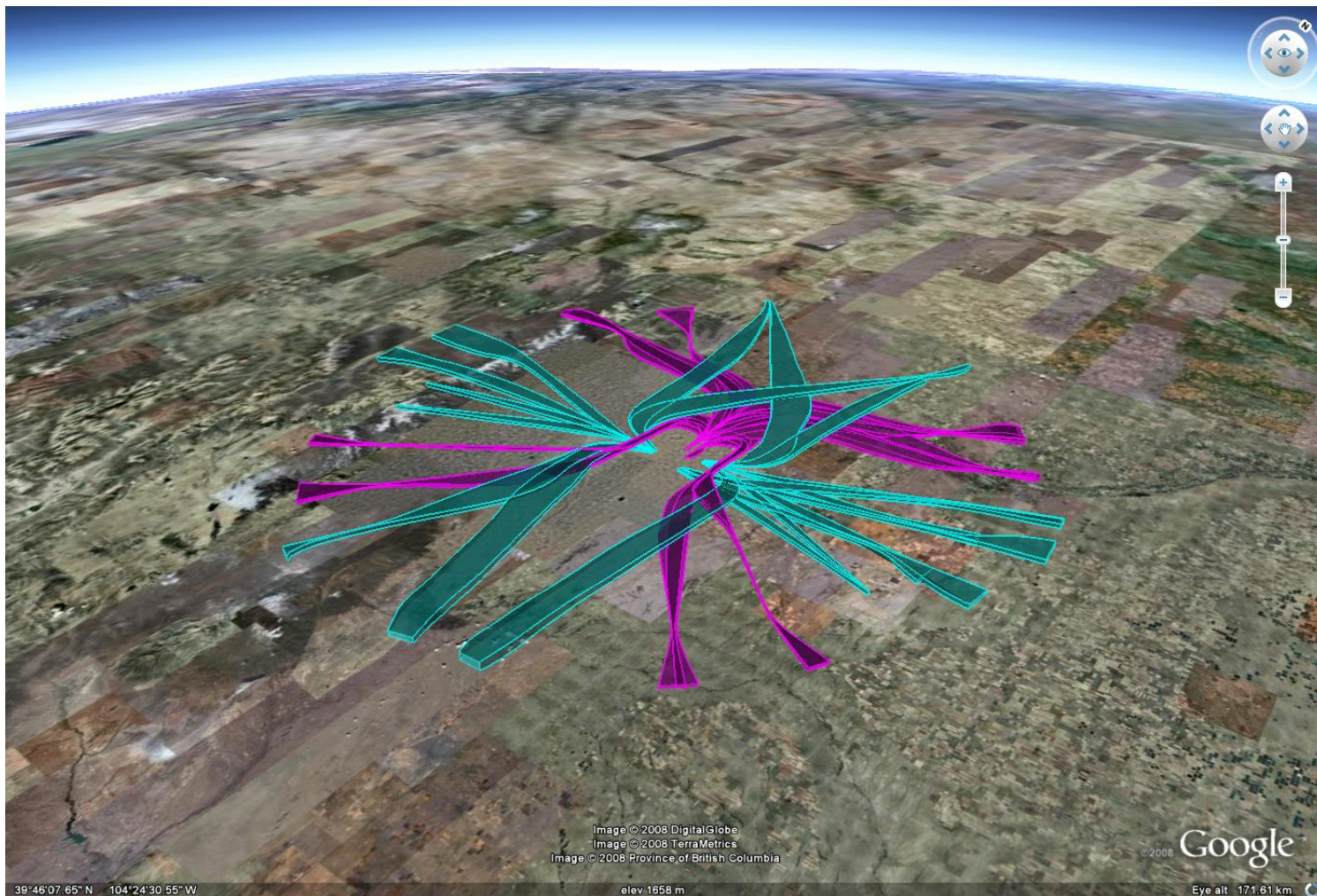
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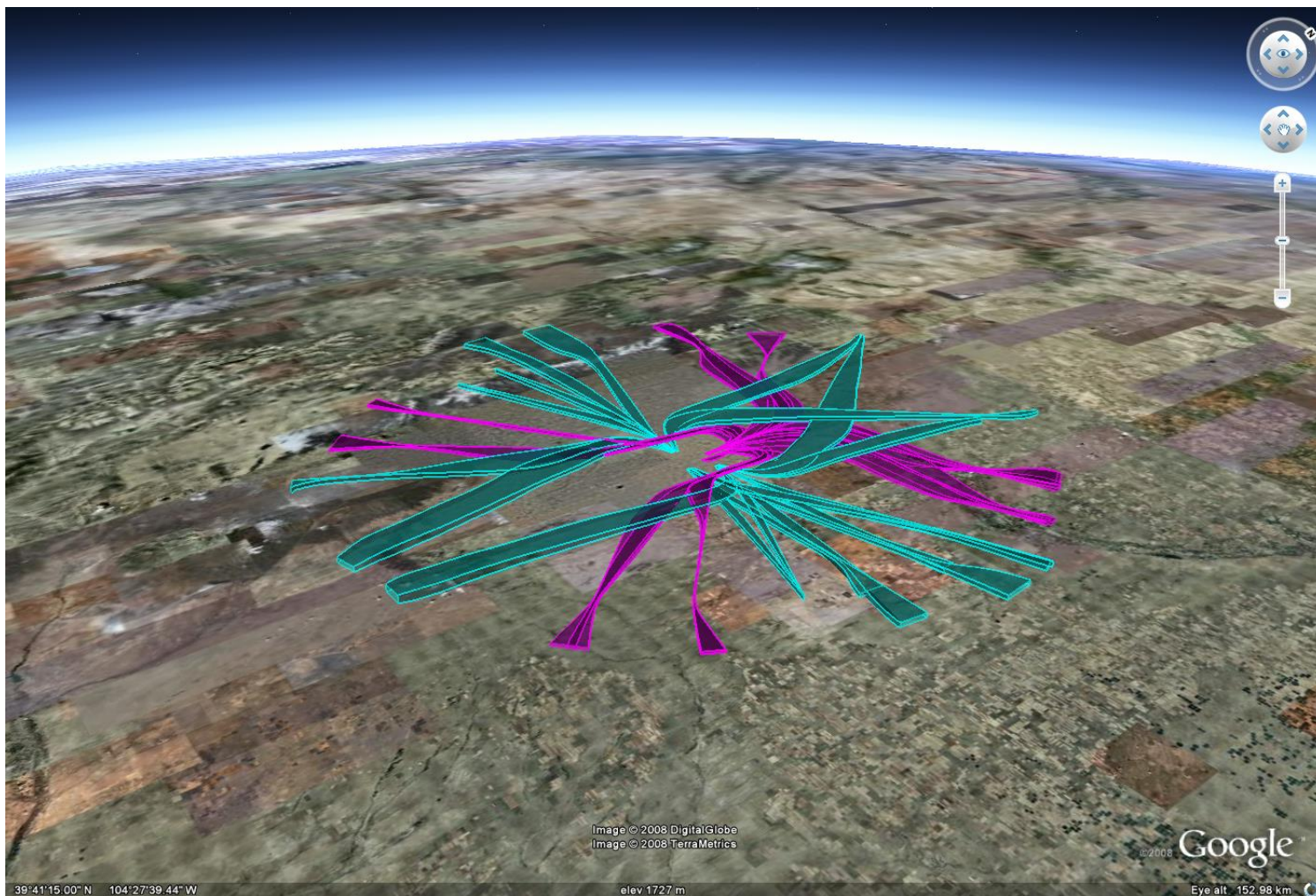
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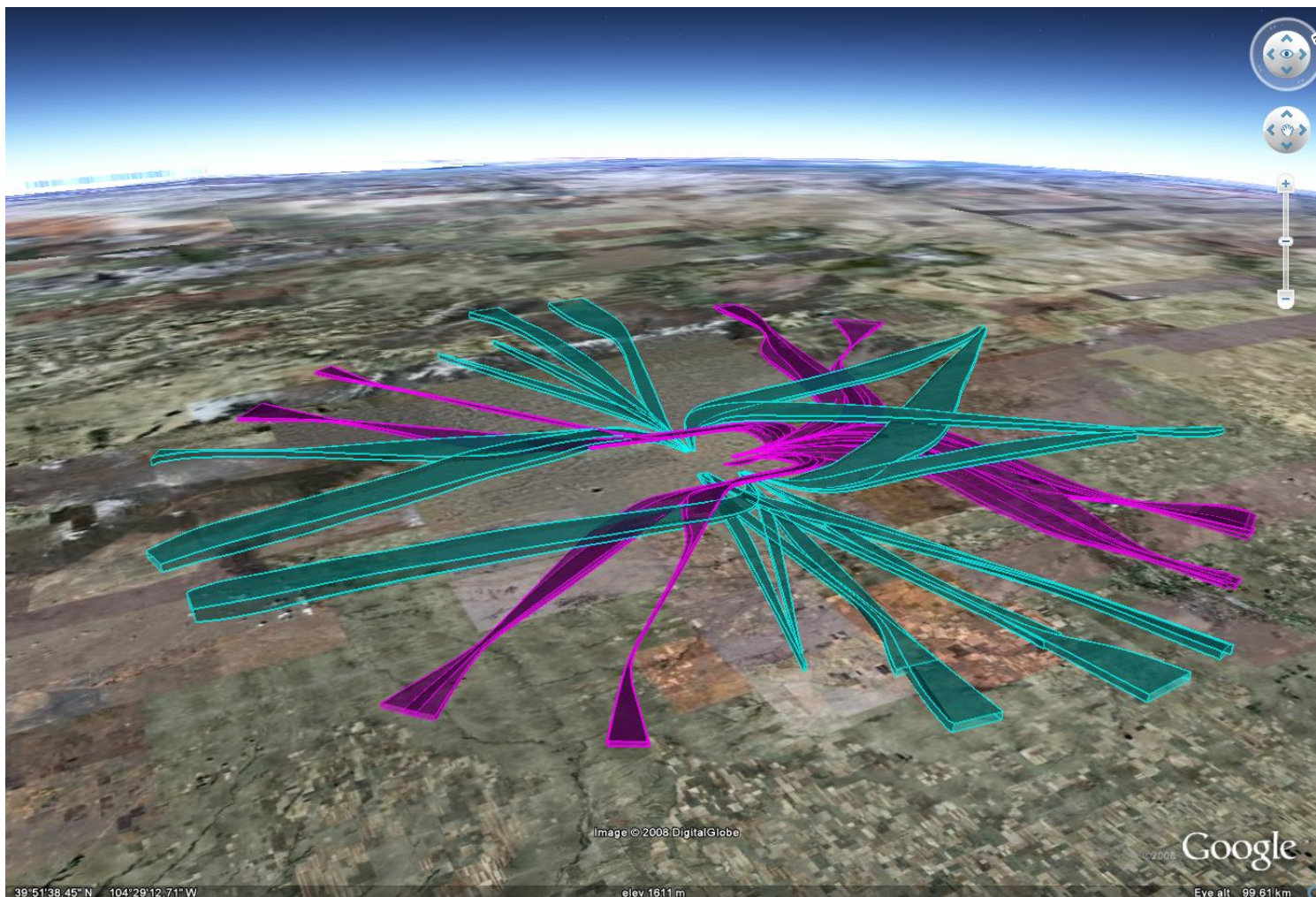
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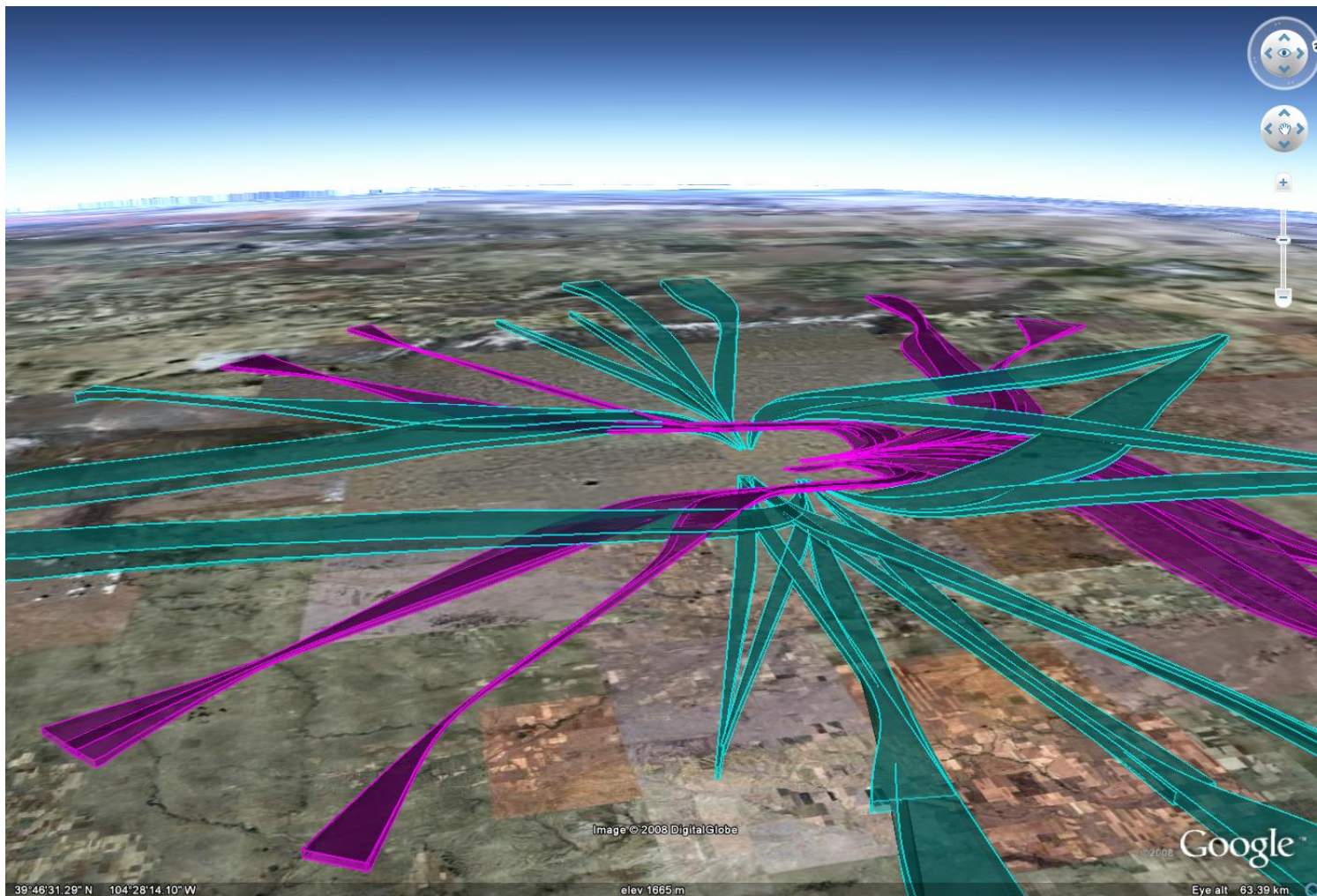


