Automated Data Assimilation and Flight Planning for Multi-Platform Observation Missions

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Outline

- Review of application problem
- Components of our system
  - Data Assimilation Assistant
  - Flight Planning Assistant
  - Data and Plan Visualization
- Future work and Conclusions

Intercontinental Chemical Transport Experiment (INTEX) mission

- Science focus: Effects of aerosols on climate and air quality.
- Evidence of pollution plumes from Asia being advected across Pacific Ocean to North America.
- Evidence of Mexico City pollutants reaching USA within 3-5 days.
- Need to understand life cycle of pollutants.

INTEX Flight Goals

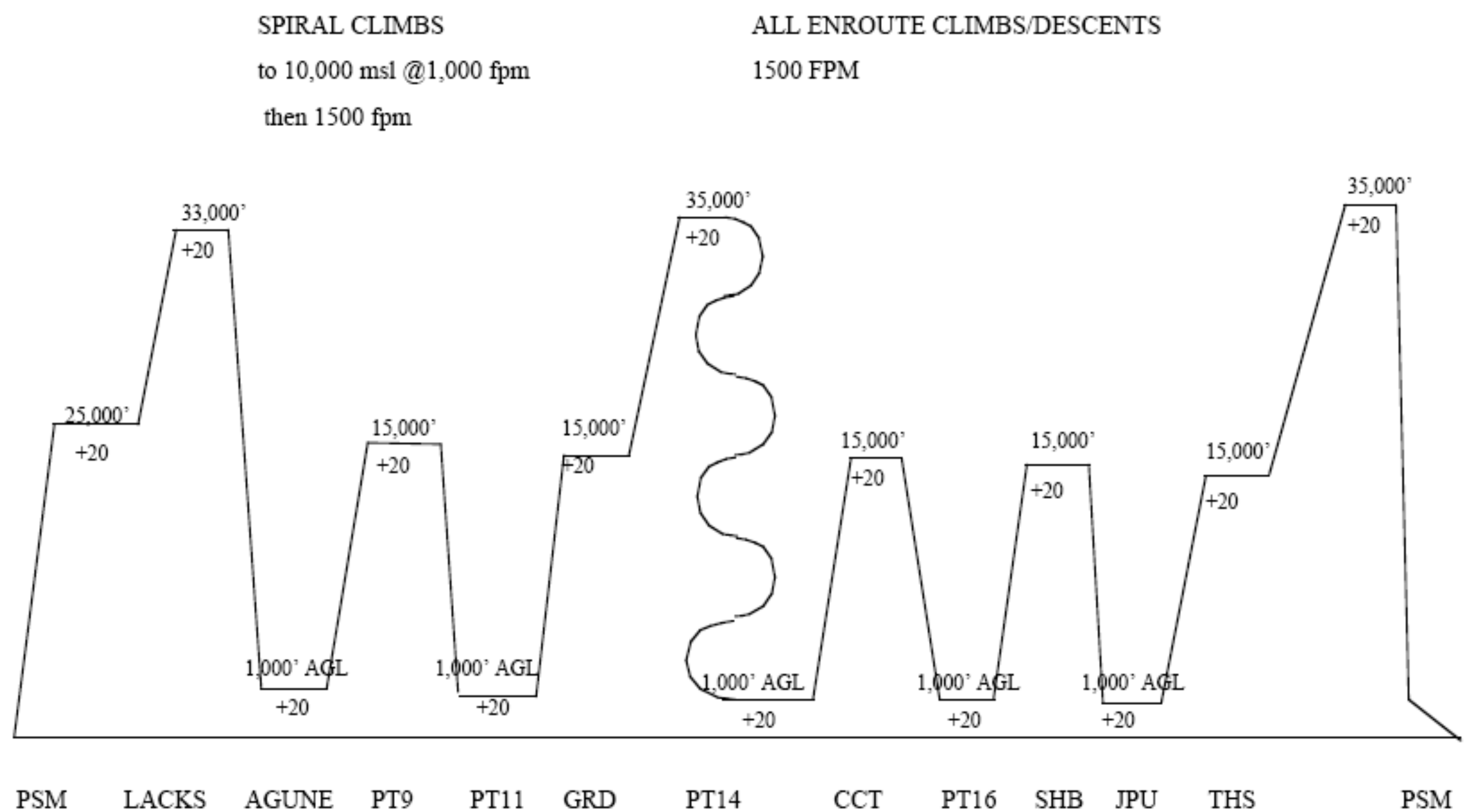
- Inter-comparison flights among multiple platforms.
  - Multiple airborne platforms.
  - Ships and fixed monitoring sites.
  - Satellite validation.
- Large-scale characterization of troposphere.
- American and Asian pollution plumes
  - Analysis
  - Characterize layers.

INTEX Flight Goals (2)

- Large-scale continental outflow characterization: Ventilation of sources (Pacific, Gulf of Mexico) through different pathways.
- Chemical aging: Sampling Mexican outflow over the Gulf on successive days to track chemical evolution.
- Study aerosol radiative effects---effects of aerosols on radiation and climate.

