Dynamical-Network Evaluation and Design Tools for Strategic-to-Tactical Air Traffic Flow Management

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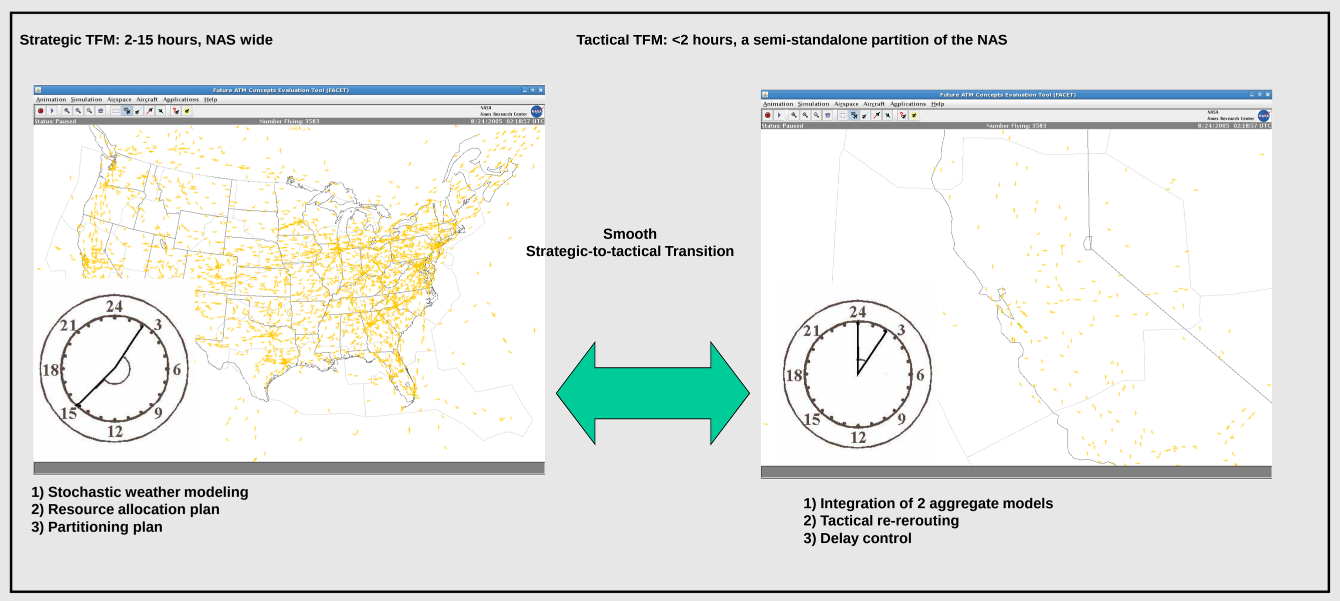
Objective

Develop tools for comprehensive design and optimization of air traffic flow management capabilities at multiple spatial and temporal resolutions: a national airspace-wide scale and one-day time horizon (strategic time-frame); and at a regional scale (of one or a few Centers) and a two-hour time horizon (tactical time-frame).



Approach

Develop a suite of tools for designing complex multi-scale dynamical networks, and in turn to use these tools to comprehensively address the strategic-to-tactical traffic flow management problem. The two directions of intellectual merit in tool development include 1) the meshed modeling/design of flow- and queueing-networks under network topology variation for cyber- and physical- resource allocation, and 2) large-scale network simulation and numerical analysis. This research will yield aggregate modeling, management design, and validation tools for multi-scale dynamical infrastructure networks, and comprehensive solutions for nation-wide strategic-to-tactical traffic flow management using these tools.