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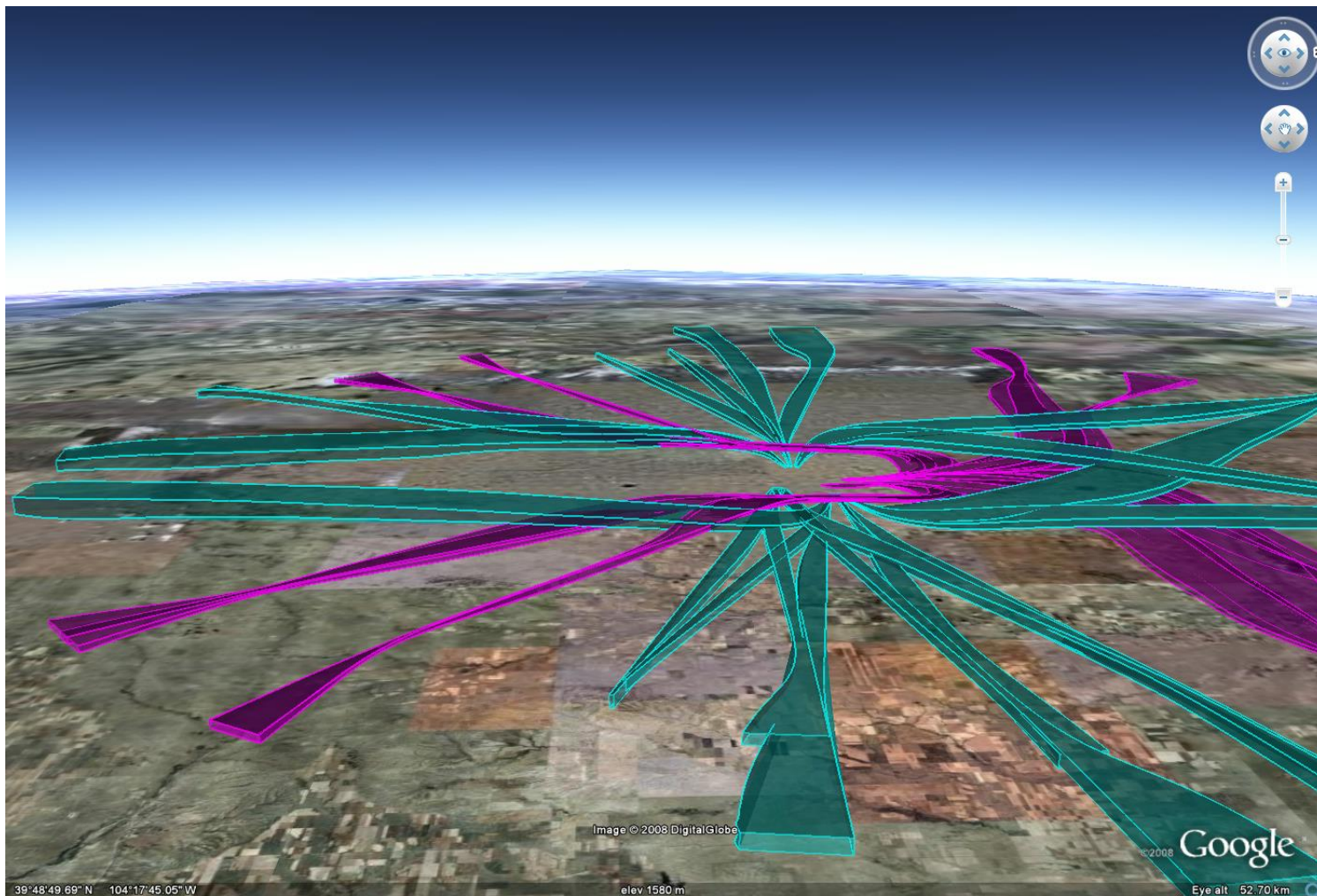
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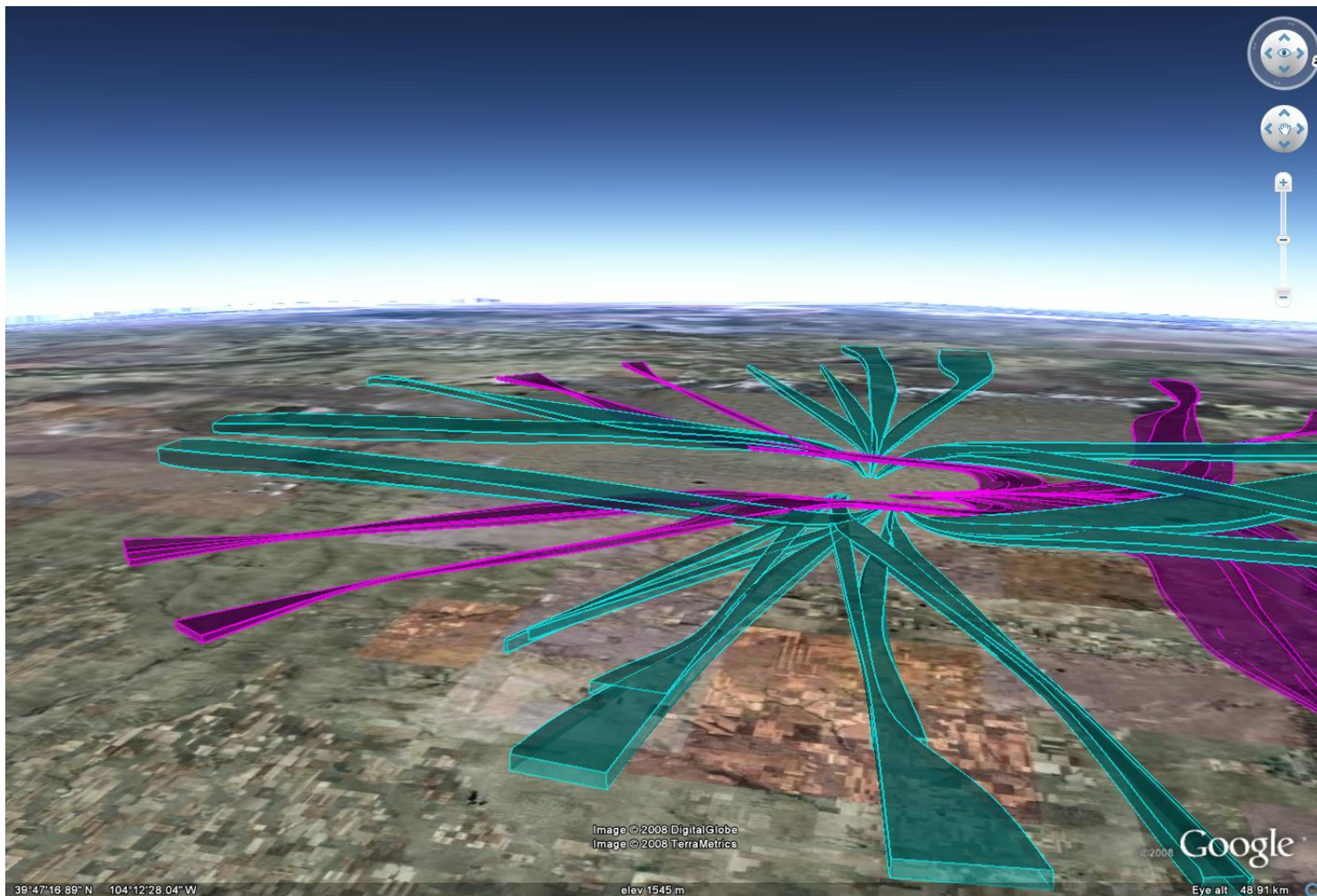
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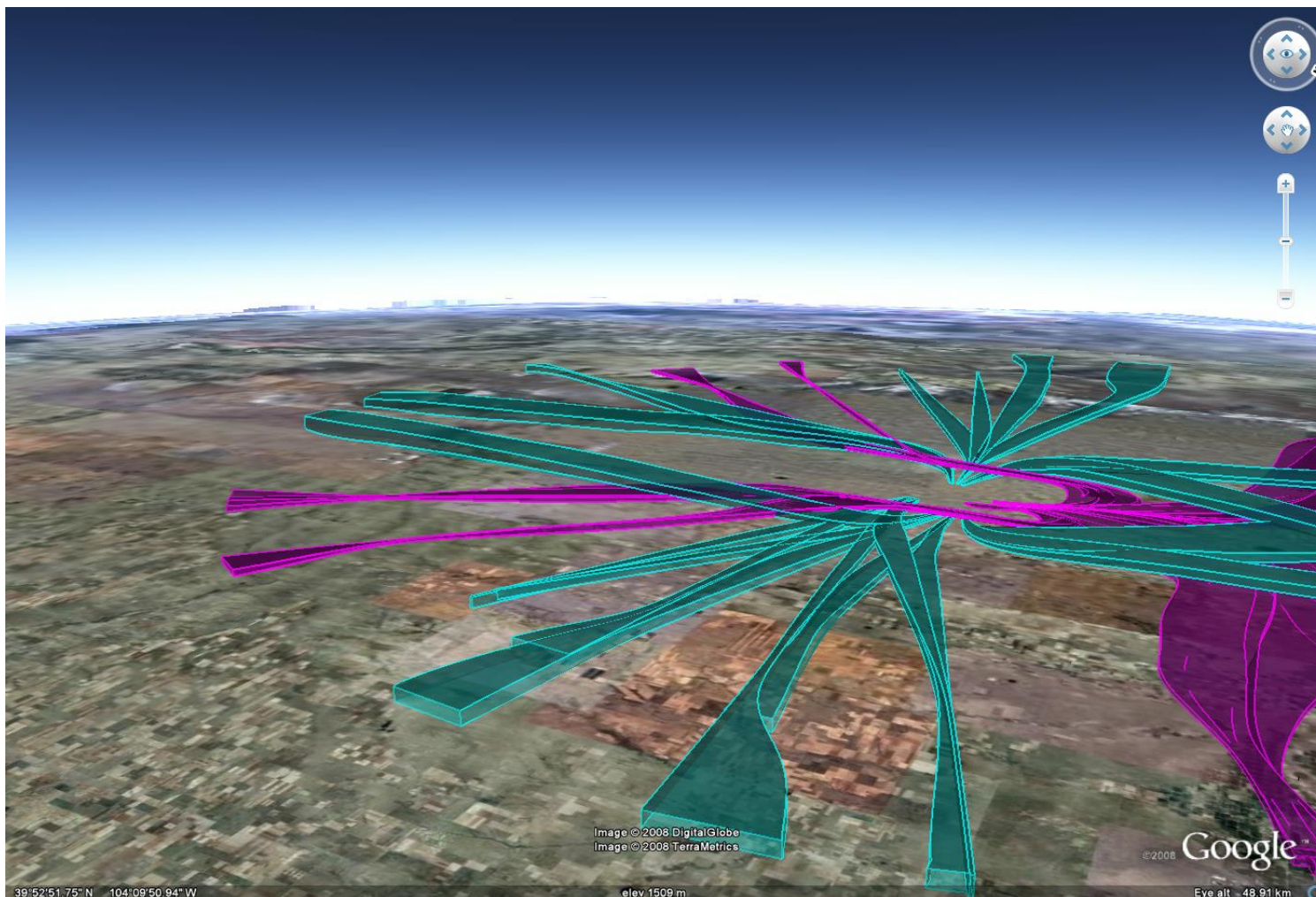


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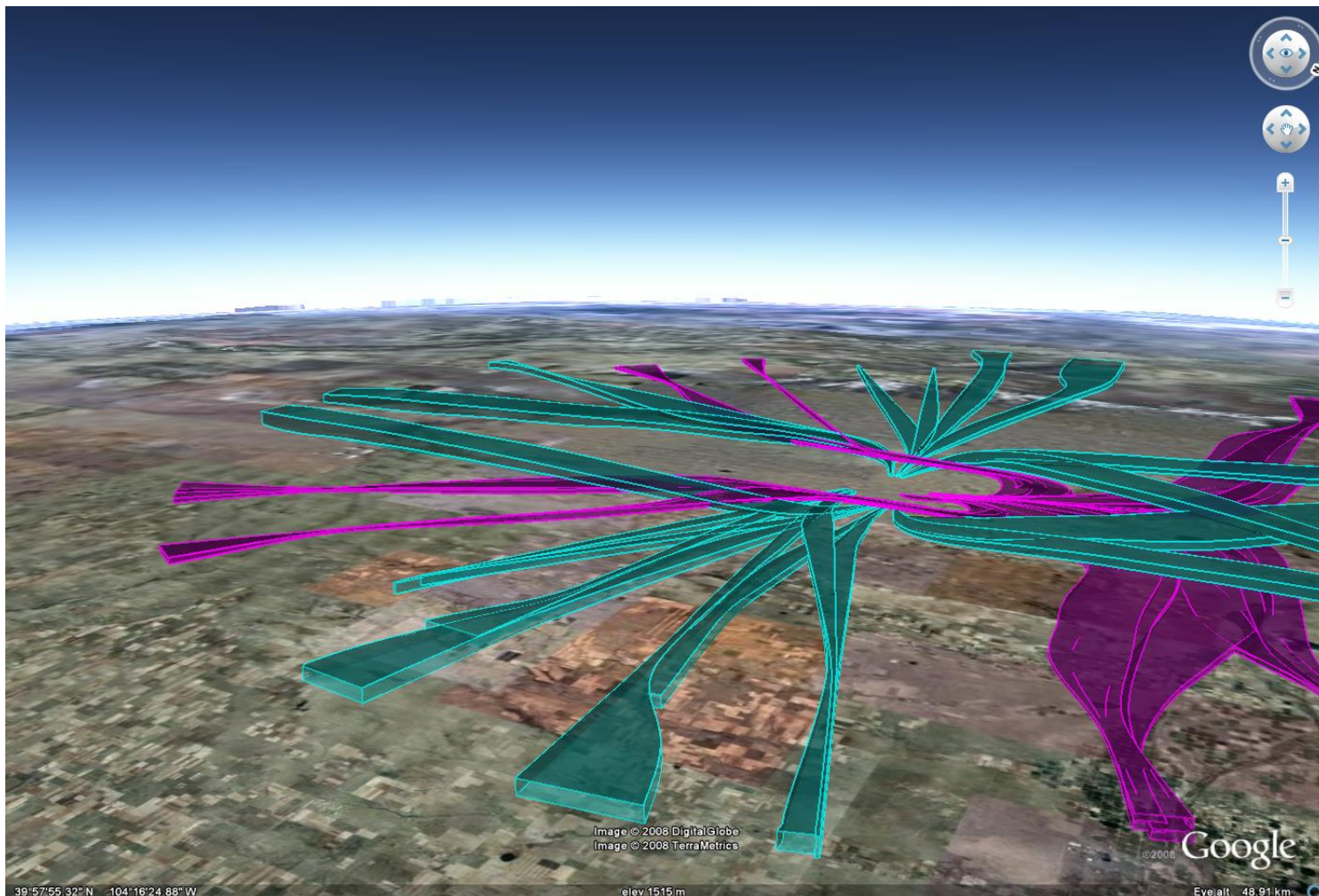
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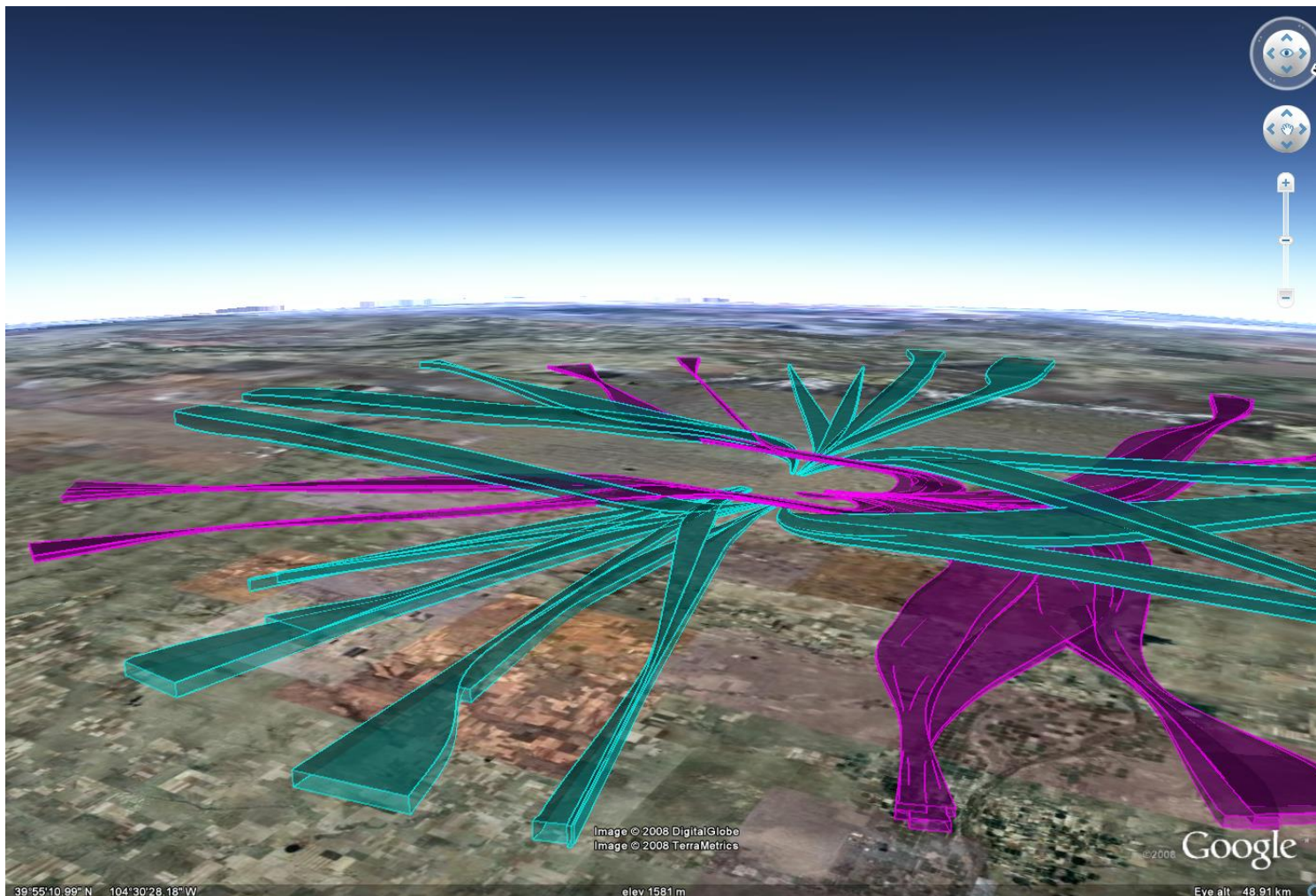