INTEX sample plan

DC-8 NASA 817 INTEX 06 Aug 04

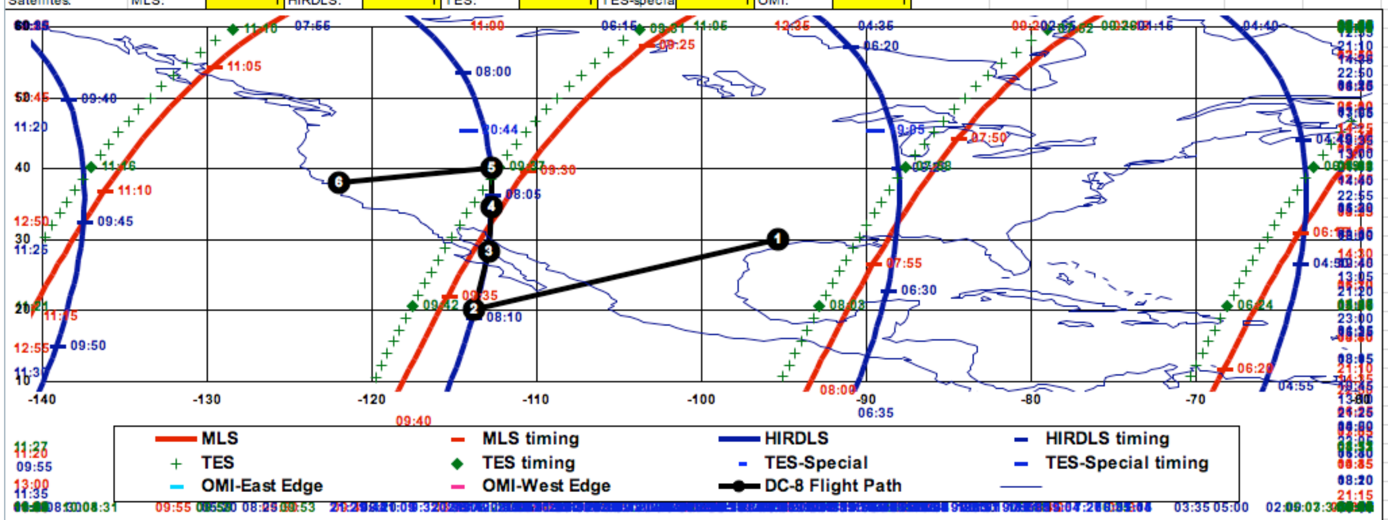


INTEX current mission planning procedure

- Instrument platform (e.g., DC-8) flown on many days (35) over 2.5 months.
- After flight, 10-15 mission planners and scientists devise next flight plan based on
  - Overall mission goals
  - Model predictions, data from satellites, ground-based sensors
  - Odd observations from previous day.
- Labor intensive, little automation
- Small amount of data examined
- Few plans examined

INTEX planning tool

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Latitude	29.97	20	28.3	34.5	40	38											
Longitude	-95.35	-113.8	-112.9	-112.7	-112.7	-122											
Cum. Flt. Time	0:00	3:19	4:45	5:49	6:46	8:03	END	END	END	END	END	END	END	END	END	END	
Leg Flt. Time		3:19	1:25	1:03	0:56	1:17	END	END	END	END	END	END	END	END	END	END	
Local Time	12:30	15:49	17:15	18:19	19:16	20:33	END	END	END	END	END	END	END	END	END	END	
UTC	18:30	21:49	23:15	0:19	1:16	2:33	END	END	END	END	END	END	END	END	END	END	
Spiral																	
Leg Speed (m/s)	180	180	180	180	180	180	180	160	160	160	160	160	160	160	160	160	
3/22/06	Day: 0-15	14	AM:	0	PM:	1	UTC diff:	6									
Satellites:	MLS:	1	HIRDLS:	1	TES:	1	TES-specia	1	OMI:	1							



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Distance (km)		2159	927	689	611	833	END	END	END	END	END	END	END	END	END	END	
Distance (nm)		1166	500	372	330	450	END	END	END	END	END	END	END	END	END	END	
Cum. (km)		2159	3086	3775	4386	5219	END	END	END	END	END	END	END	END	END	END	
Cum. (nm)		1166	1666	2038	2368	2818	END	END	END	END	END	END	END	END	END	END	
BL (knots)	270	-or-	138.8988	m/s		Planning Speeds											
FT (knots)	400	-or-	205.776	m/s		DC-8	160	m/s									
Avg (knots)	320	-or-	164.6208	m/s		C-130	125	m/s									

INTEX planning tool (2)

T	U	V	W	X
Profile Data		Cumulative Time		
	Duration	Minutes	hh:mm	Altitude
Start	0	0	0:00	0
Climb to 37K	30	30	0:30	33
140 min leg	140	170	2:50	33
Decend to 5 K	20	190	3:10	5
25 min leg	25	215	3:35	5
climb to 33K	20	235	3:55	33
25 min leg	25	260	4:20	33
Descend to 25	10	270	4:30	25
25 min leg	25	295	4:55	25
Descend to 10k	10	305	5:05	10
25 min leg	25	330	5:30	10
Land	20	350	5:50	0
		0	0:00	0
		0	0:00	0
		0	0:00	0
		0	0:00	0
		0	0:00	0
		0	0:00	0
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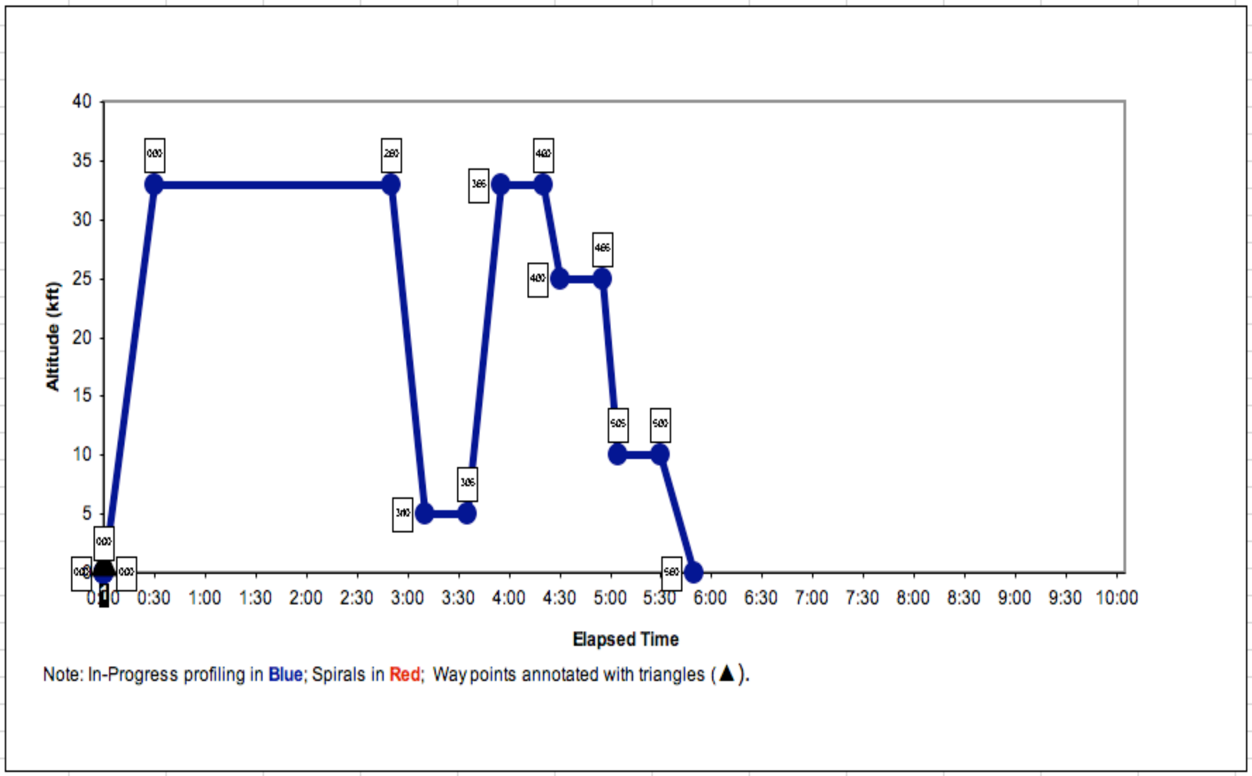

