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

Nikunj C. Oza (PI)
Robert Morris
Anthony Strawa
Elif Kurklu
Leslie Keely
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

SPIRAL CLIMBS

to 10,000 msl @ 1,000 fpm

then 1500 fpm

ALL ENROUTE CLIMBS/DESCENTS

1500 FPM

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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
## INTEX Planning Tool (2)

### Profile Data

| T  | U | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | AI | AJ | AK |
|----|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|
|    |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |
| Start | Duration | Minutes | hh:mm | Altitude |
| Climbing to 37K | 30 | 30 | 0:30 | 33 |
| 140 min leg | 140 | 170 | 2:50 | 33 |
| Descending to 5 K | 20 | 190 | 3:10 | 5 |
| 25 min leg | 25 | 215 | 3:35 | 5 |
| Climbing to 33 K | 20 | 235 | 3:55 | 33 |
| 25 min leg | 25 | 260 | 4:20 | 33 |
| Descending to 26 | 10 | 270 | 4:30 | 26 |
| 25 min leg | 25 | 295 | 4:55 | 25 |
| Descending to 10 | 10 | 305 | 5:05 | 10 |
| 25 min leg | 25 | 330 | 5:30 | 10 |
| Landing | 20 | 350 | 5:50 | 0 |

Note: In-progress profiling in Blue; spirals in Red; Waypoints annotated with triangles (▲).
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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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
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.
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 tessellation 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