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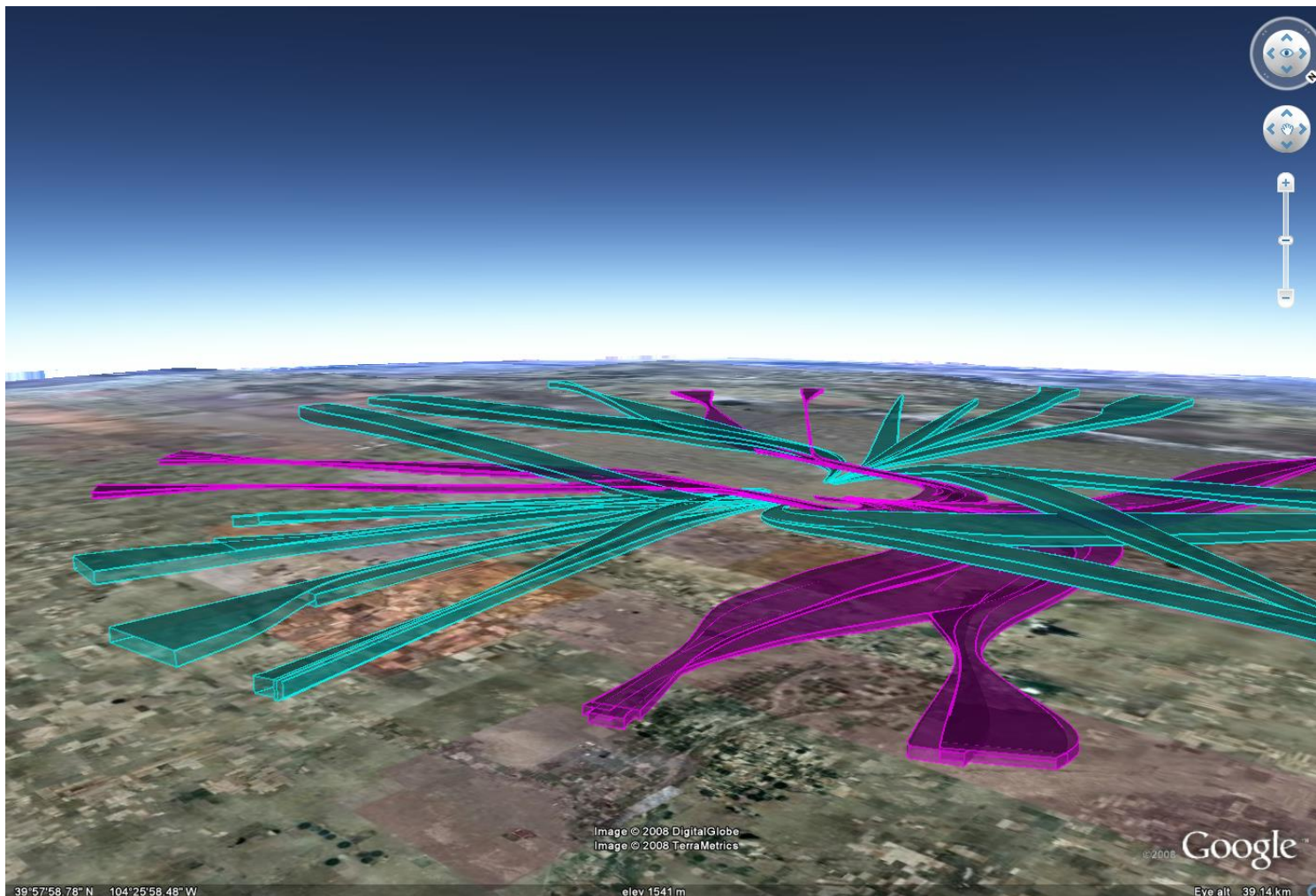
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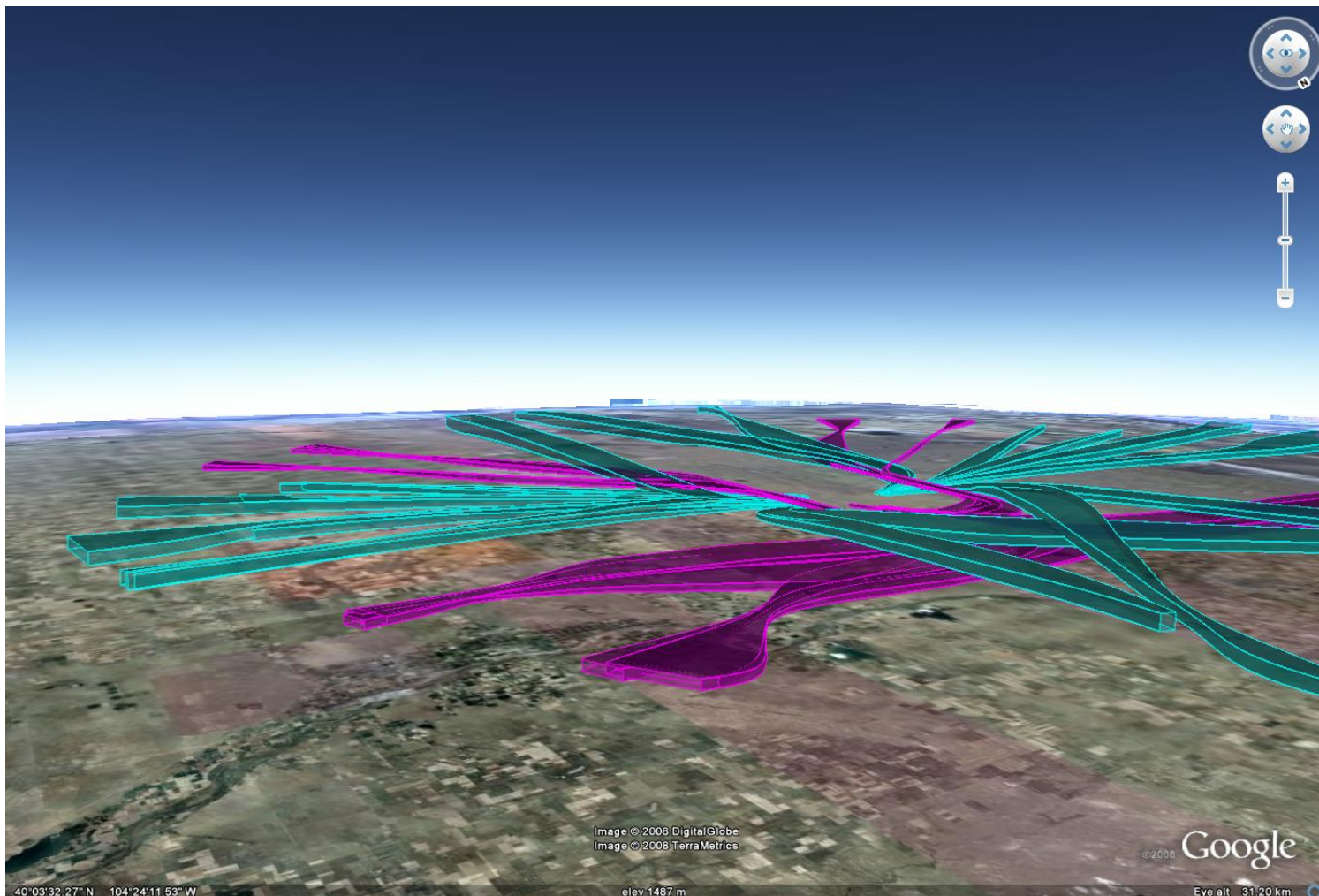


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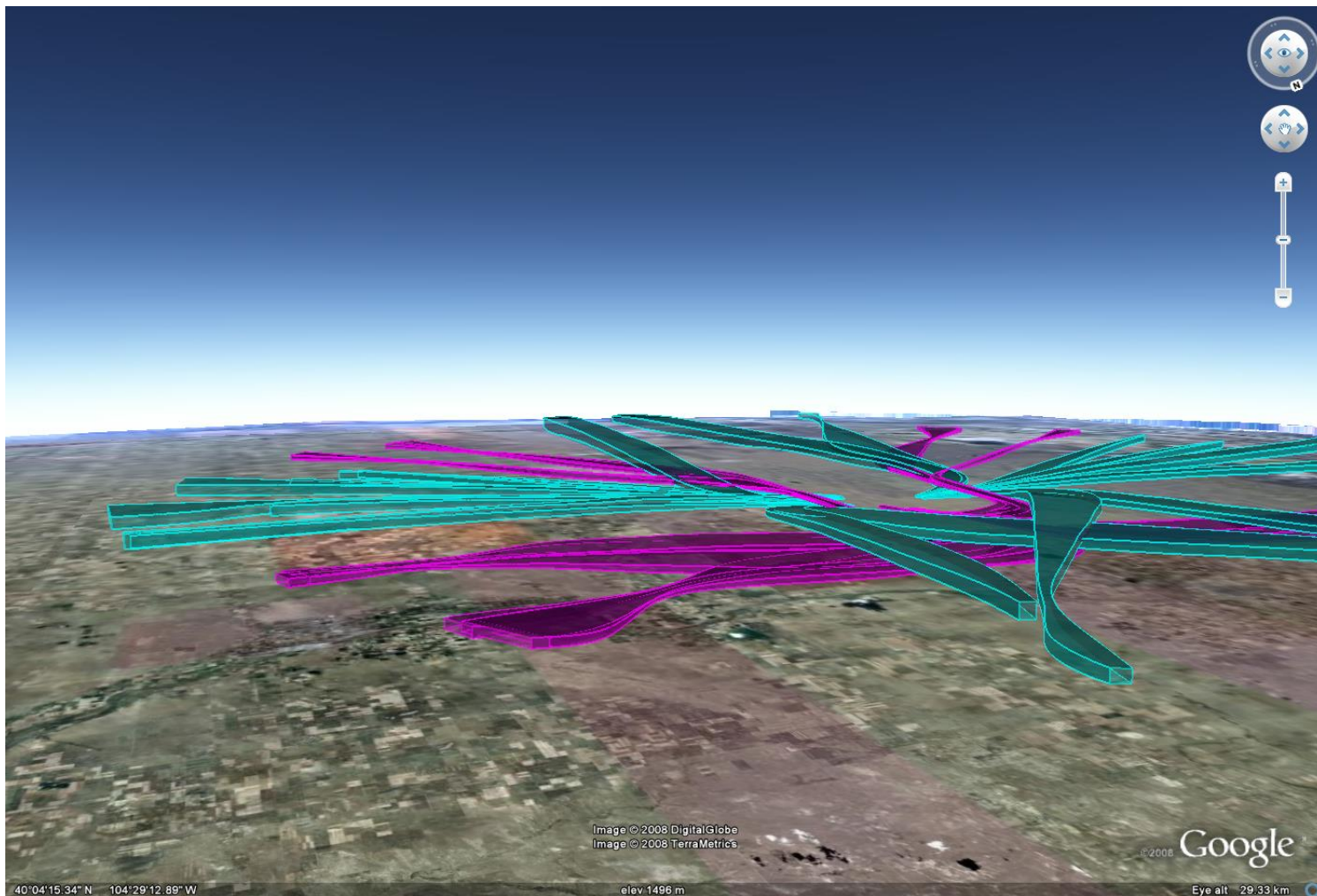
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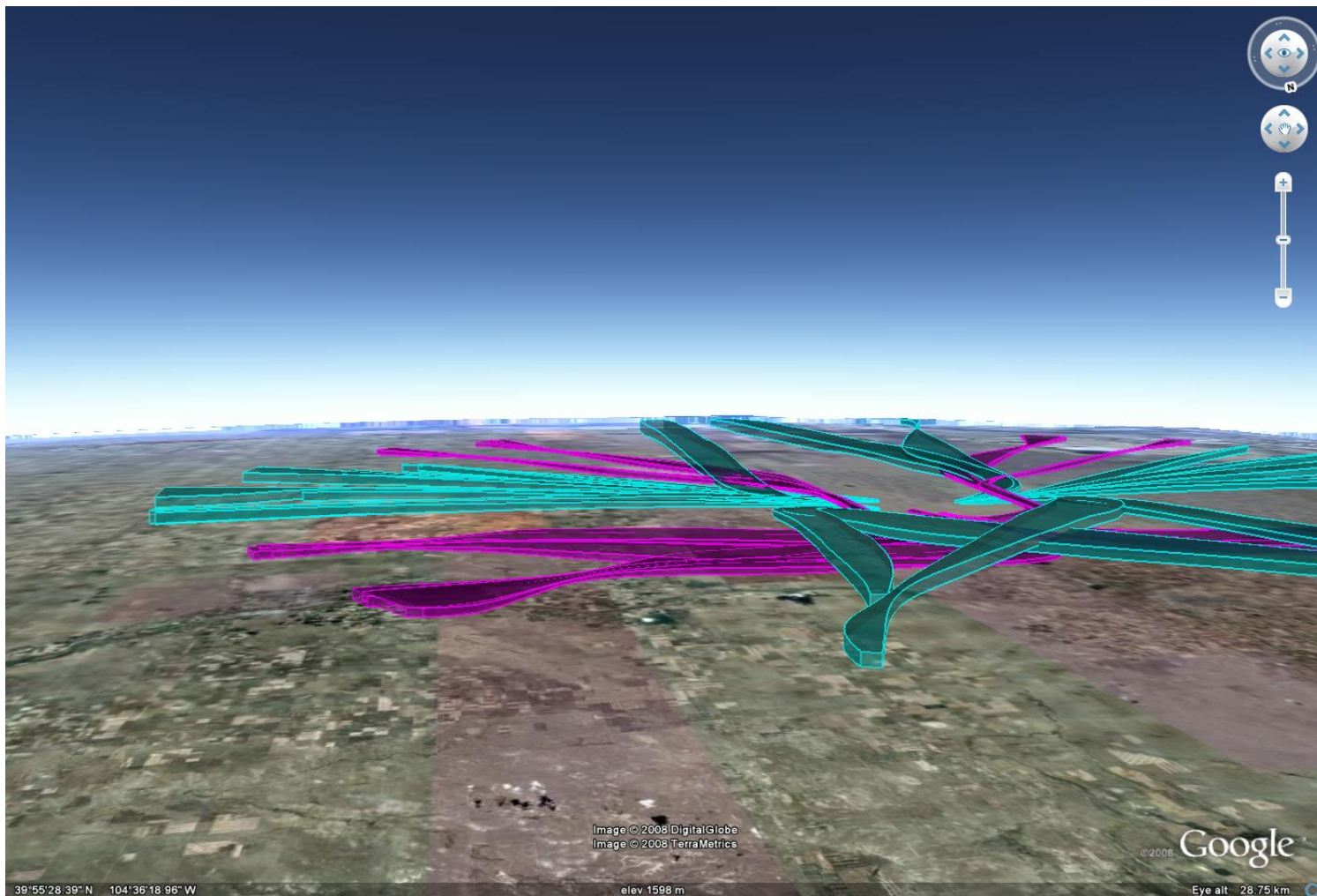


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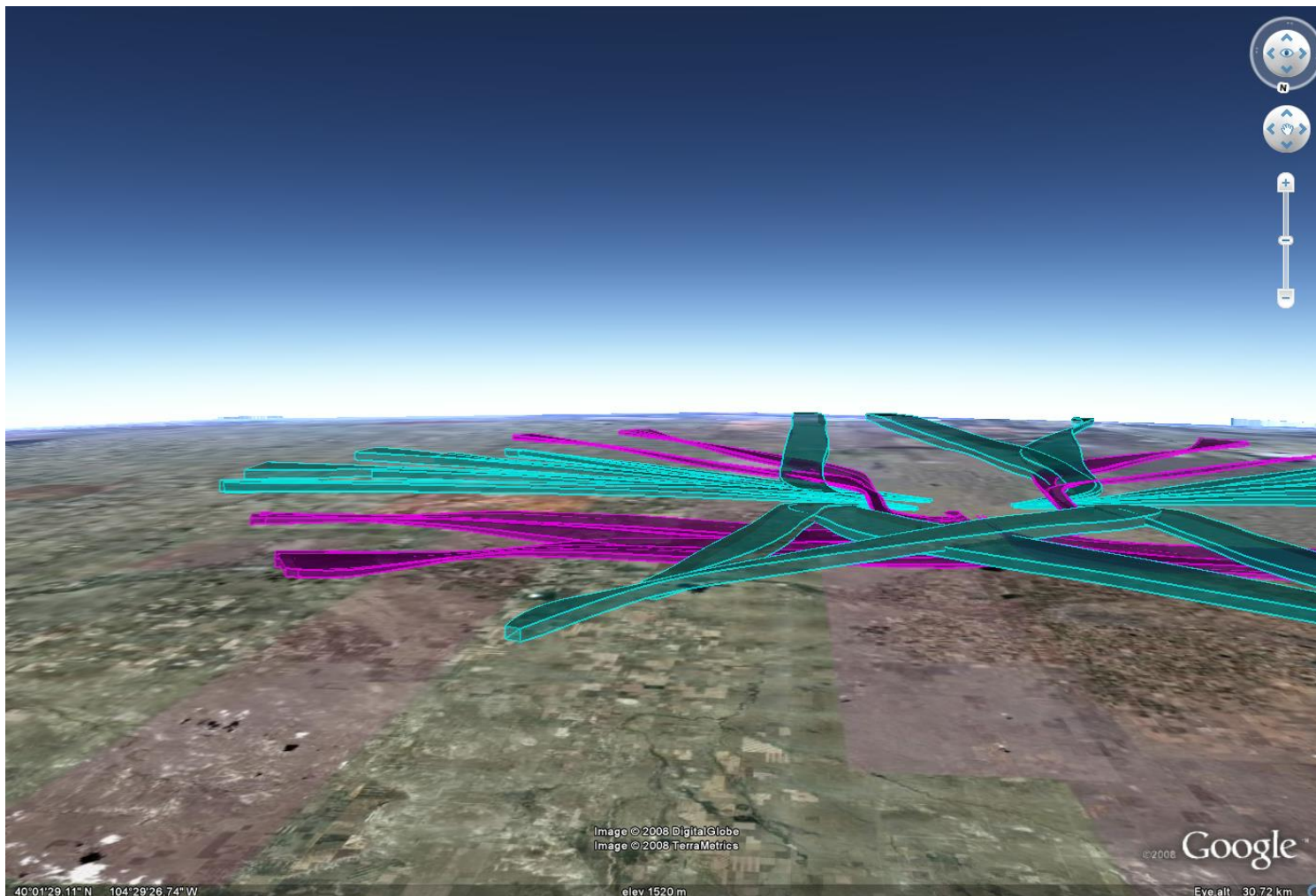
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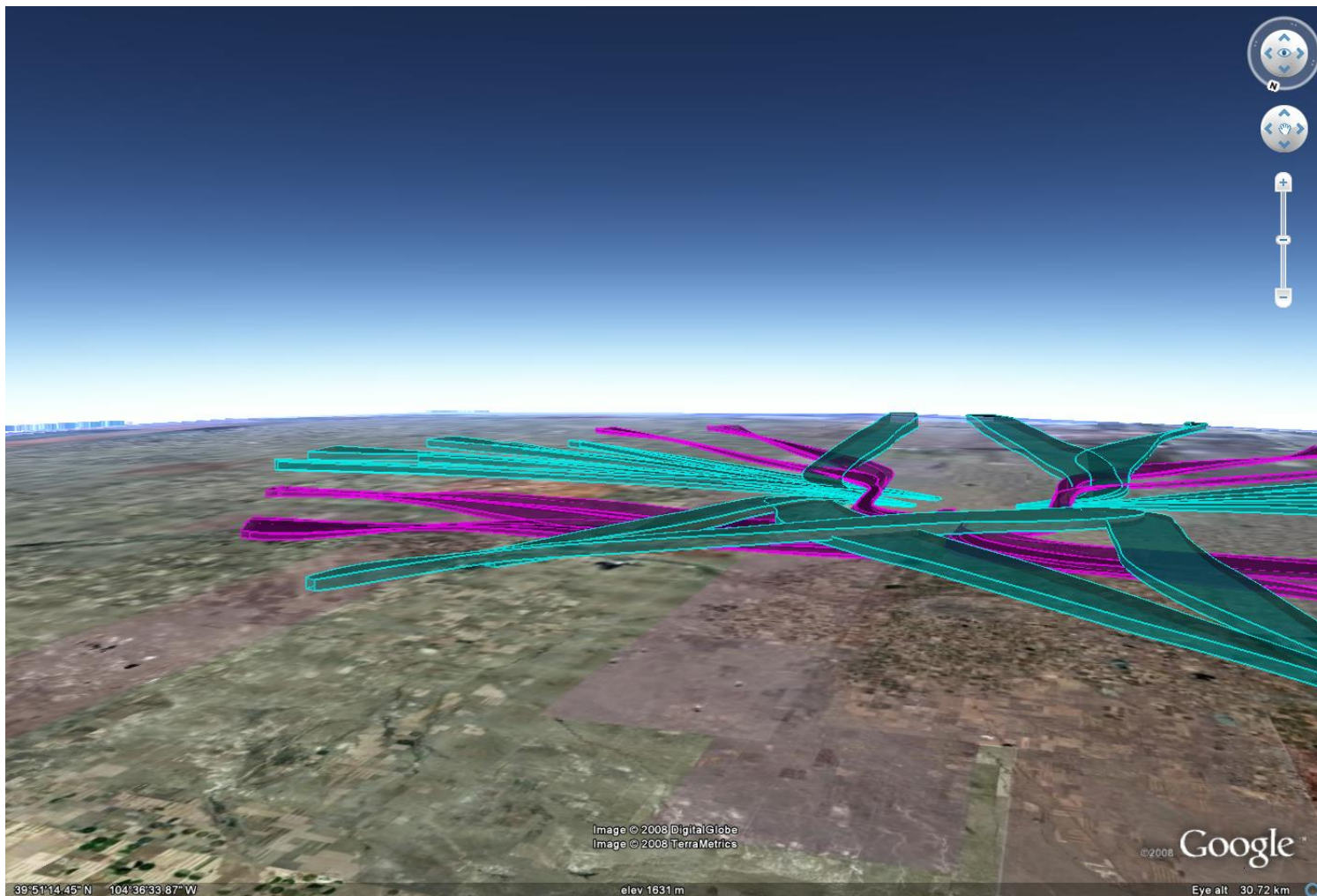