Technology Objectives

- Target: sequences of daily observations
- Data mining and automated planning need to be integrated into daily observations
  - To help identify "interesting" observation targets: areas where observations deviate from model predictions.
  - Leverage more data, information to make daily observation plans.
  - Make planning faster.
  - Yield more scientifically valuable measurements.

Our specific scenario

- Make flight plan for March 19, 2006.
- Data available to us
  - Satellite observations of Carbon Monoxide (CO)
    - Atmospheric Infrared Sounder (AIRS)
    - Measurement Of the Pollution In The Troposphere (MOPITT)
    - Use measurements of March 19 as surrogate for projections from earlier measurements.
  - Model predictions of CO (Model of Ozone Research in the Troposphere (MOZART))
  - Mission goals

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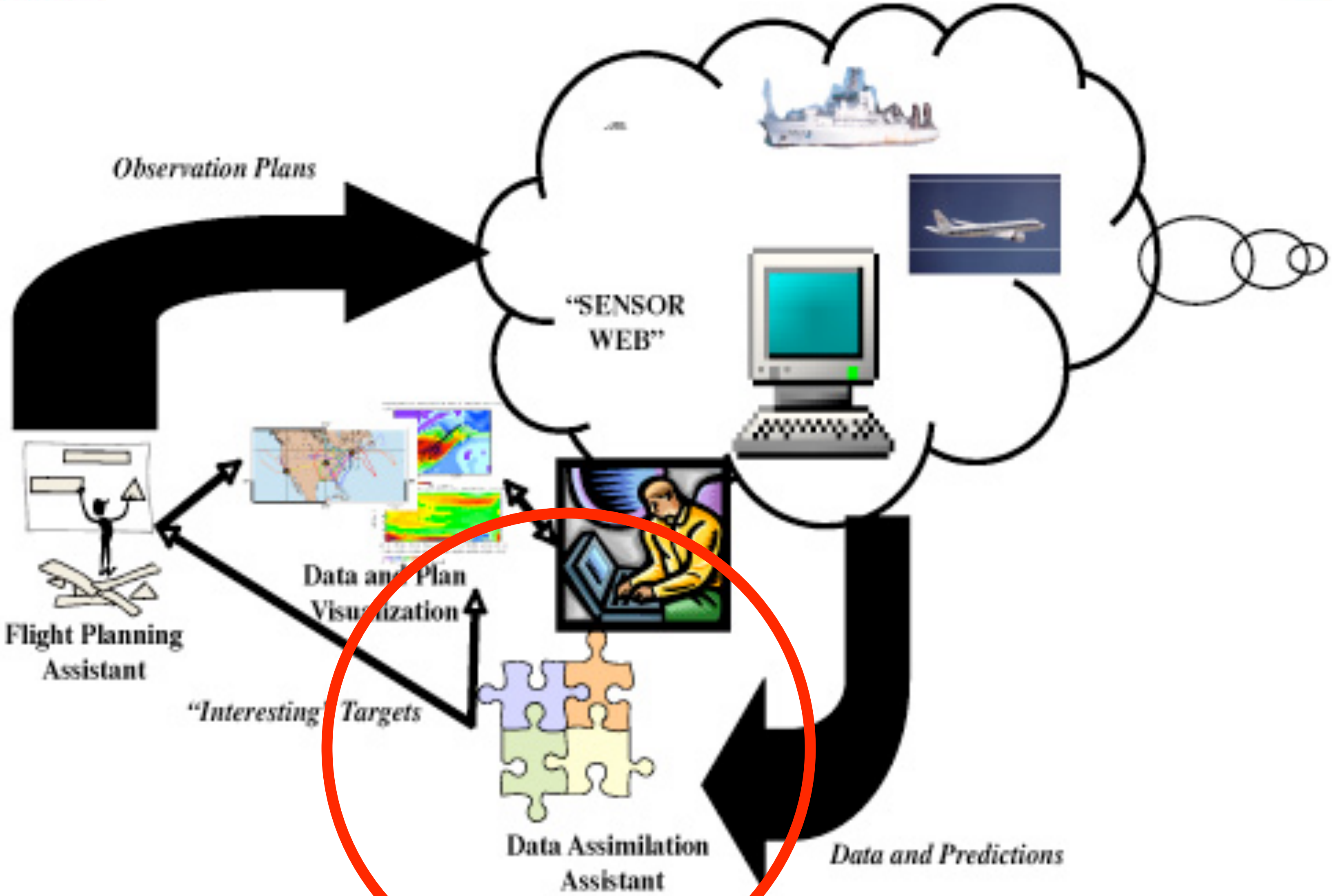