Contributions to NSF CPS Themes

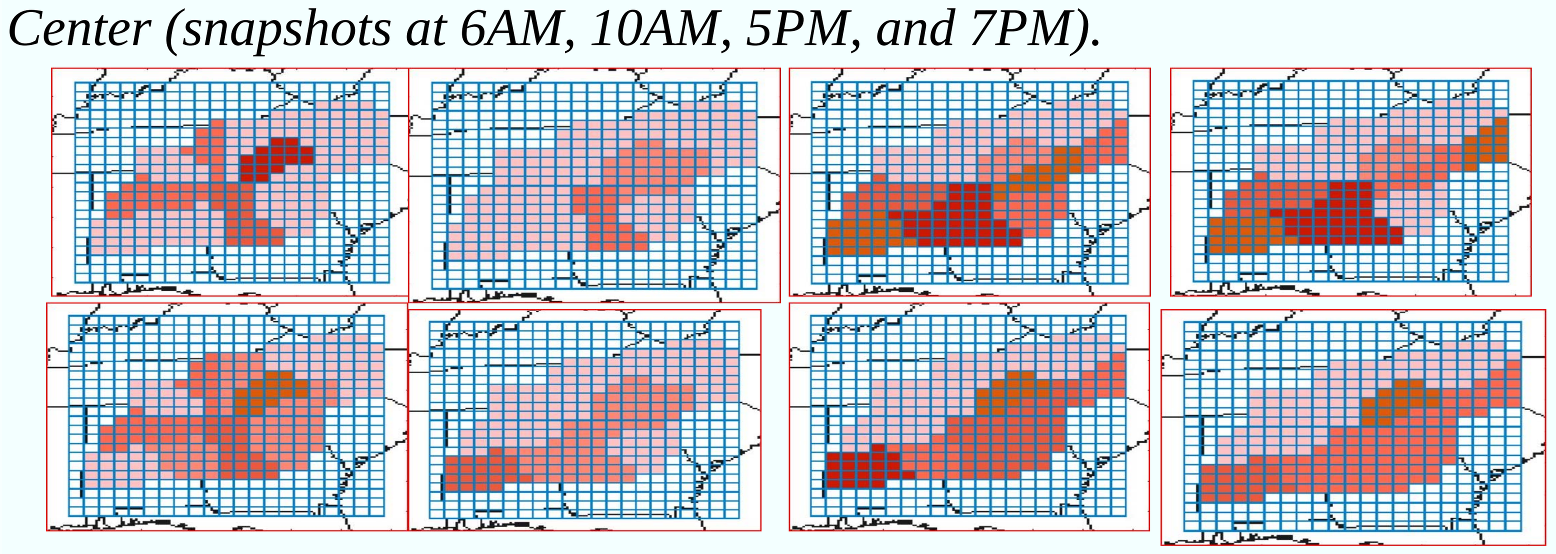
This research effort is providing both mathematical foundations, and concrete methods and tools, for tractably modeling environmental and physical-world uncertainties using cyber- capabilities. In this scope, the project can broadly permit the tight conjoining of cyber- and physical-resources in designing decision-support capabilities for infrastructure networks. Specifically, multiple core challenges in the study of cyber-physical systems are addressed:

1) Our efforts permit the design of cyber- decision-support capabilities that can account for uncertainties in infrastructure-network dynamics
2) Our efforts facilitate robust, adaptive decision-making by increasing the cyber-system's awareness of infrastructure-network dynamics, at a resolution and time-horizon that is apt for decision-making.