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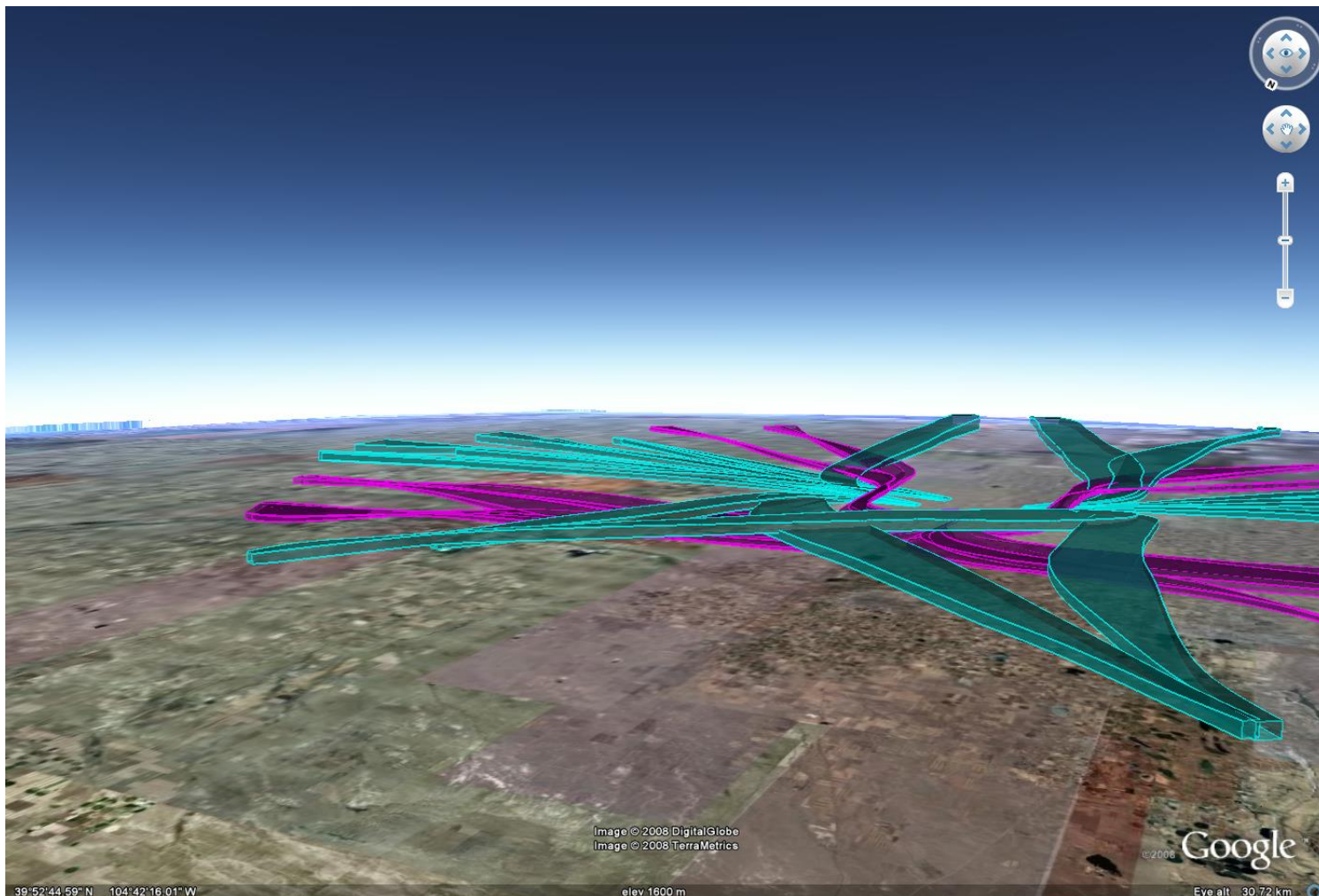


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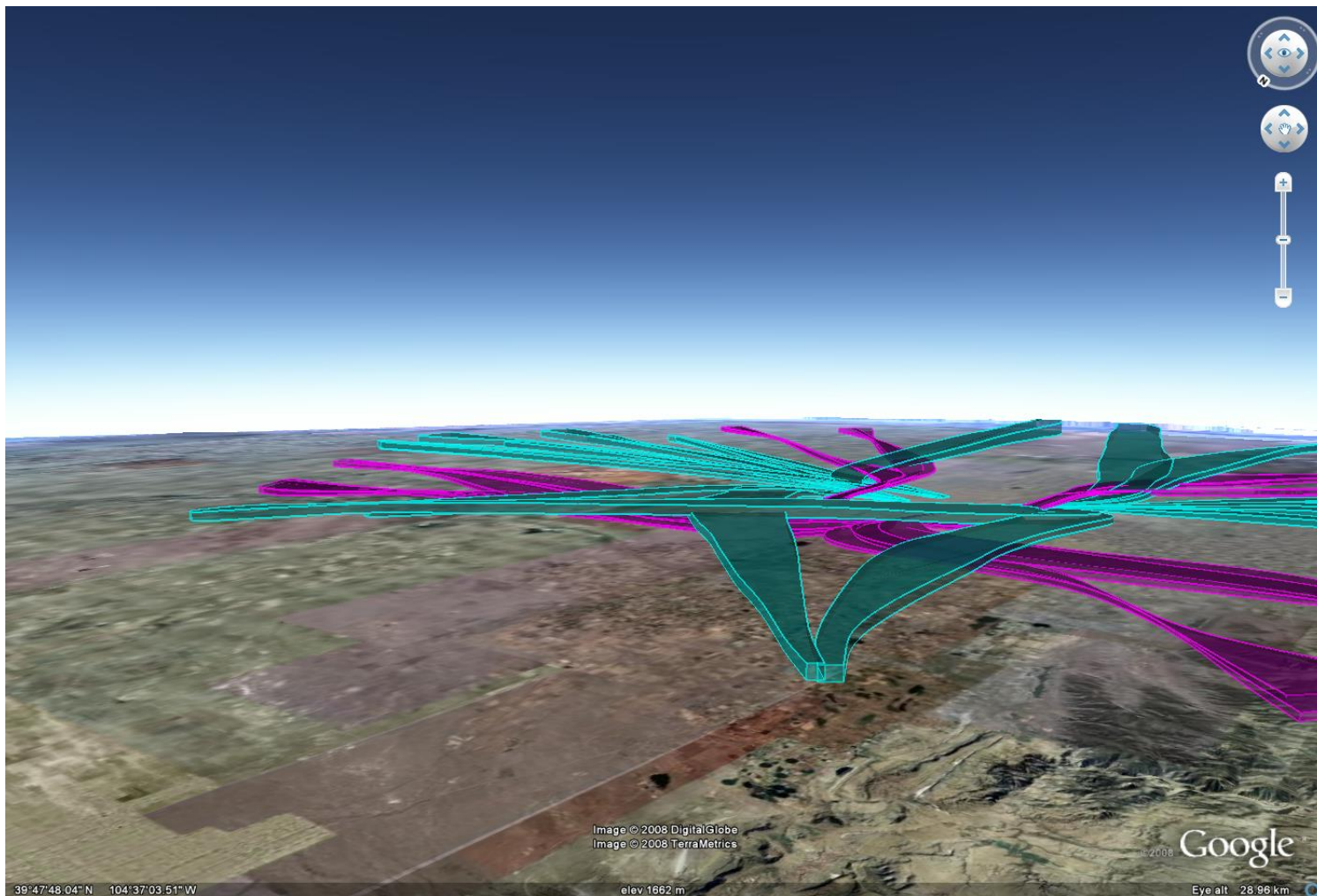
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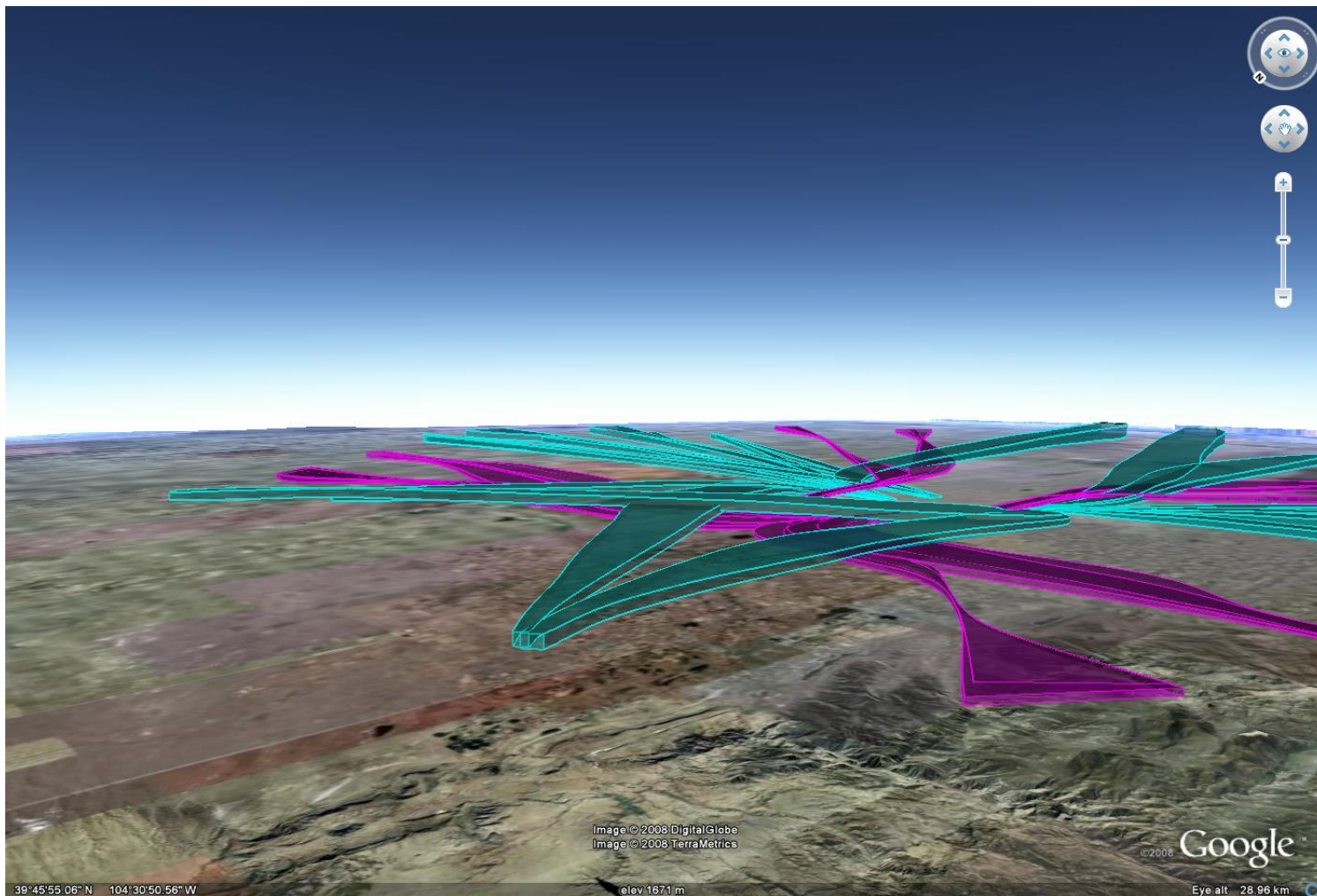


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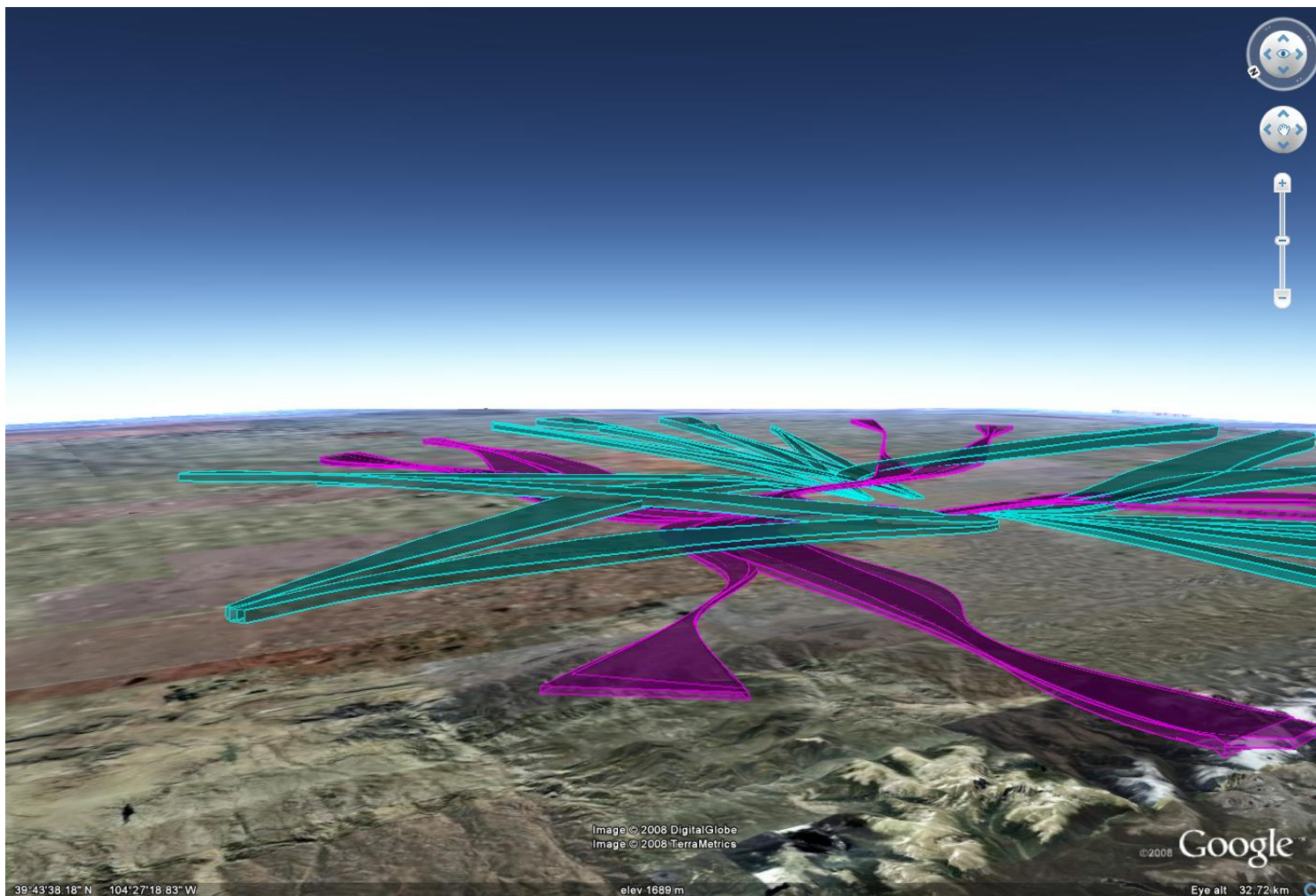