Observation Plans
"SENSOR WEB"
Data and Plan Visualization
Flight Planning Assistant
"Interesting" Targets
Data Assimilation Assistant
Data and Predictions

Data assimilation/mining

- Assimilate measurements, data, physical models. Provide guidance to flight planner---waypoints where measurements should be taken.
- Provide analysis results to scientists---identify where model predictions and measurements deviate.

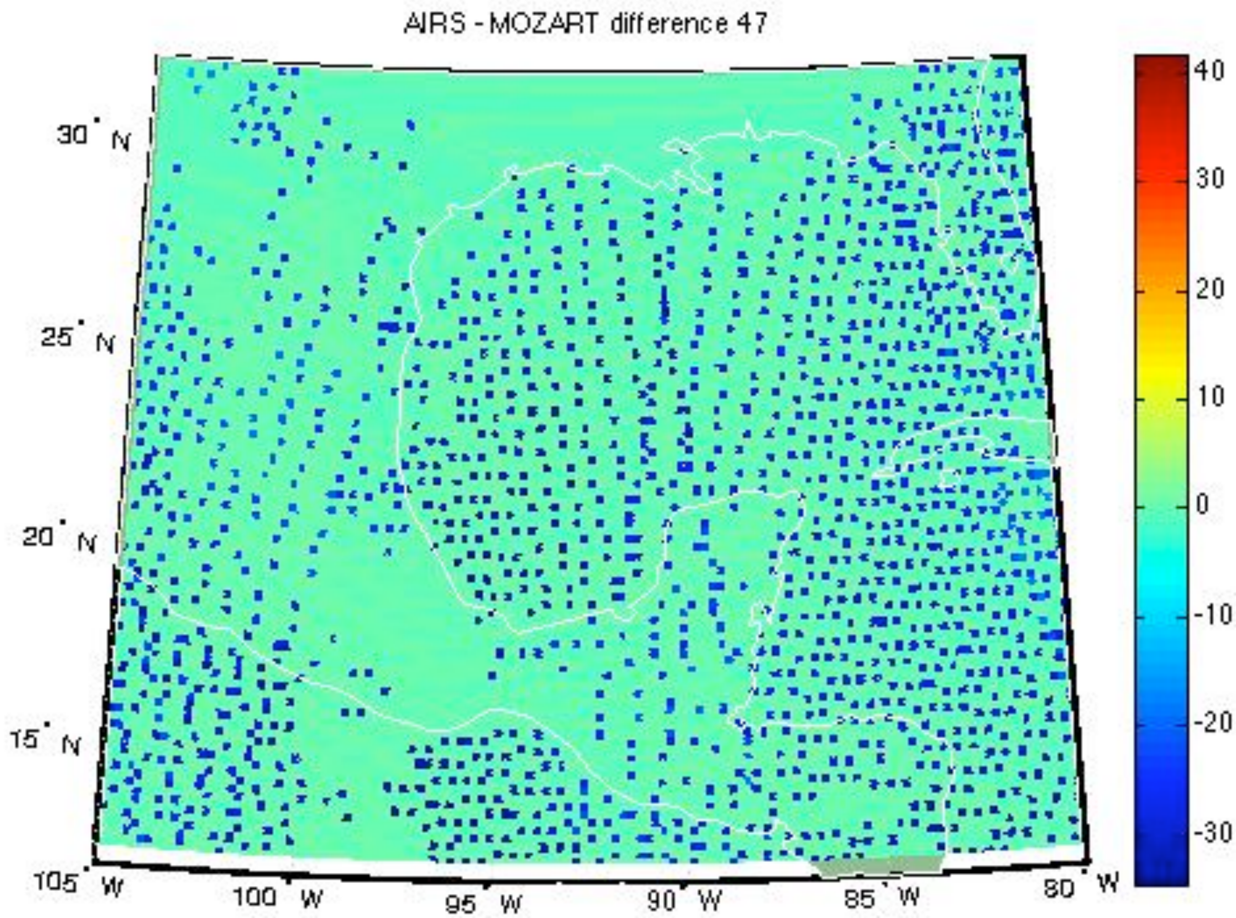
Data assimilation/mining attempts

- Attempted one-class Support Vector Machines (SVMs) with AIRS, MOPITT, Moderate Resolution Imaging Spectroradiometer (MODIS Aerosol, MODIS Clouds), and MOZART
  - No systematic anomalies observed.
- Attempted to find other data as a function of MOZART for prediction purposes.
  - Learn from today and earlier data.
  - Predict regions where anomalies likely to appear
  - Such modeling appears too complicated.
- Normal method involves using trajectory analysis to project locations of pollutants in the future.