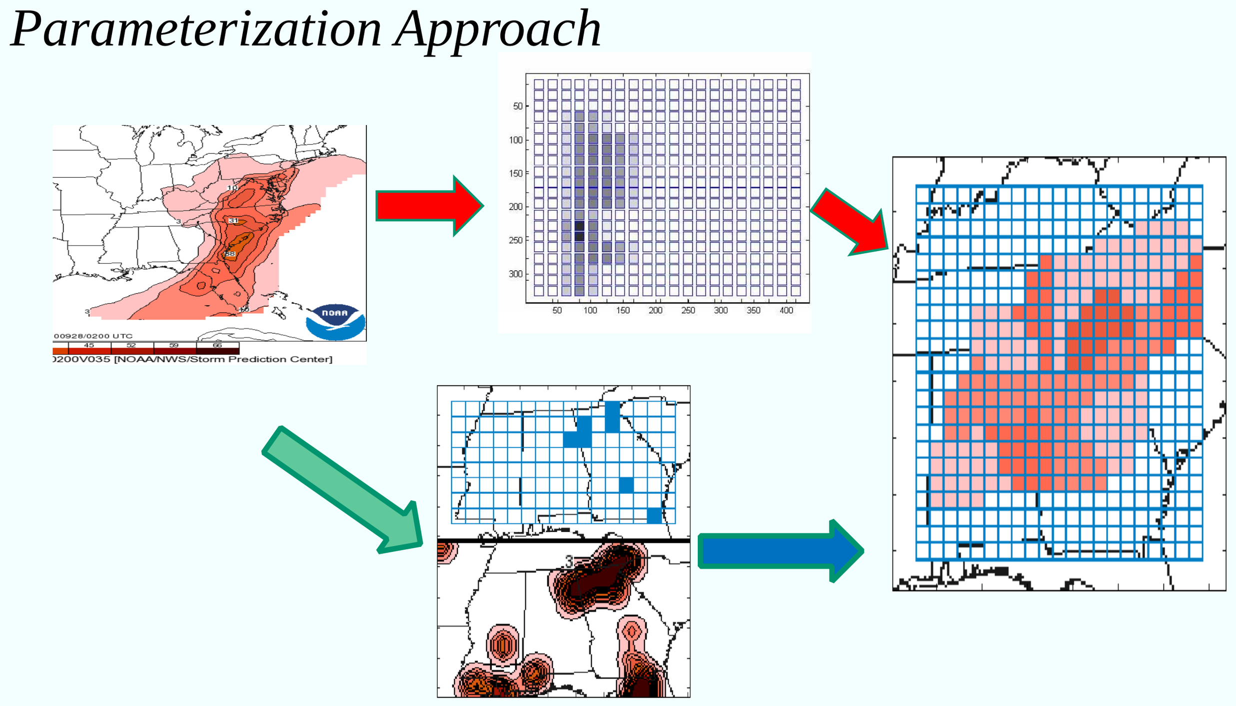
Year-1 Results

Focus and Core Outcome at Washington State University: The focus has been on the development of stochastic weather-impact (WI) simulator for the National Airspace System (NAS), that can aid in strategic decision-support. Core outcome has been the mathematical formulation, parameterization, analysis, and software prototyping of the WI simulator. The result significantly enhances planned weather forecasting capabilities for the Next Generation Air Traffic System, by: 1) capturing weather-impact rather than weather; 2) generating scenarios that capture spatio-temporal propagation of impact; 3) modeling weather (and impact) at the proper resolution ; 4) permitting extensive analysis at low computational cost, including spatial and temporal correlation analysis, representative-scenario generation, and educed-order modeling at critical locations.

Two stochastically-generated scenarios of WI propagation in Atlanta Center (snapshots at 6AM, 10AM, 5PM, and 7PM).