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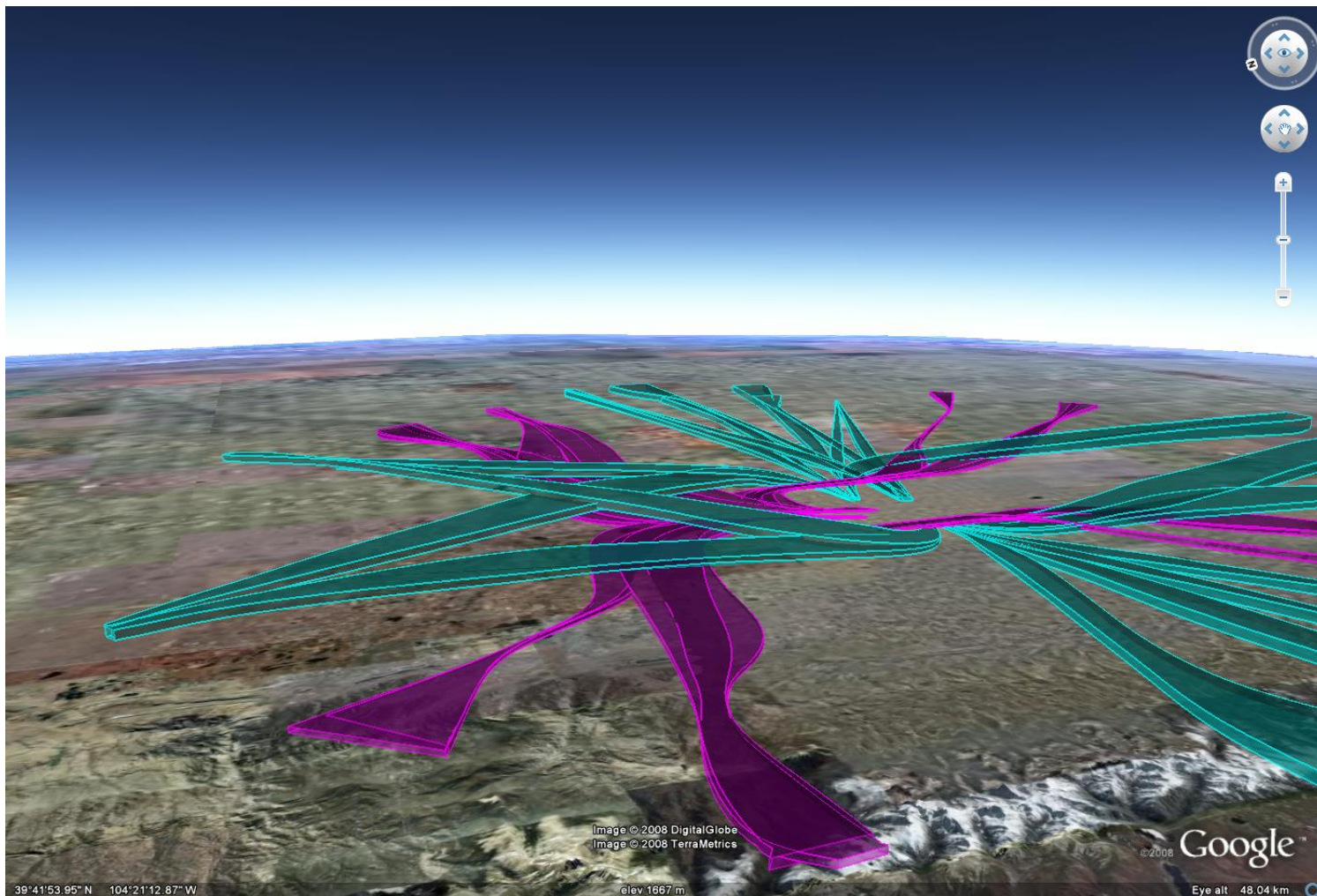
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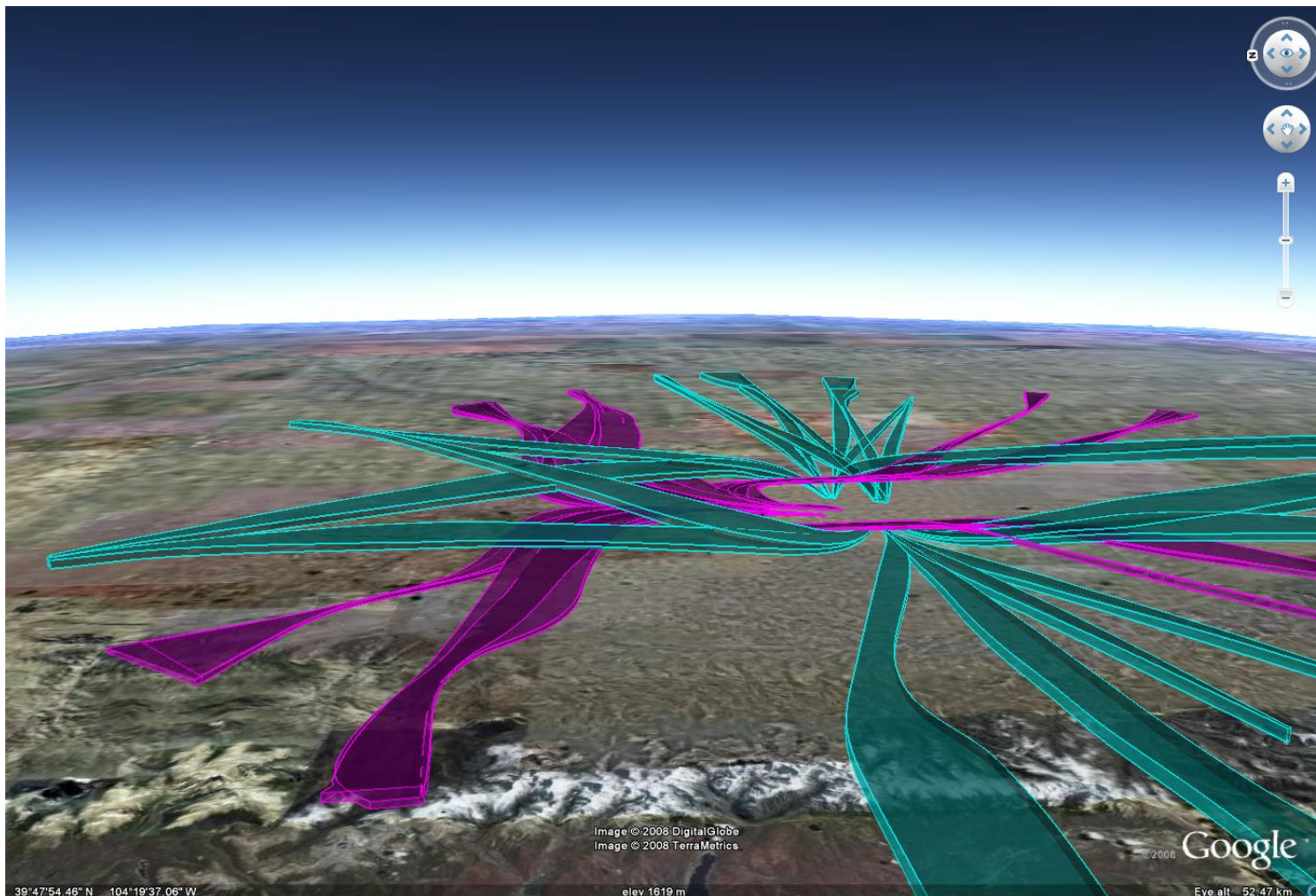


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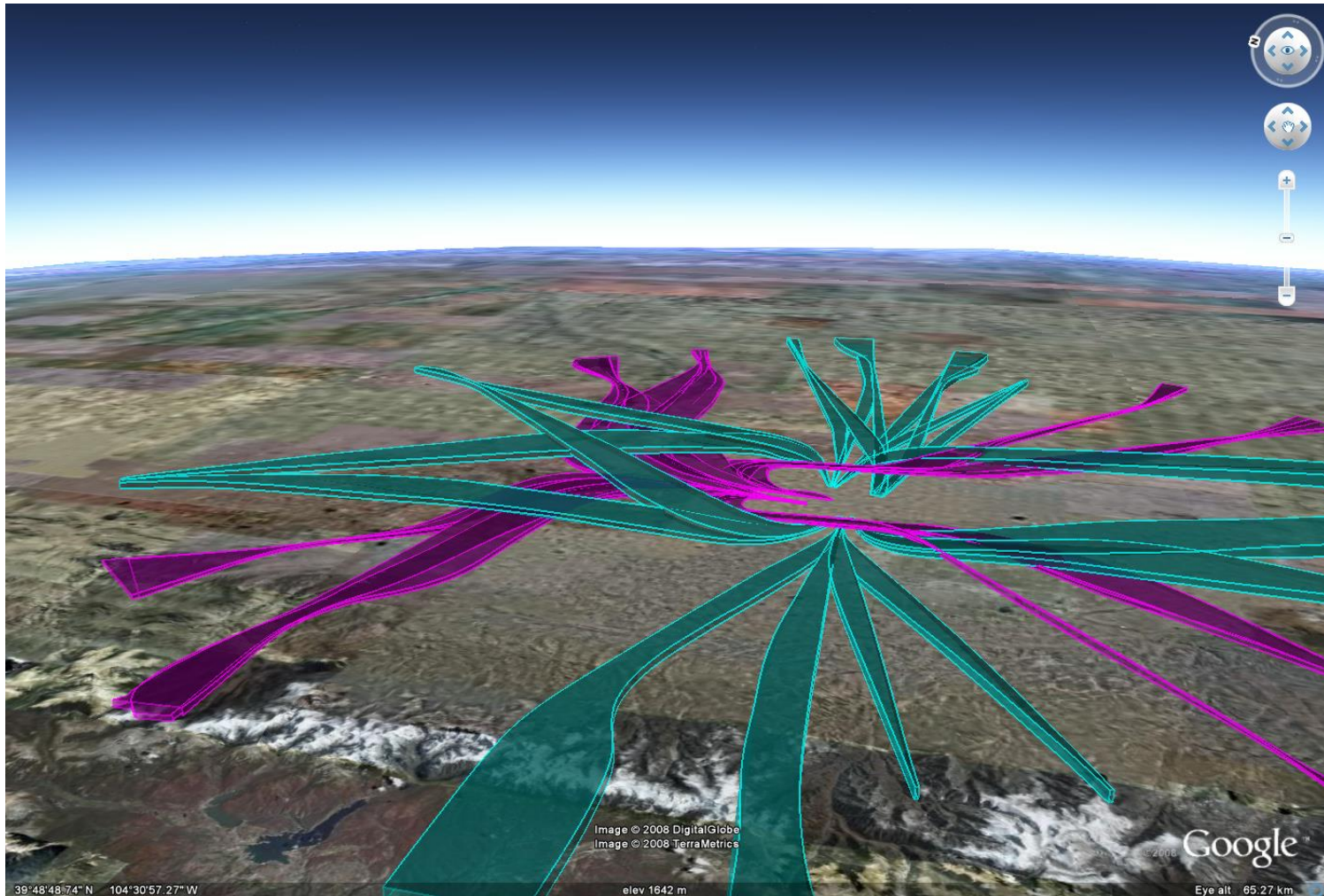
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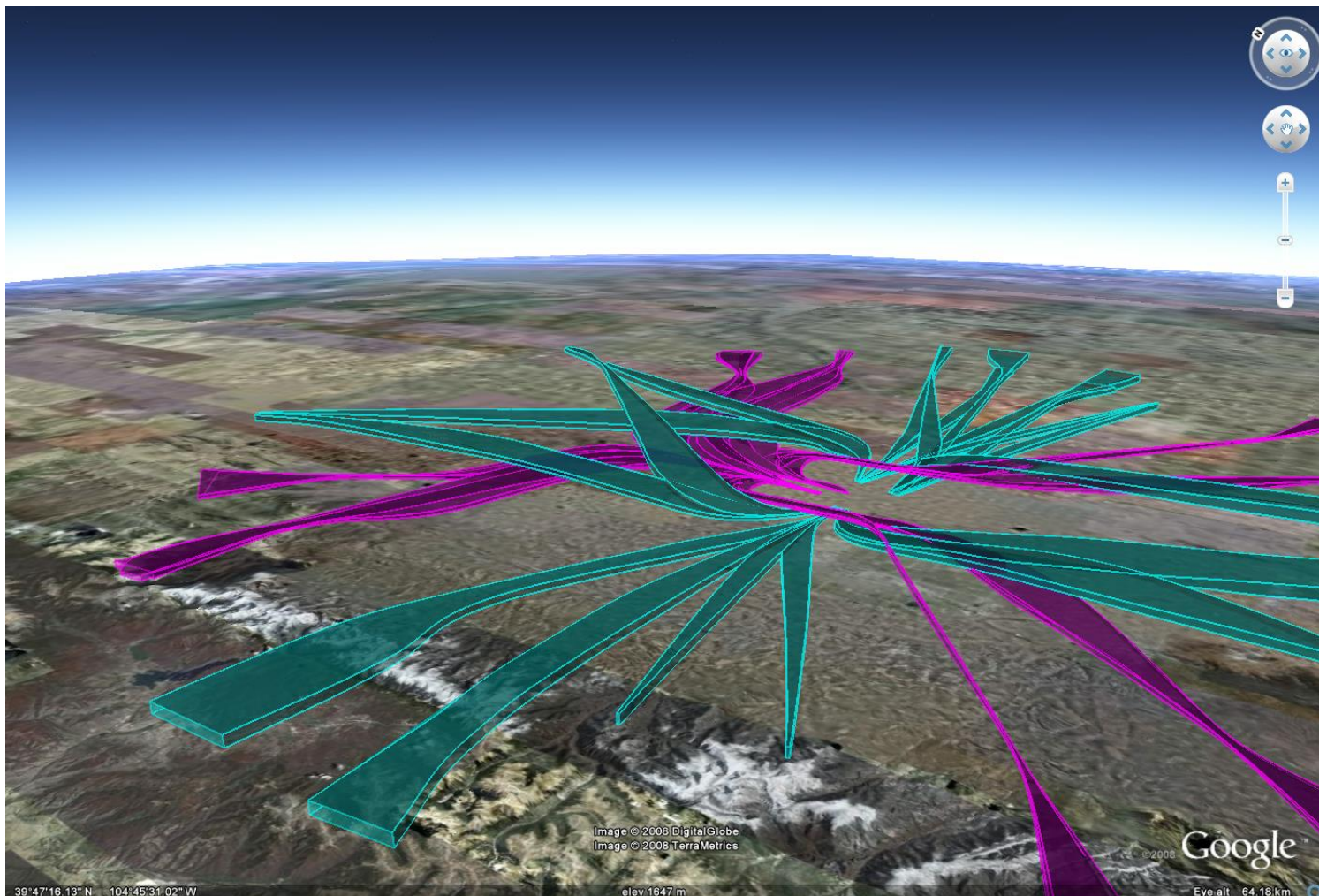