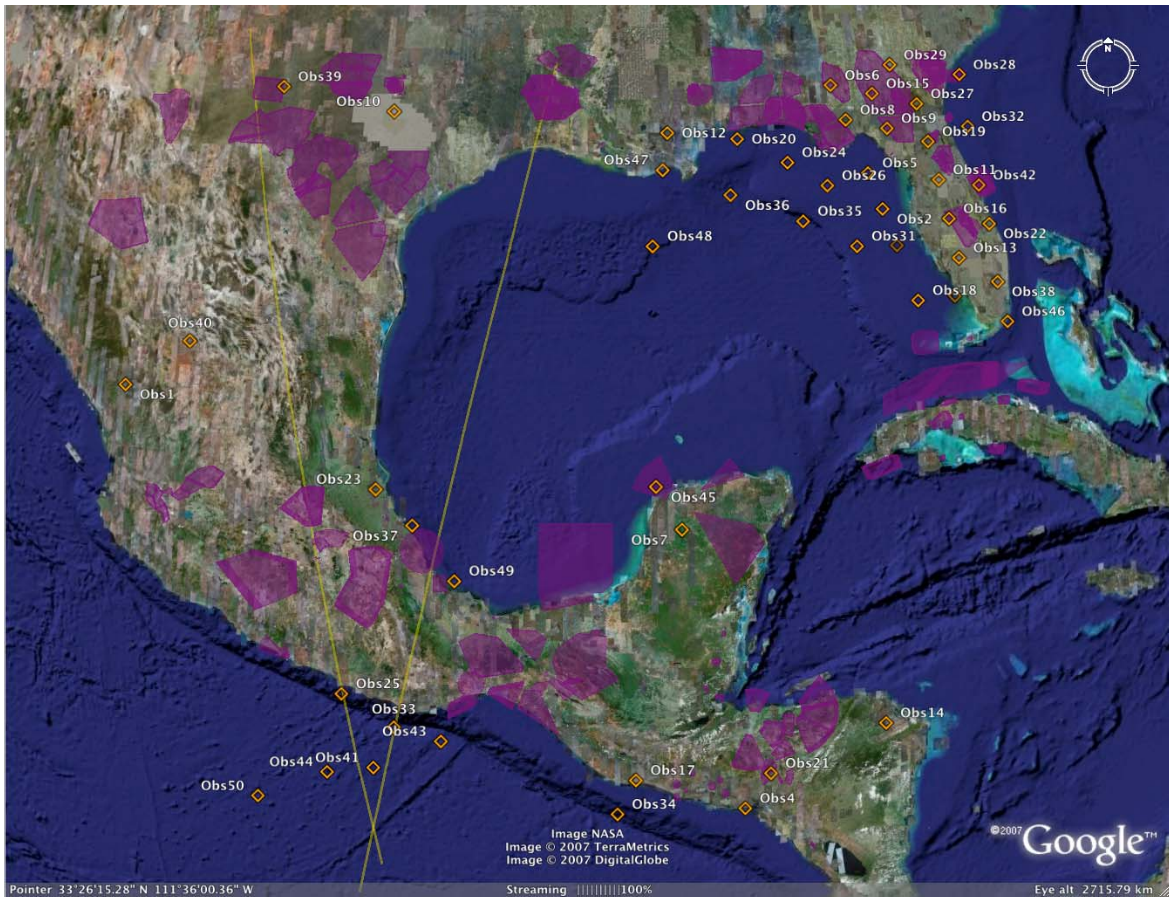
Data assimilation/mining

- Used March 19's satellite data as a surrogate for projections.
- Difference between MOZART predictions and AIRS measurements of CO.
- Difference between MOZART predictions and MOPITT measurements of CO.
- Turn these into priorities. Select out at most 50 highest priority points that are at least 10 minutes apart.
- Execution time: Around 40 seconds from inputs to priorities on MacBook Pro 2.4 GHz.

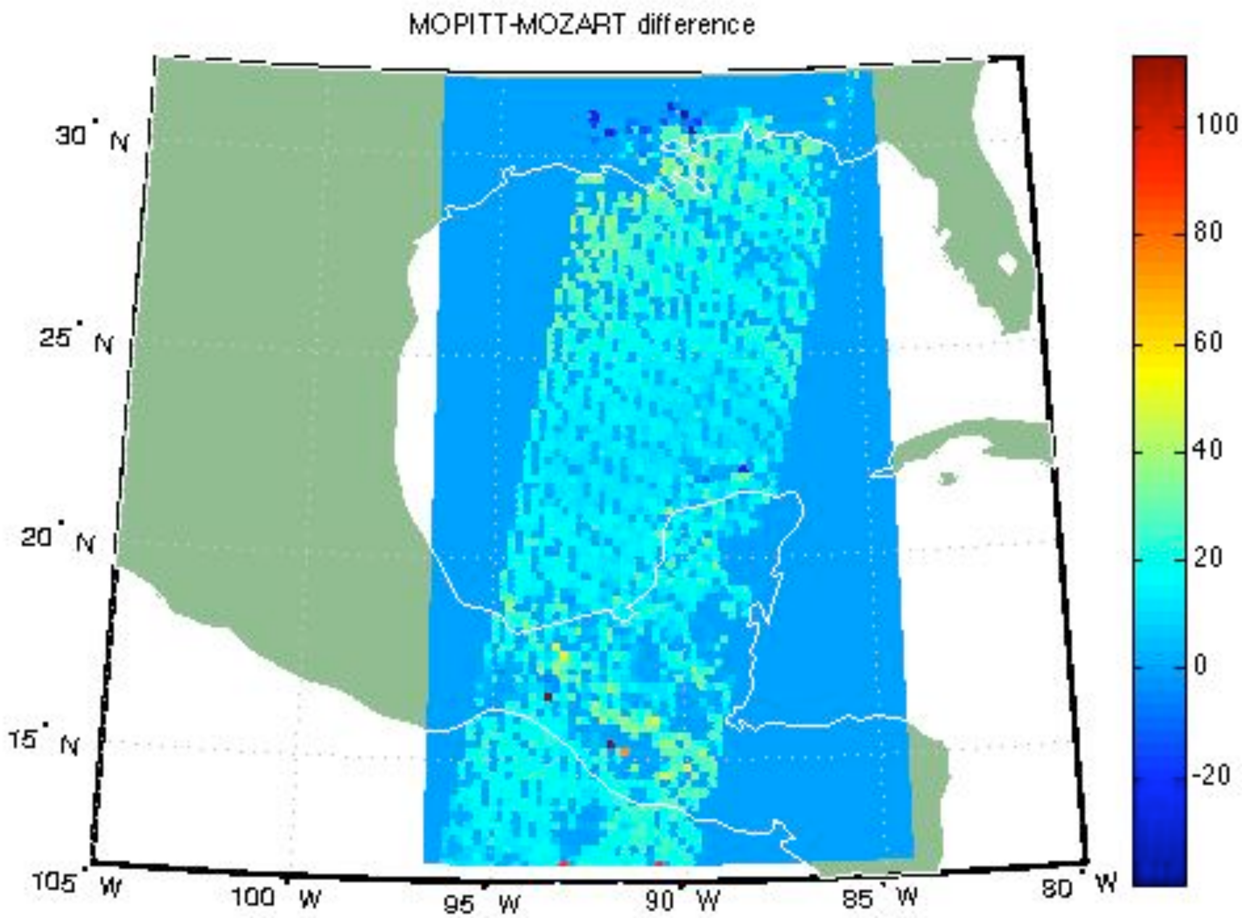
AIRS-MOZART difference



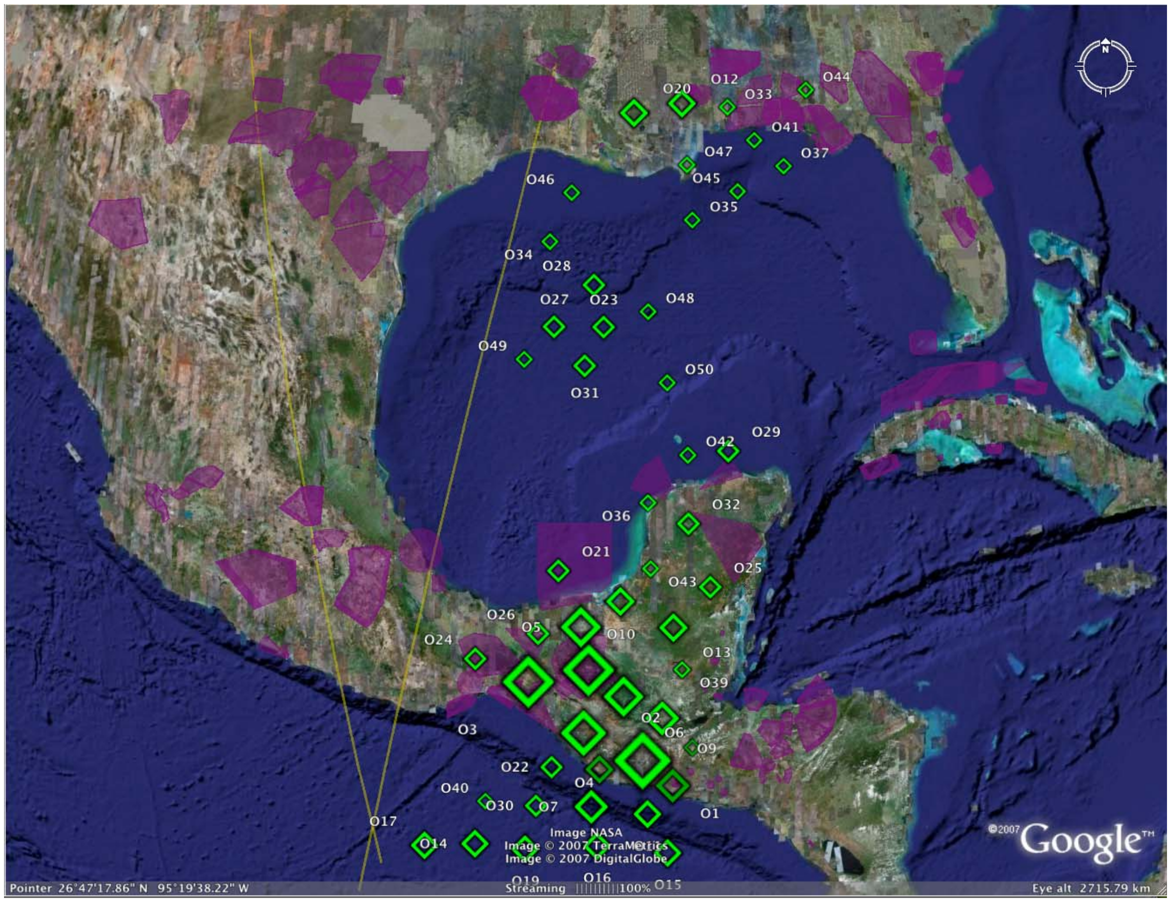
AIRS-MOZART difference->waypoints

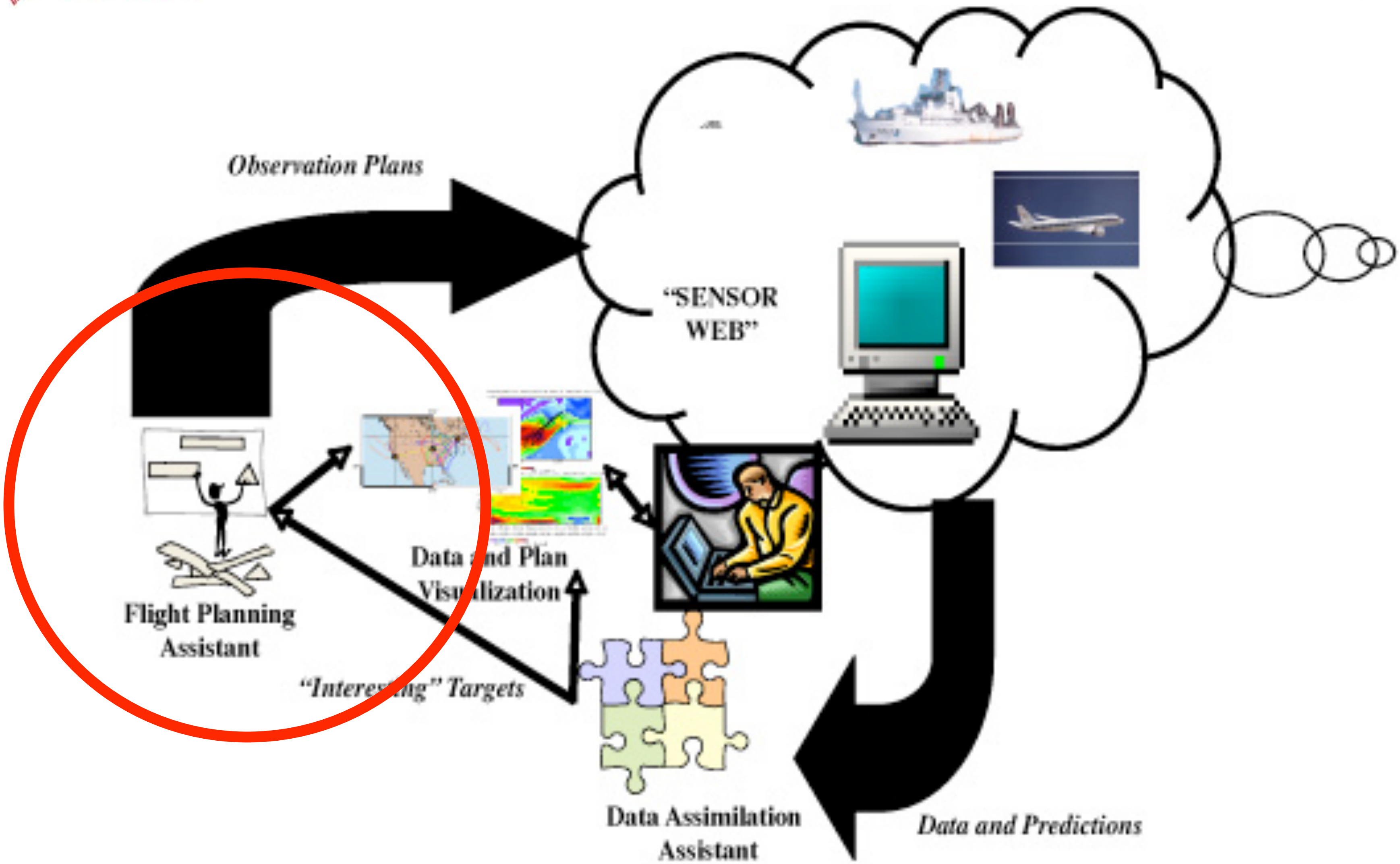


MOPITT-MOZART difference



MOPITT-MOZART difference -> waypoints

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Planning Problem

- Goal: Produce a flight plan that optimizes on the science value of the total measurements taken.
- Inputs
  - Set of waypoints from assimilation tool.
  - Other mission goals and associated constraints (e.g. flight paths from other observing platforms).
- Constraints
  - Instrument
  - Navigational (e.g. avoidance of Special Use Airspace, SUA)
  - Aircraft operational constraints (e.g., fuel, time to climb, airspeed)

Planning Approach

- Problem is instance of Orienteering Problem.
  - Oversubscription (more goals than can be serviced)
  - Cost (travel time) and utility of waypoints
  - Constraint on total travel time (related to fuel, crew time).
- Greedy constructive search
  - Dynamic (re)-ordering of candidate waypoints
  - Incremental extension of partial plan until no more waypoints can be added.

SUA Avoidance Approach

- SUA is approximated by convex hull
  – Using Graham Scan algorithm
- SUA intrusion is detected by intersection with straight line path between waypoints.