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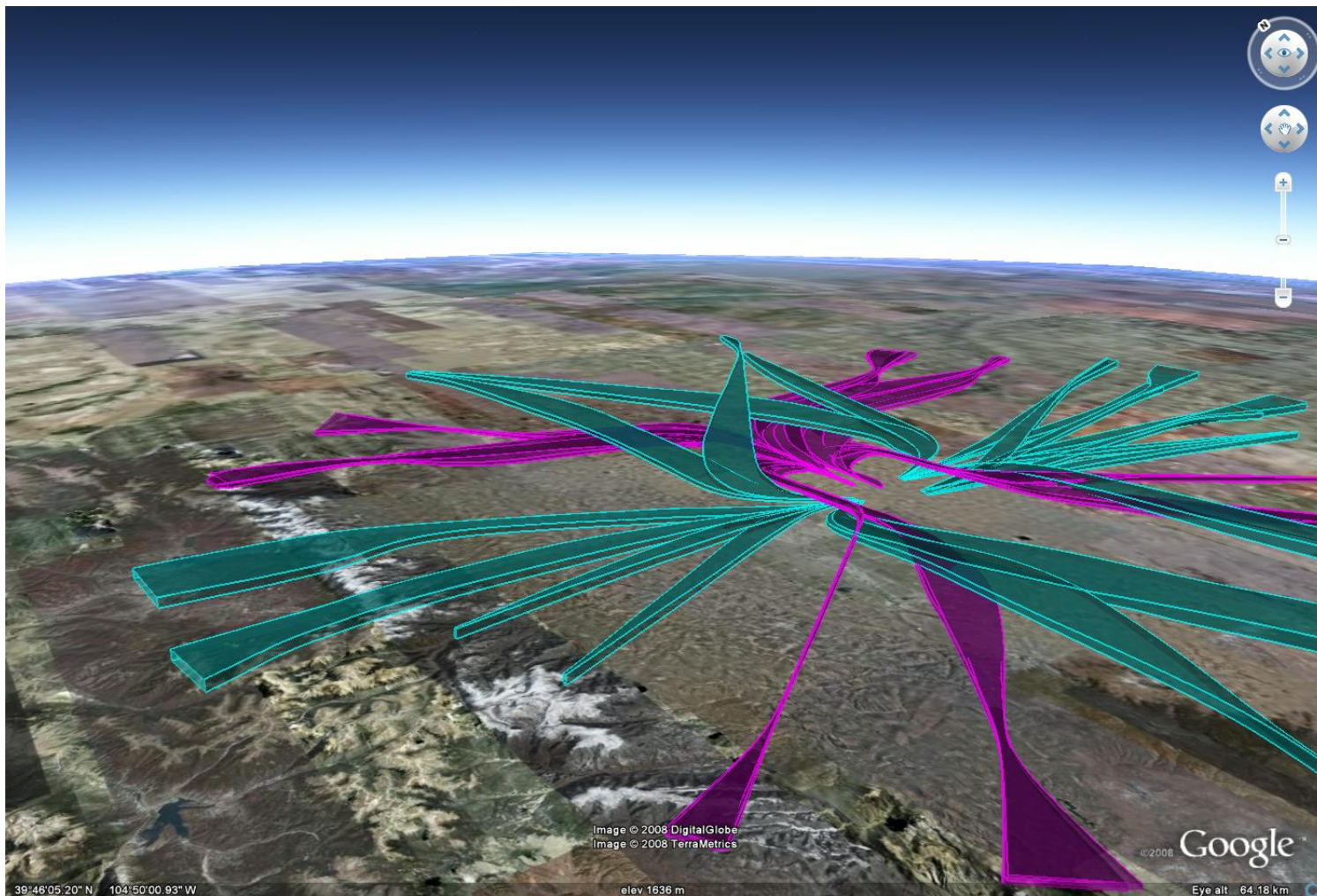
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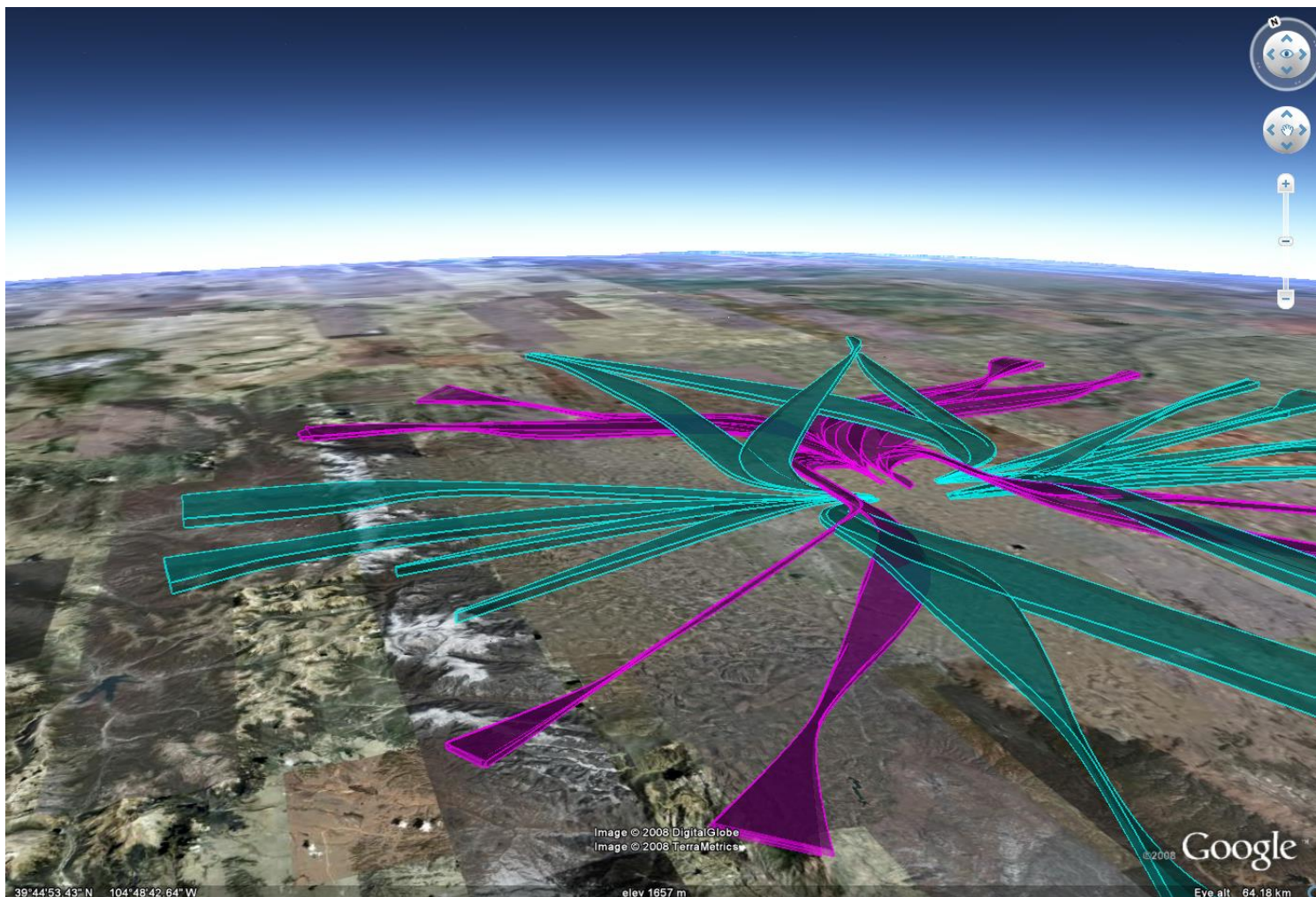
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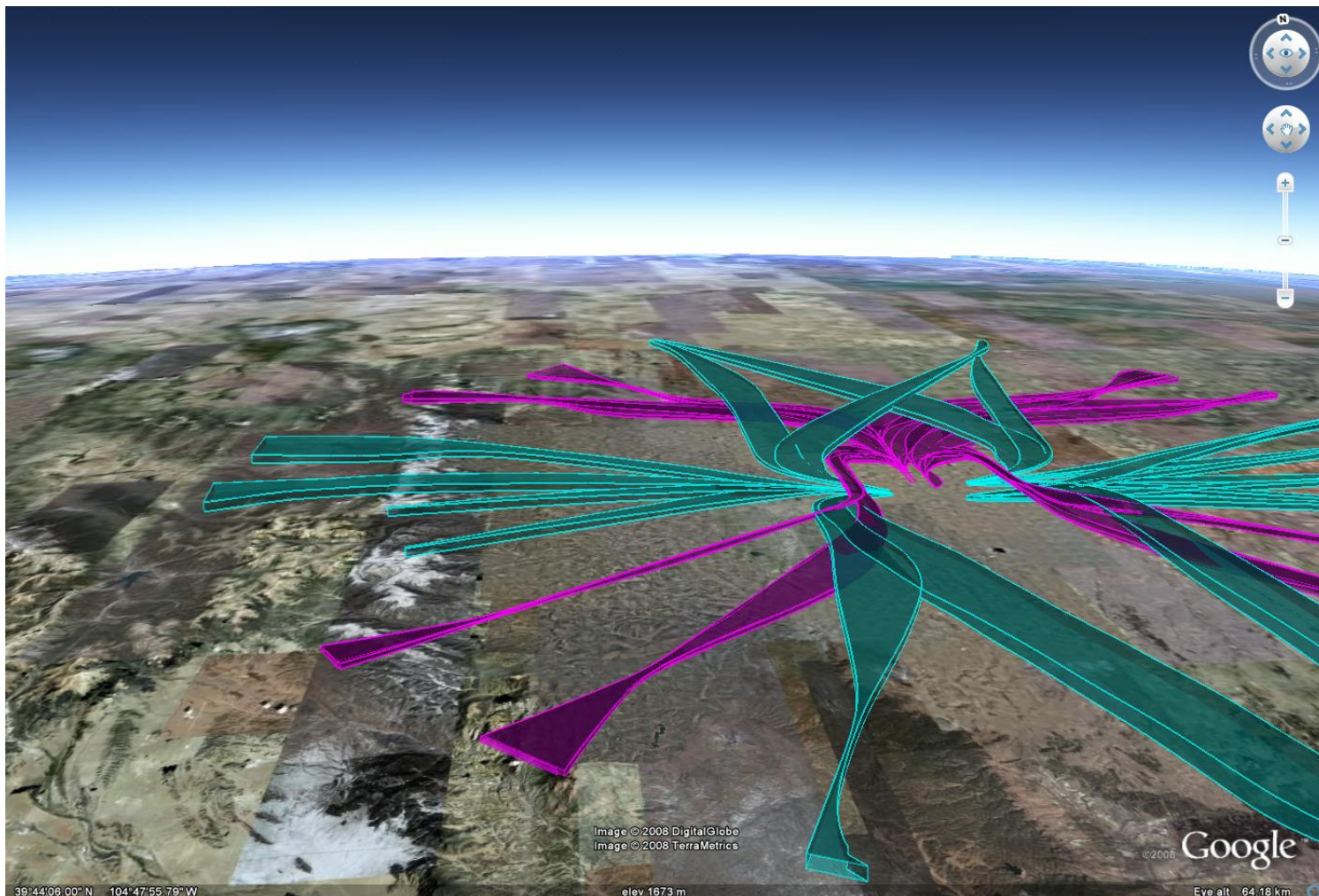


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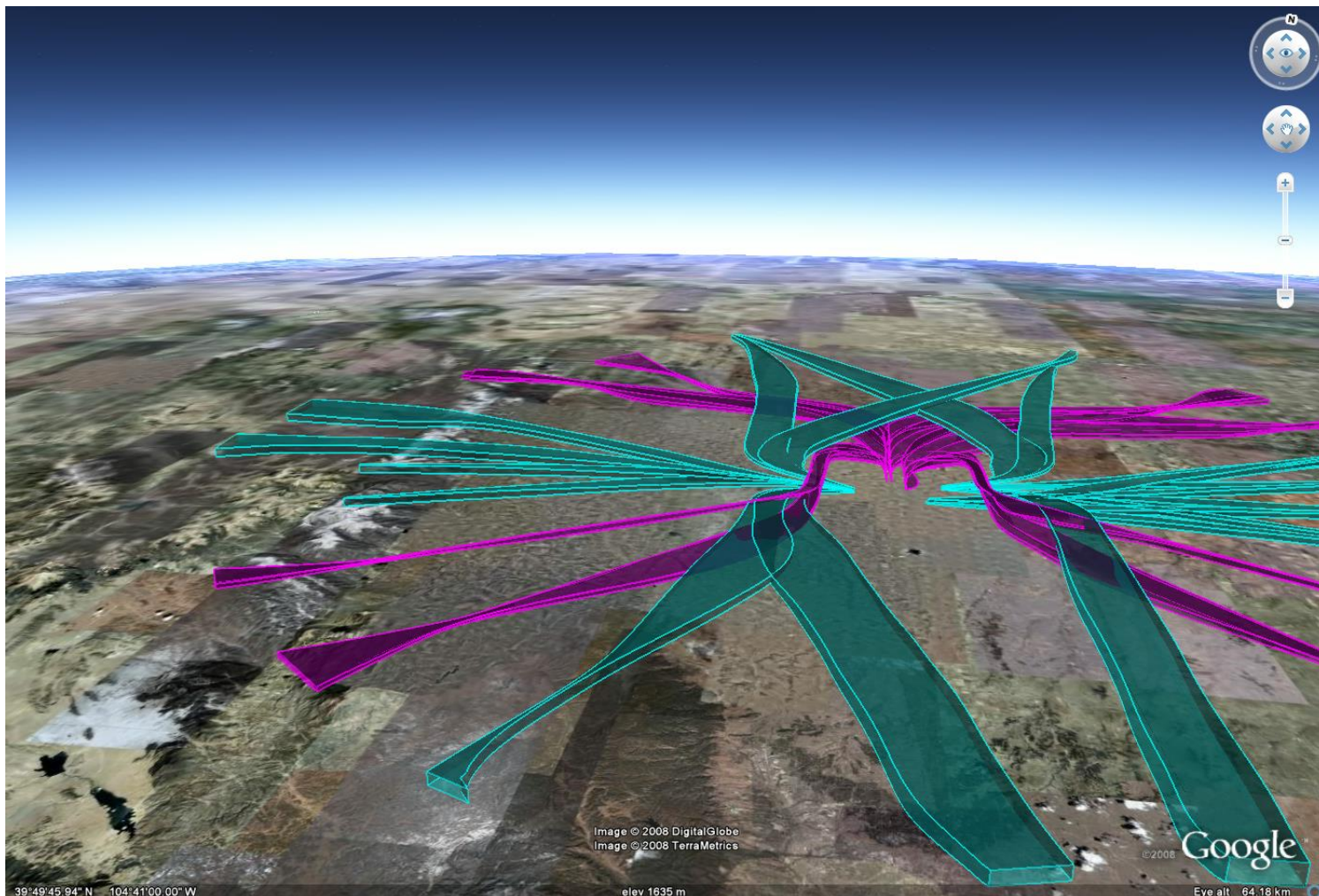
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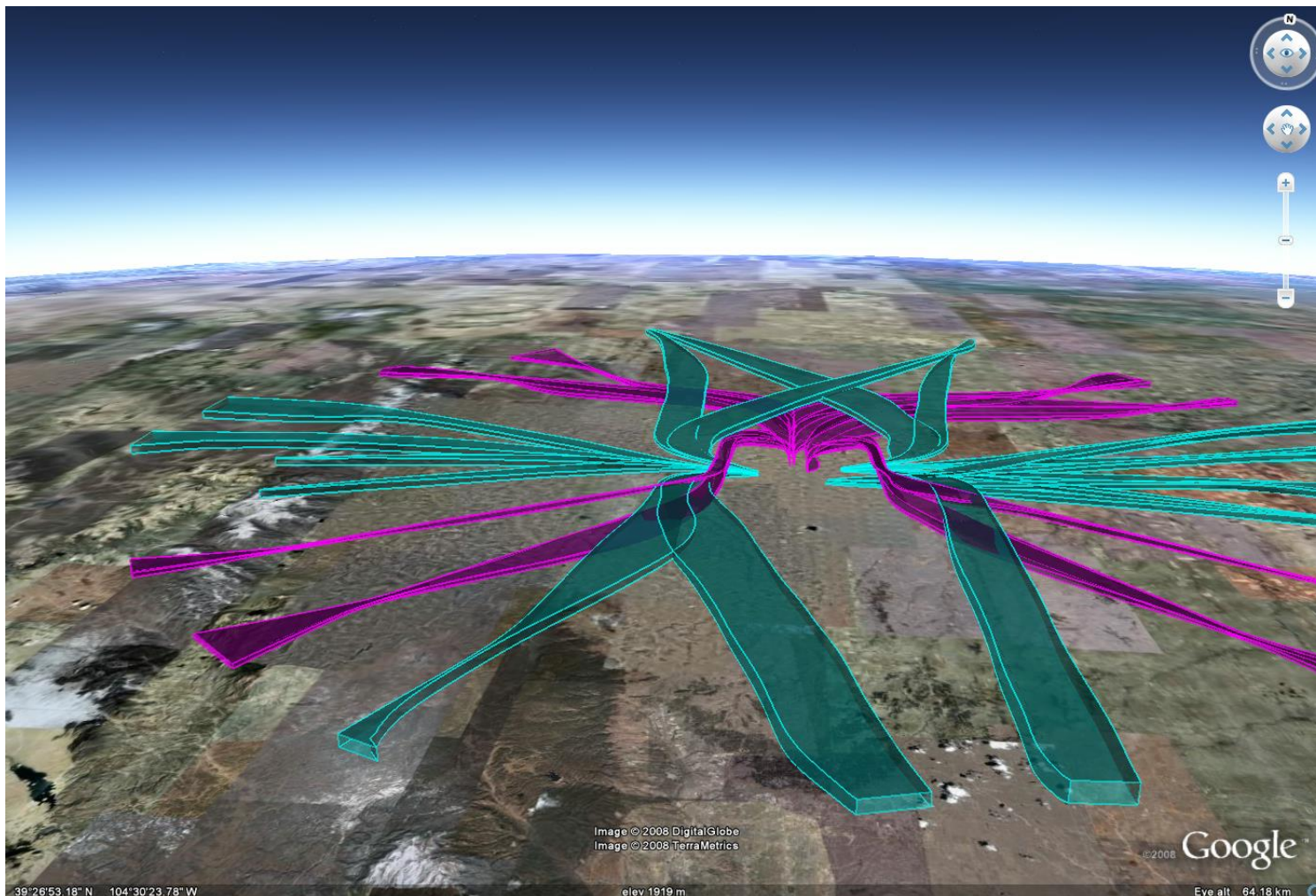