- Visibility graph is constructed out of vertices of hull
- Single source shortest path algorithm (Dijkstra) applied to find path around SUA.

Performance of Planner: Observations

- Worst case performance is polynomial in
  - number of observations
  - number of SUAs, and
  - the shape (number of vertices) in visibility graph.
- Dominant factor in performance is clearly SUA avoidance.
- Up to 10 minutes to generate plan with 50 data mining waypoints, 350 SUAs.


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Visualization

- Objectives:
  - Provide a 3-D representation of the spatial context of the mission at selectable scales and viewpoints
  - Display input data sets and results of data mining and planning within spatial context
  - Provide interactive interrogation of spatial context, data, and results
  - Deliver visualization in manner convenient to mission scientists

Visualization Software

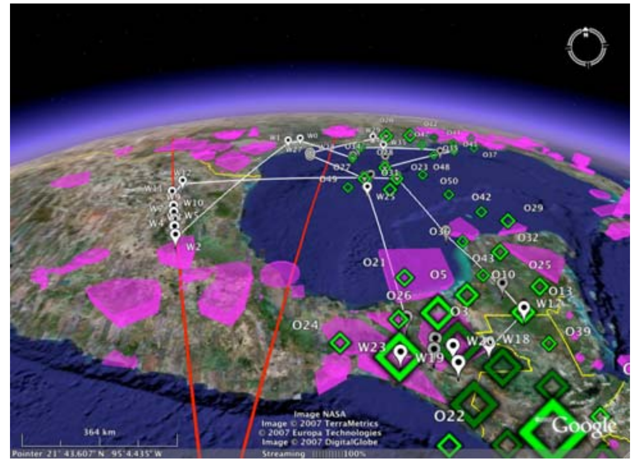
- Mercator - Visualization Creation
  - New software under development at Ames
  - Provides programmable Java environment
  - Based on scene graph and OpenGL libraries for visualization technique development
- Google Earth - Visualization Deployment
  - Commonly used software
  - Handles multi-scale visualization
  - Provides hide capability for scene management

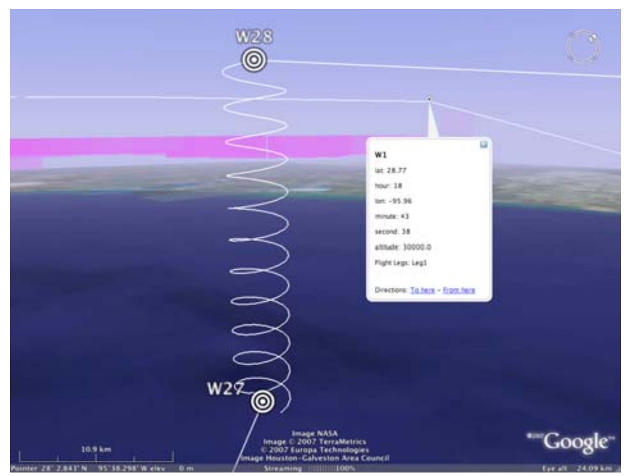
Visualization Techniques

- Visualizations
  - SUA: extruded concave polygons with ceiling and floor (required tesselation to convex polygons)
  - MOZART model: multi-value layers based on CO, concentration indicated by transparency
  - Observation point: icon scaled by priority
  - Waypoint: icon with queryable details
  - Path: line tesselated to conform to Earth curvature
  - Satellite ground track: polygon draped on ground
- Visualizations were created in Mercator and output in KML for Google Earth

Visualization Results

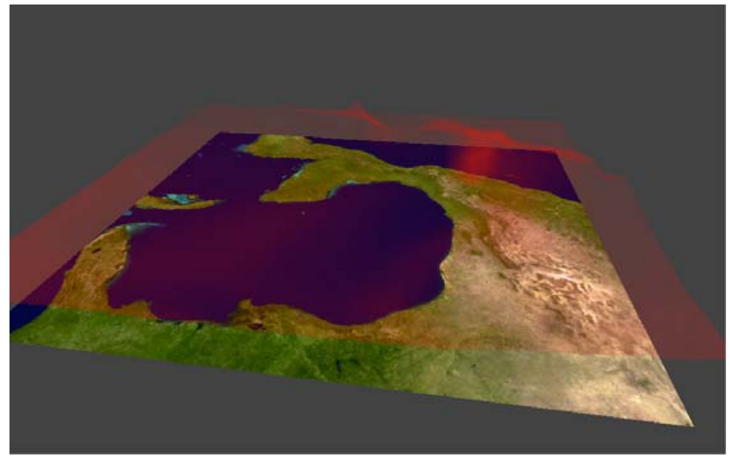
- *Top*: Google Earth with SUAs (magenta), Satellite ground track (red), MOPITT/MOZART difference observations (green), and plan (white)
- *Bottom*: Close-up of plan showing a spiral leg and details for a waypoint

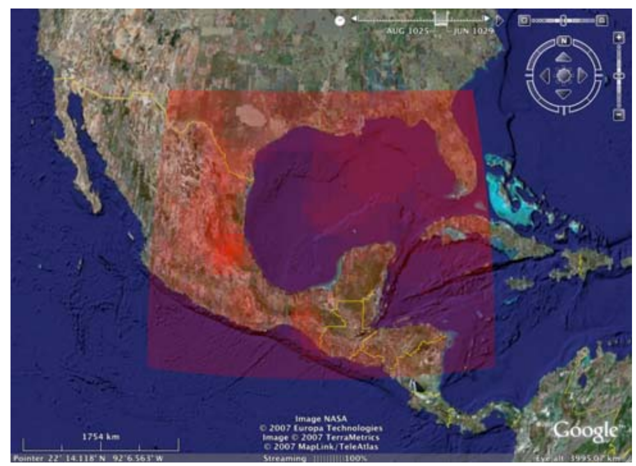




Visualization Results (cont.)

- *Top*: View of MOZART level 27 at 100x vertical exaggeration in Mercator. The more concentrated areas are less transparent.
- *Bottom*: View of MOZART in Google Earth. Level is selected via the slider at the top. The plume over Mexico City is visible as a bright spot.





Current practice vs. Future practice

- Limited data handled manually
- Constraints incorporated into planning manually
- Visualization through fixed charts

- Automatic data handling
  - Potential to leverage more data, results
- Planning automatically incorporates constraints
- Interactive visualization---everything in one tool

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Possible Future Work

- Allow access to more data, parameters, planning targets (beyond CO) to make more realistic, comprehensive plans.
- Planning over multiple days, incorporating mission goals and previous days' measurements.
- Work with ARCTAS and other missions to build what they need while keeping fundamental components generic.

Conclusions

- Data Mining will improve the ability to identify regions of interest for the current day's flight.
- Automating flight planning will enable a systematic search over a large space of possible flight plans, balancing the achievement of mission goals with taking "interesting" measurements.
- Results: improved ability to find optimal plans.

Acronym List

- AIRS: Atmospheric Infrared Sounder (instrument)
- AIST: Applied Information Systems Technology
- ARCTAS: Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
- CO: Carbon Monoxide
- DAA: Data Assimilation Assistant
- FPA: Flight Planning Assistant
- INTEX: Intercontinental Chemical Transport Experiment
- MODIS: Moderate Resolution Imaging Spectroradiometer (instrument)
- MOPITT: Measurement Of the Pollution In The Troposphere (instrument)
- MOZART: Model of Ozone Research in the Troposphere
- SUA: Special Use Airspaces (restricted airspaces)
- SVM: Support Vector Machines
- TOPS: Terrestrial Observation and Prediction System
- KML: Keyhole Markup Language
- XML: eXtensible Markup Language