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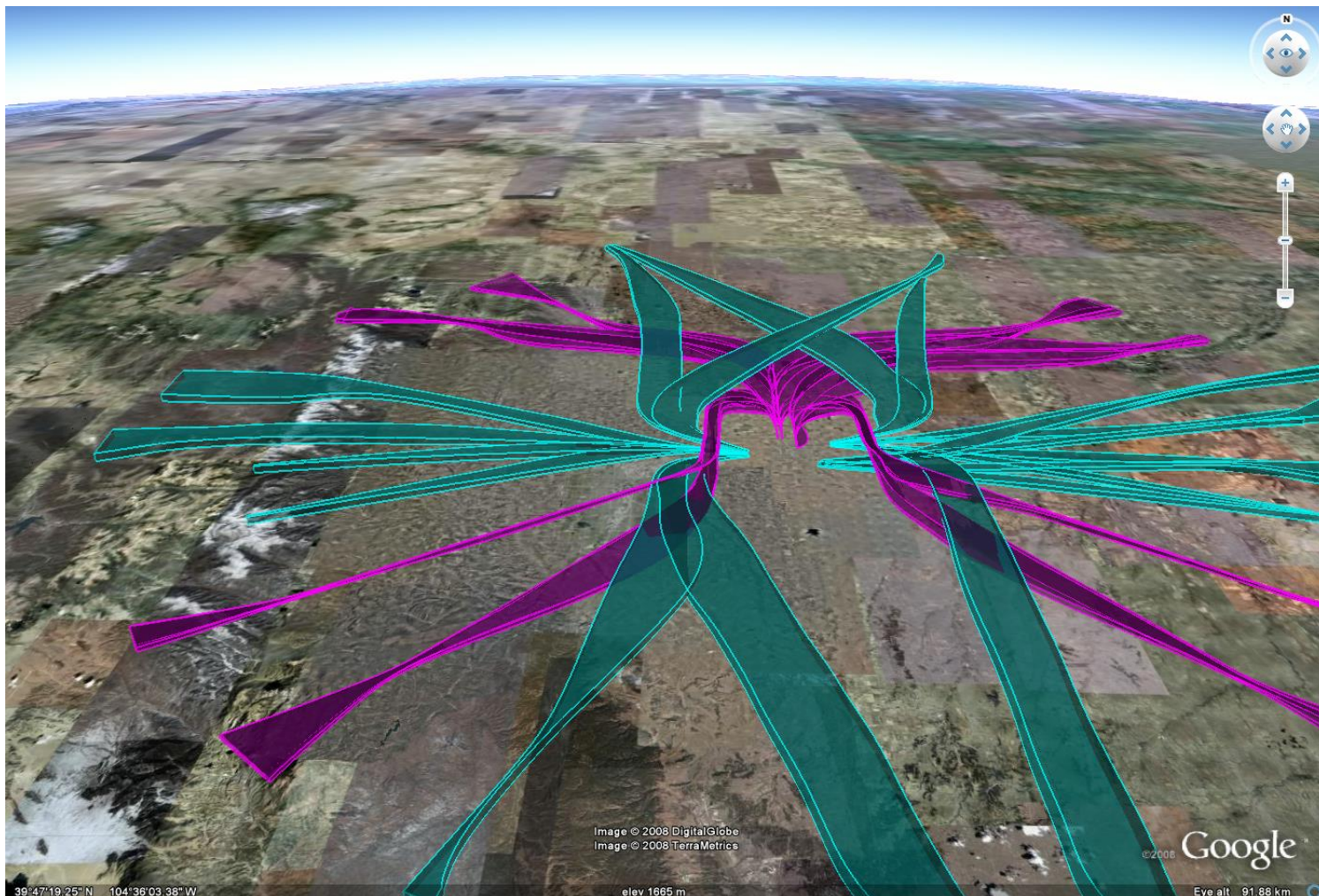
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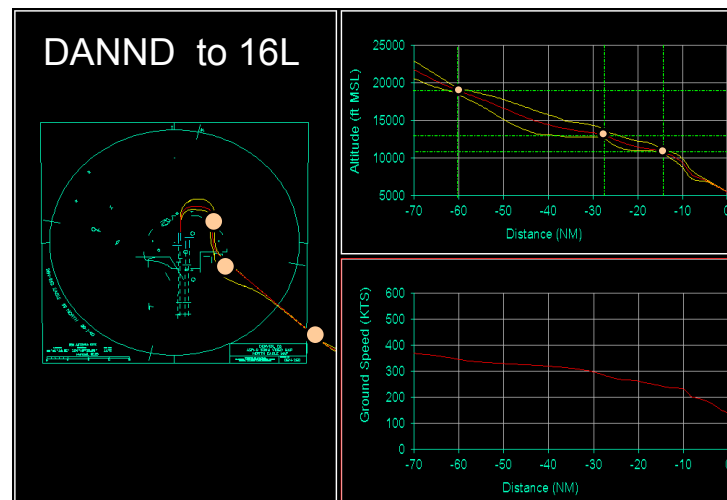
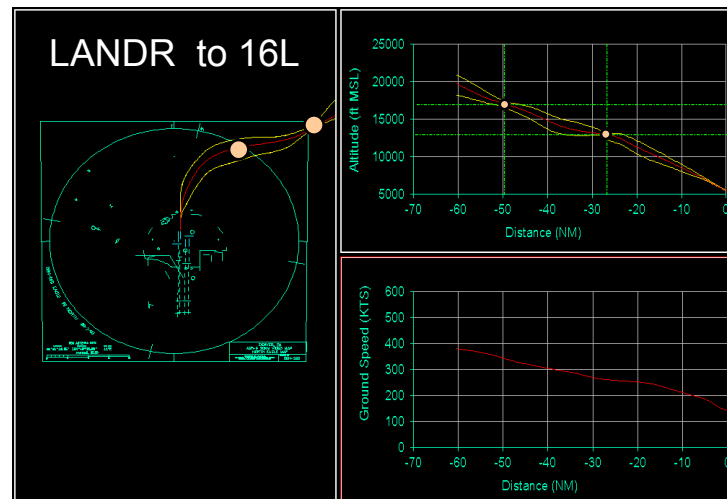




# Baseline Arrival Flows

## Plan and Profile View

- **Baseline tracks flow tubes are shown for two sample flows**
  - Red lines are the average track
  - Yellow lines bound the flow tubes
- **Waypoints and altitude restrictions are indicated**
  - Yellow dots indicate where the level-offs occur
  - **LANDR to RWY16L level-offs**
    - 17,000 ft MSL (TRACON entry)
    - 13,000 ft MSL (under departures)
  - **DANDD to RWY16L level-offs**
    - 19,000 ft MSL (TRACON entry)
    - 13,000 ft MSL (over departures)
    - 11,000 ft MSL (turn onto final)





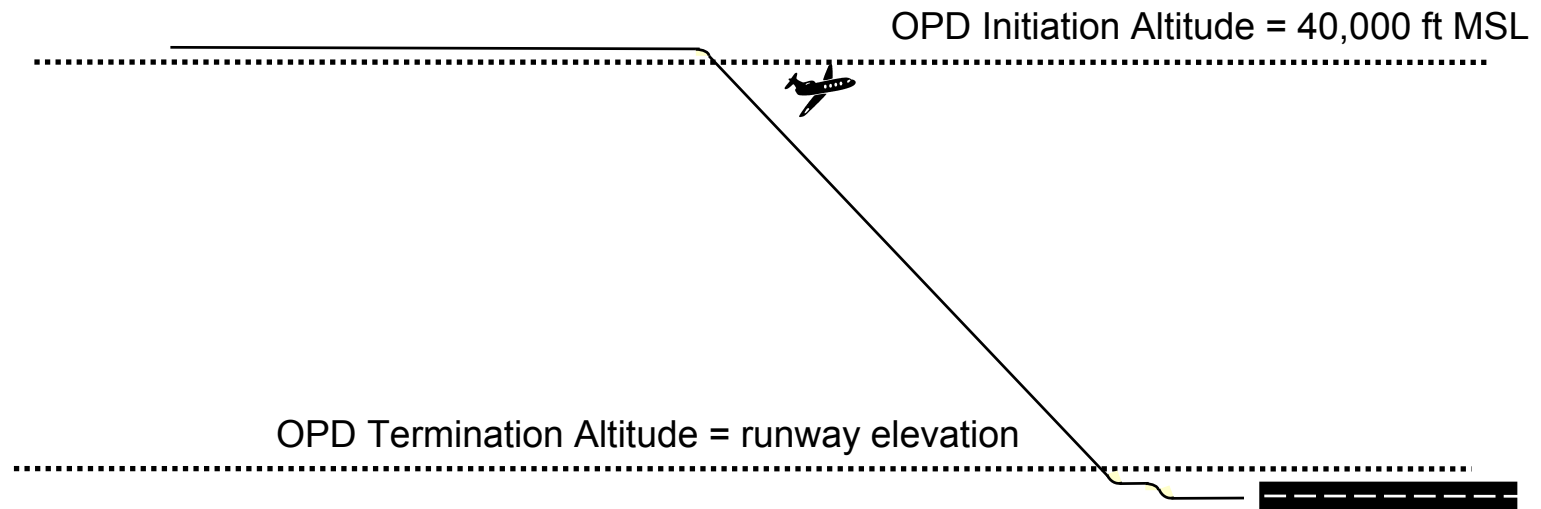


# Scenario 1

## Unrestricted OPD



- **Extent of the OPD portion**
  - Begins at the maximum cruise altitude
  - Ends as the aircraft transitions to the landing configuration



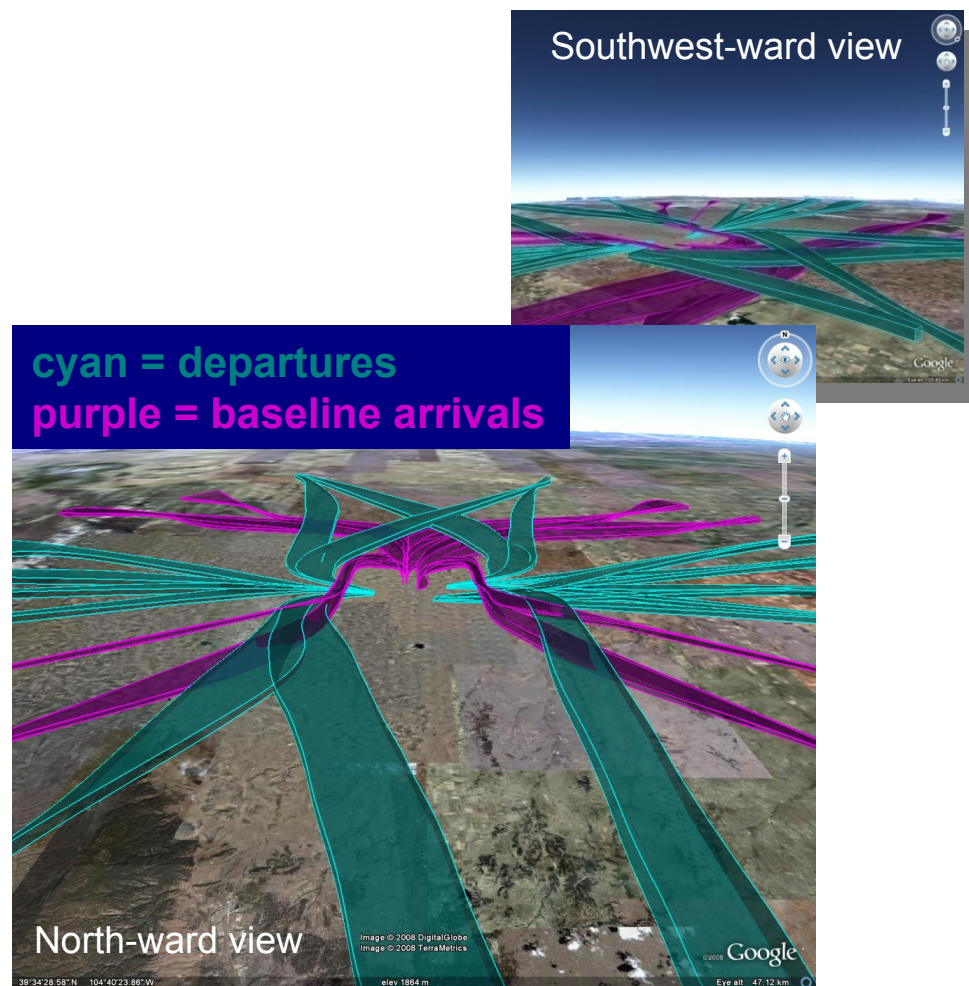


# Conflict Zones

## Baseline Arrivals



- **Tubes shown enclose ~90% of the tracks in each flow**
- **Northern arrivals**
  - All flows fly under the departures heading north
- **Southern arrivals**
  - Arrivals from POWDR and DANDD fly over departures
  - Arrivals from LARKS and QUAIL fly under departures





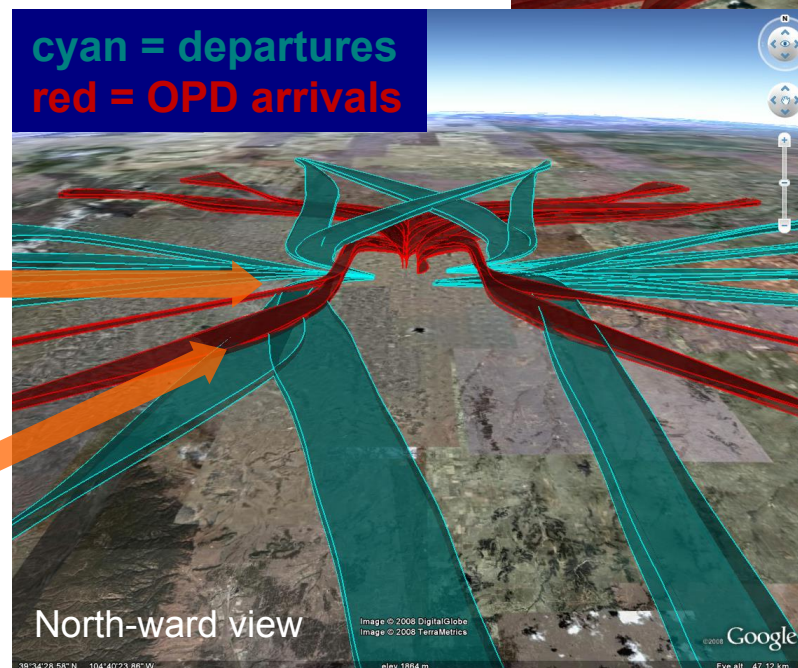
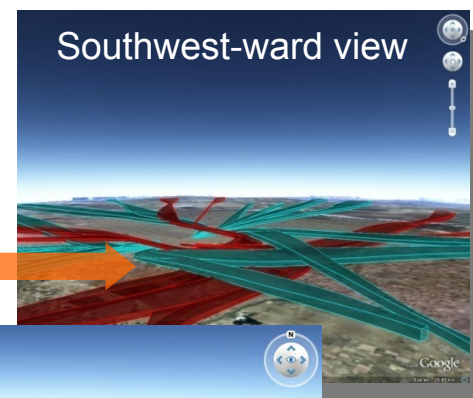


# Conflict Zones

## Unrestricted OPD



- **Equivalent OPD flow tubes have higher altitudes**
- **Northern arrivals**
  - *Slight conflict* with departures to the north
- **Southern arrivals**
  - Arrivals from POWDR and DANDD fly higher over departures – *decreased conflict*
  - Arrivals from LARKS and QUAIL fly through departures – *direct conflict*

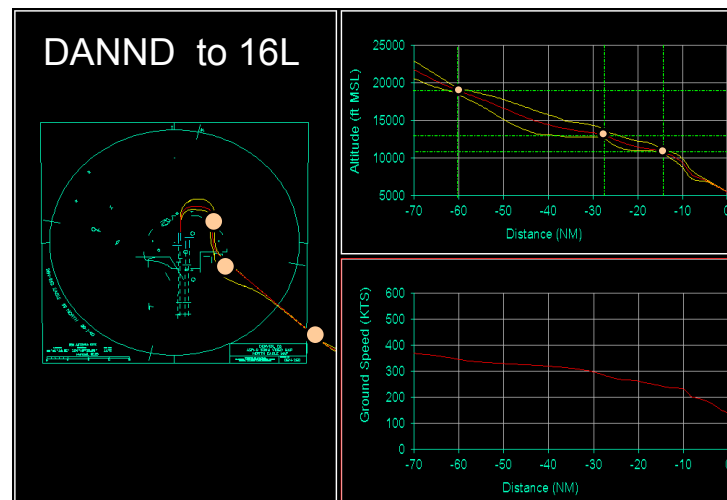
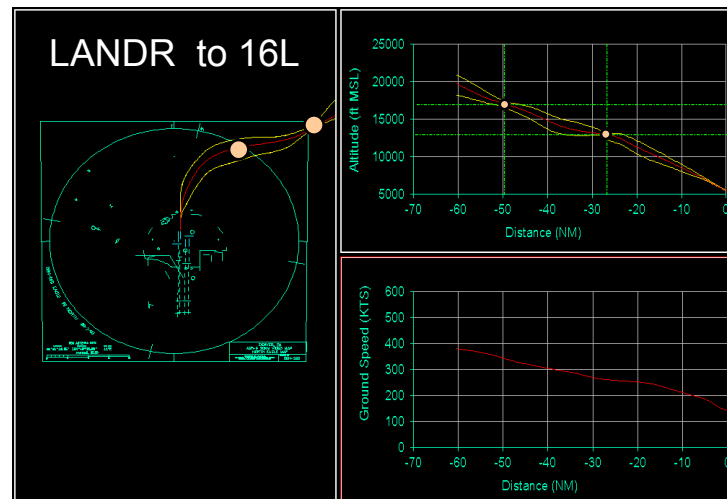




# Baseline Arrival Flows

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    - 11,000 ft MSL (turn onto final)



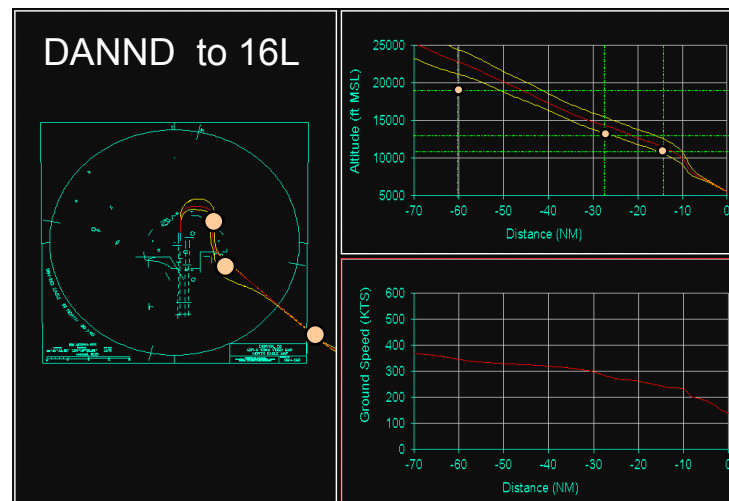
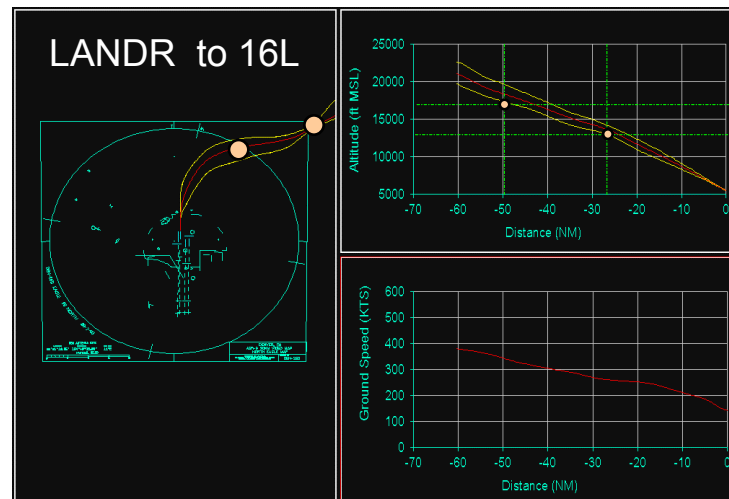




# Equivalent OPD Arrival Flows

## Plan and Profile View

- **Equivalent OPD flow tubes are shown**
  - Altitudes are higher
  - Widths are larger
  - Vertical constraints of baseline operations are not met
- **Previous altitude restrictions are removed**
  - Yellow dots indicate where the level-offs previously occurred
  - **LANDR to RWY16L level-offs**
    - 17,000 ft MSL (TRACON entry)
    - 13,000 ft MSL (under departures)
  - **DANDD to RWY16L level-offs**
    - 19,000 ft MSL (TRACON entry)
    - 13,000 ft MSL (over departures)
    - 11,000 ft MSL (turn onto final)





# Scenario 1

## Maximum Fuel and Emissions Savings Estimate

Average Savings per Flight by Arrival Fix				
	Arrival Fix	Fuel Savings (lbs)	Emissions Savings	
			CO <sub>2</sub> (lbs)	SO <sub>2</sub> (lbs)
Short-Side	RAMMS	132	416	0.106
	TOMSN	139	439	0.111
	SAYGE	135	426	0.108
	LANDR	141	445	0.113
Long-Side	QUAIL	292	921	0.234
	DANDD	228	719	0.182
	POWDR	264	833	0.211
	LARKS	261	823	0.209

- **Total maximum fuel savings and emissions benefit can be estimated by assuming unrestricted OPD implementation with no conflict mitigation compromises**
  - Savings of approximately 20,000 gallons per day
  - Daily reduction of approximately 200 tons CO<sub>2</sub> and 100 lbs of SO<sub>2</sub>
  - Actual implementation will require compromises to avoid conflicts between aircraft, which will reduce the overall actual savings realized



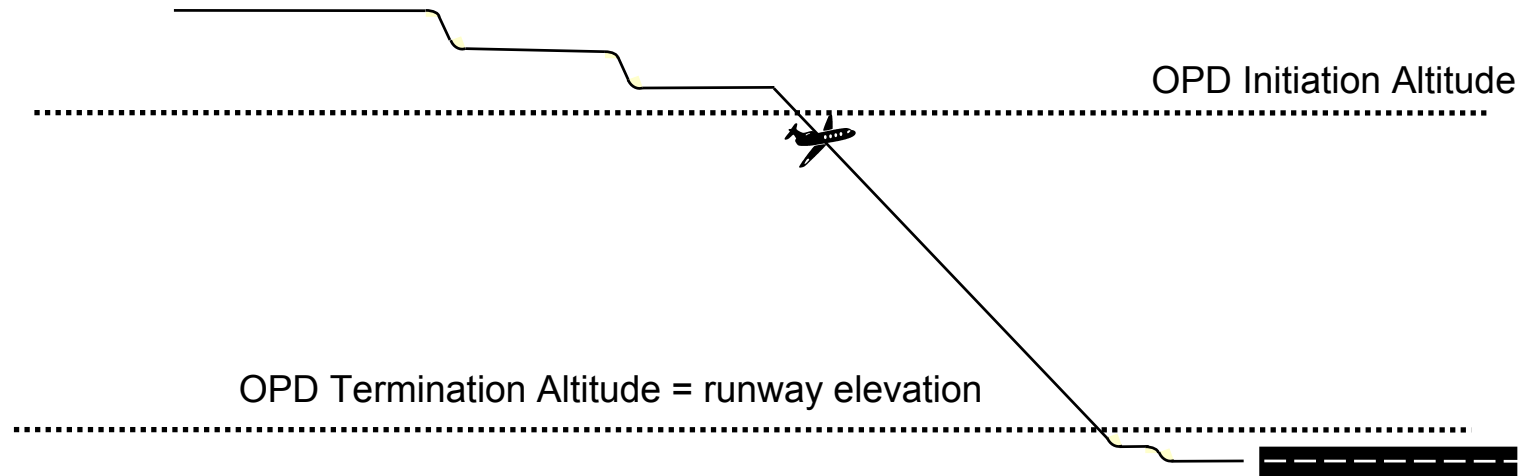


# Scenario 2

## Delayed Initiation



- **Extent of the OPD portion**
  - **Begins by the specified OPD initiation altitude**
    - Above that altitude the aircraft may be in normal operations
    - Allows step down transitions from cruise
  - **Ends as the aircraft transitions to the landing configuration**

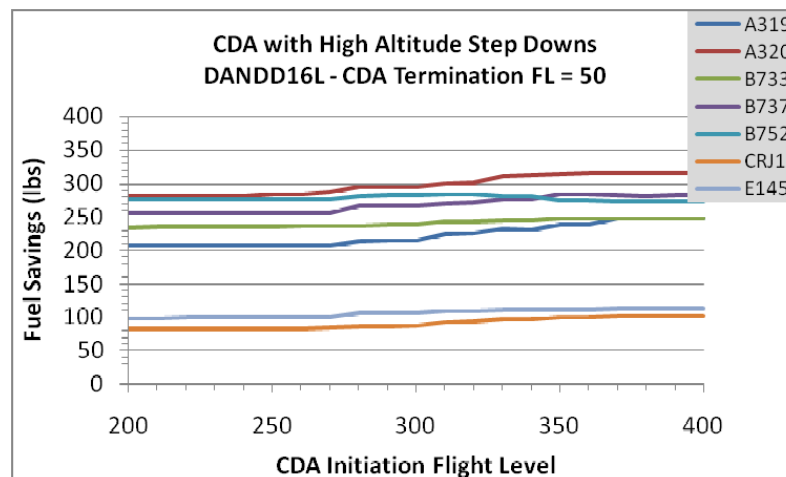
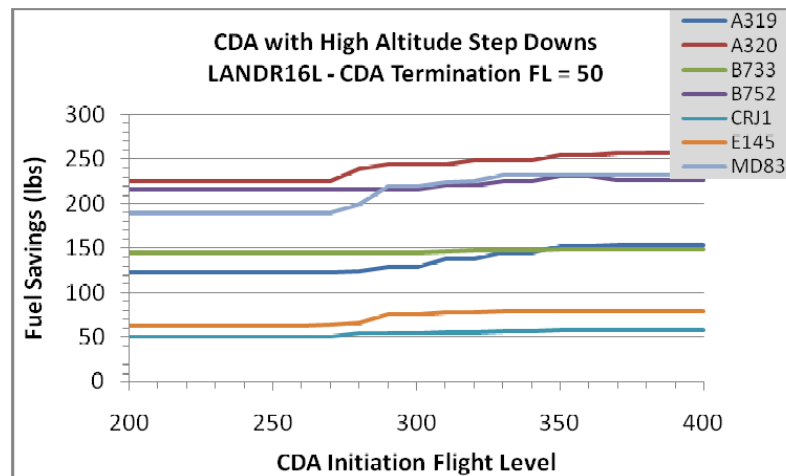




## Scenario 2

### Benefit vs. Initiation Altitude

- Values for initiation altitude of Flight Level (FL) 400 equal the unrestricted OPD benefits
- Fuel savings benefits decrease as the initiation altitude is lowered
- Approximately 85% of the maximum fuel savings benefit can still be obtained with an initiation altitude of FL250





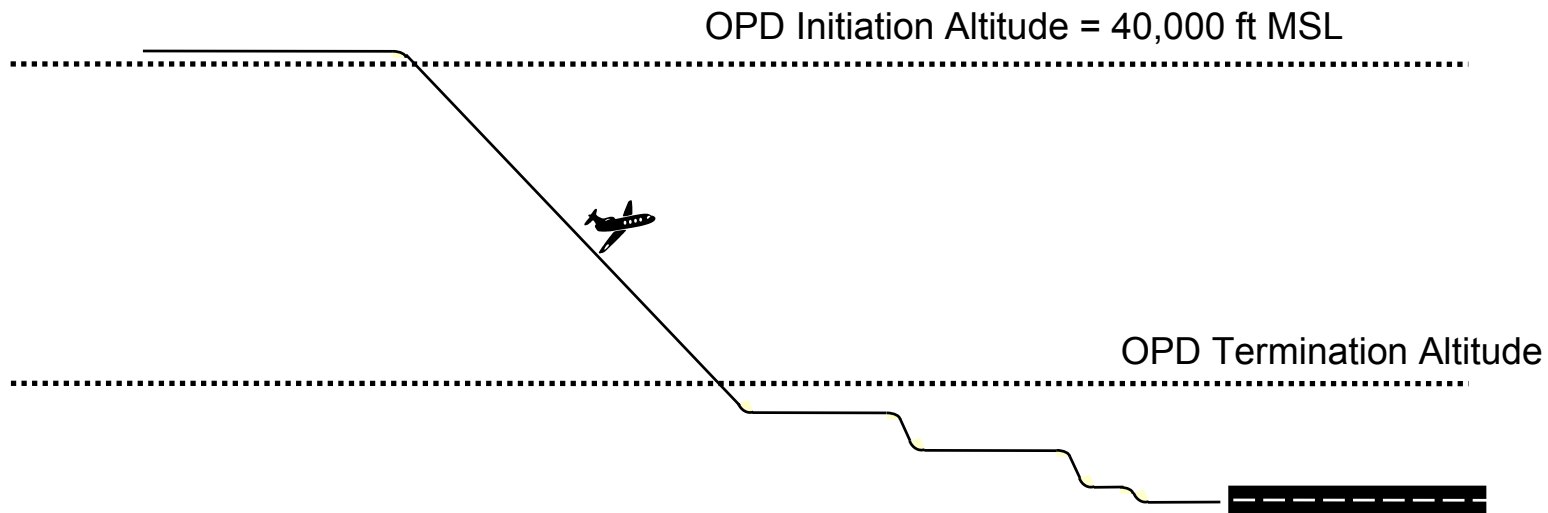


# Scenario 3

## Early Termination



- **Extent of the OPD portion**
  - Begins at the maximum observed cruise altitude
  - Ends at a specified OPD termination altitude
    - Below that altitude aircraft are in normal operations
    - Allows arrival shelf level-offs for merging and spacing

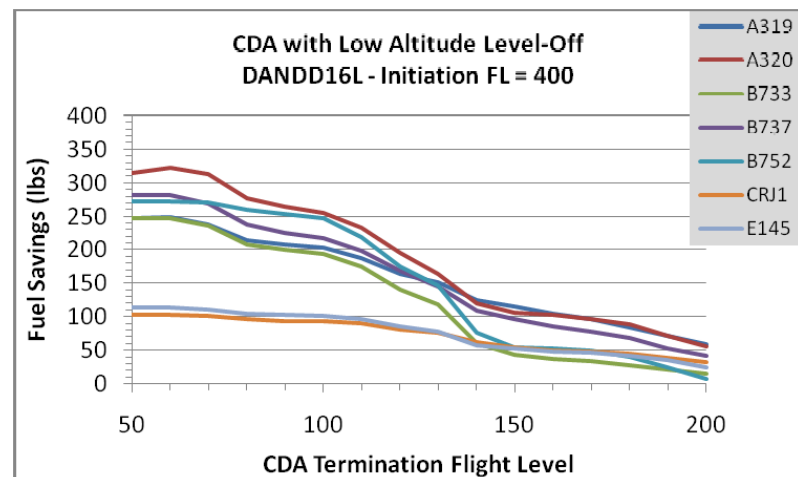
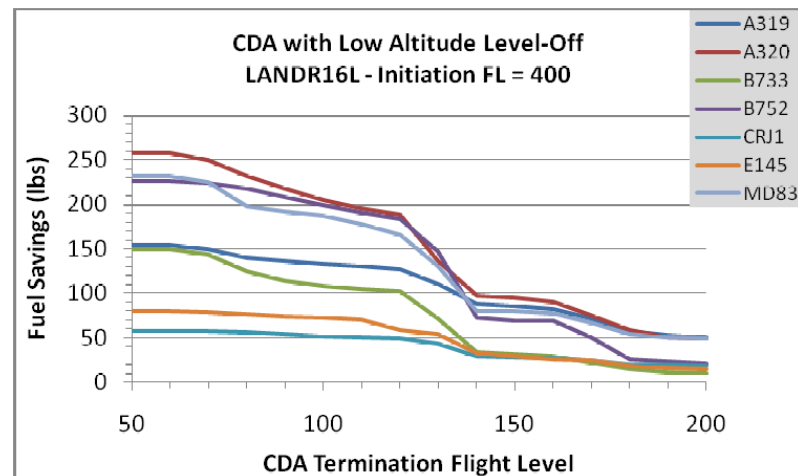




# Scenario 3

## Benefit vs. Termination Altitude

- Termination altitude at the field elevation is equivalent to unrestricted OPD
- Fuel savings benefits fall as the termination altitude rises
- Approximately 30% of the maximum fuel savings benefit can still be obtained with a termination altitude of FL150

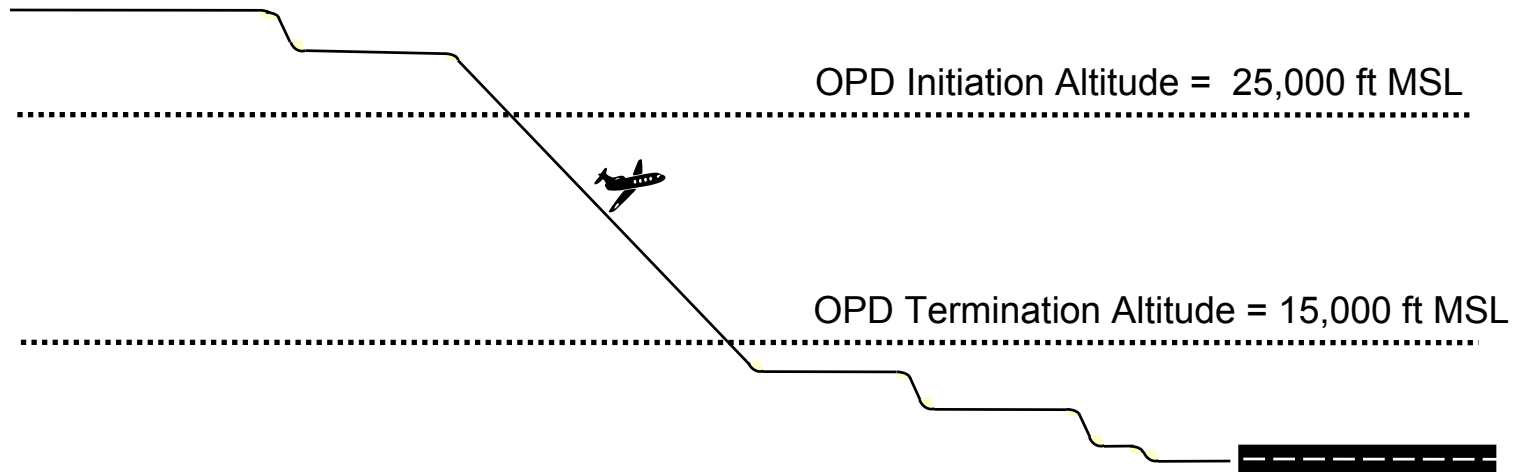




# Scenario 4

## Delayed Initiation plus Early Termination

- **Extent of the OPD portion**
  - Begins above FL250
  - Ends at FL150
  - This scenario removes the level-off at TRACON entry, but keeps other level-offs within the TRACON







# Scenario 4

## Fuel and Emissions Savings Estimate

Average Savings per Flight by Arrival Fix				
	Arrival Fix	Fuel Savings (lbs)	Emissions Savings	
			CO <sub>2</sub> (lbs)	SO <sub>2</sub> (lbs)
Short-Side	RAMMS	27	85	0.022
	TOMSN	35	111	0.028
	SAYGE	17	54	0.014
	LANDR	17	54	0.013
Long-Side	QUAIL	29	91	0.023
	DANDD	28	85	0.022
	POWDR	47	148	0.038
	LARKS	41	128	0.033

- **If the scenario 4 version of OPD can be implemented in which**
  - Initiation altitude = 25,000 ft MSL
  - Termination altitude = 15,000 ft MSL
- **The maximum per day fuel usage savings is estimated to be**
  - Savings of approximately 3,000 gallons per day
  - Daily reduction of approximately 30 tons of CO<sub>2</sub> and 15 lbs of SO<sub>2</sub>



# Summary of Scenarios

- **Unrestricted OPD implementation**

- **Continuous descent from cruise altitude down to the landing flaps configuration**
  - In this case all level-offs are removed and descents are purely at idle thrust
- **For DEN, the maximum total fuel savings is estimated to be 20,000 gallons per day with a daily reduction of approximately 200 tons CO<sub>2</sub> and 100 lbs of SO<sub>2</sub>**
  - This scenario is **highly idealized** since realistic OPD implementation will require conflict mitigation compromises, which will decrease the potential benefit

- **Delayed initiation and early termination**

- **The OPD segment of the descent begins above FL250 and ends at FL150**
  - This allows step downs from cruise at high altitude and arrival shelf vectoring at low altitude
- **For DEN, the total fuel savings is estimated to be 3,000 gallons per day with a daily reduction of approximately 30 tons of CO<sub>2</sub> and 15 lbs of SO<sub>2</sub>**
  - This implementation scenario removes the level-off prior to TRACON entry, but retains other level-offs within the TRACON
  - This scenario will still require automation and decision support for merging and spacing



# Conclusions

- **Conflicts**

- Arrivals under departures will conflict more with OPD implementation
- Arrivals over departures will conflict less with OPD implementation

- **Benefits**

- **Benefits depend on aircraft type and arrival direction**
  - Long-side arrivals have more benefit potential than short-side arrivals
  - Maximum fuel savings potential falls in the range 150-350 lbs per flight
  - Maximum emissions reduction potential falls in the range of 400 -1,000 lbs total for CO<sub>2</sub> and SO<sub>2</sub> per flight
- **Fuel and emissions savings depend on the initiation and termination altitudes**
  - Most of the benefits come from below 25,000 ft MSL
  - Step downs from cruise may be allowed with 15% loss of benefit





# Recommendations

- **Specific to DEN in south runway configuration**
  - **OPD implementation on the POWDR and DANND STARs would cause the fewest conflicts with departure flows**
  - **Conflict mitigation strategies and associated benefits**
    - High altitude step downs from cruise above FL250 can be permitted while still allowing approximately 85% of the maximum potential fuel savings benefit
    - Implementing OPDs which end at FL150, such that arrival flows can be directed under departure flows, can still yield 30% of the maximum potential fuel savings benefit
    - OPDs which permit both high altitude step downs and low altitude level-offs can still yield 15% of the maximum potential fuel savings benefit



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Implementation



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