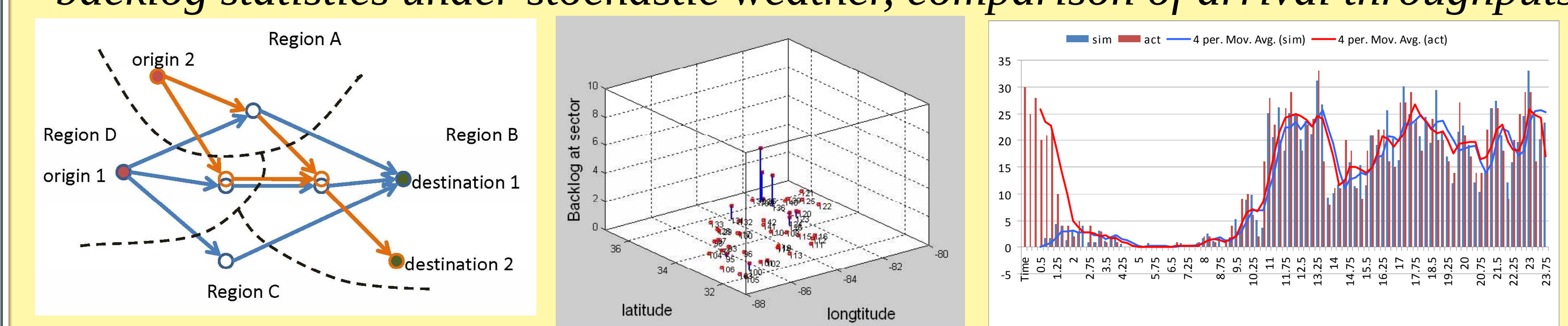
Model Parameterization Approach



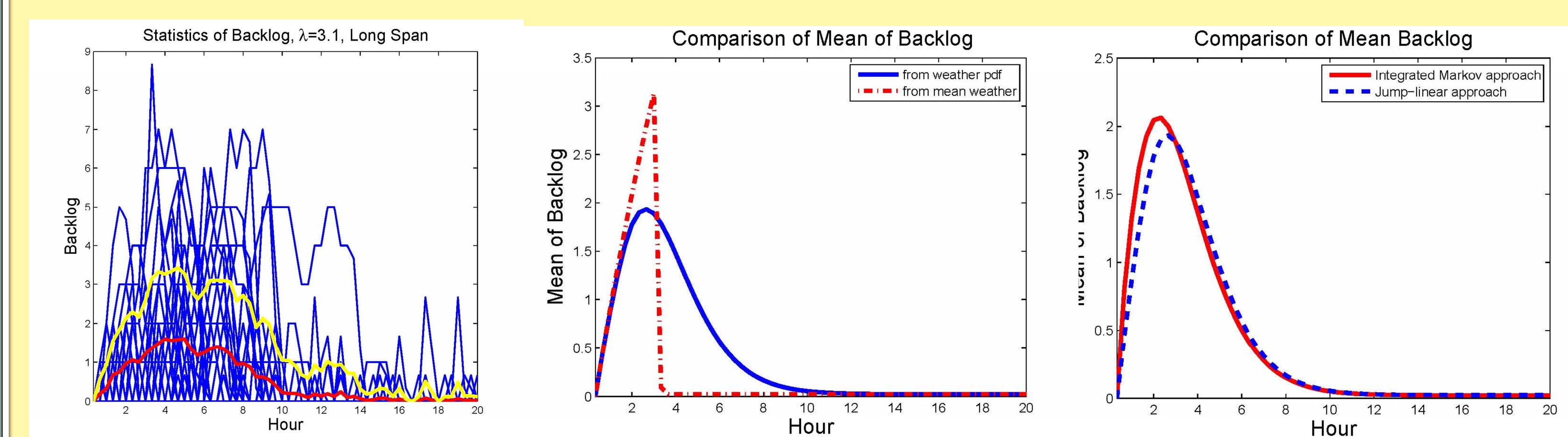
Focus and Core Outcome at University of North Texas: we have focused on the development of models and tractable analysis for strategic traffic management in the presence of weather uncertainty. The outcomes include:

a) the novel dynamical queuing network model, which 1) captures the transient dynamics of the NAS in response to dynamical weather uncertainties; 2) captures the impact of a series of management actions in practice or potential for use such as MIT/MINIT, GDP, TBM, Routing, and AFP; 3) represents traffic as stochastic flows while capturing realistic route structure, and 4) reasonably interfaces with operational practice and easily being parameterized from data.
b) the jump-linear approach to predict backlog statistics in the presence of dynamical uncertain weather. As uncertain weather plays a big role in decision-making, this novel tool for performance evaluation under uncertain weather is of critical importance.

Dynamical queuing network modeling and simulation of the NAS (from left to right: overlaid O-D pair queuing network model, simulation of sector backlog statistics under stochastic weather, comparison of arrival throughputs)

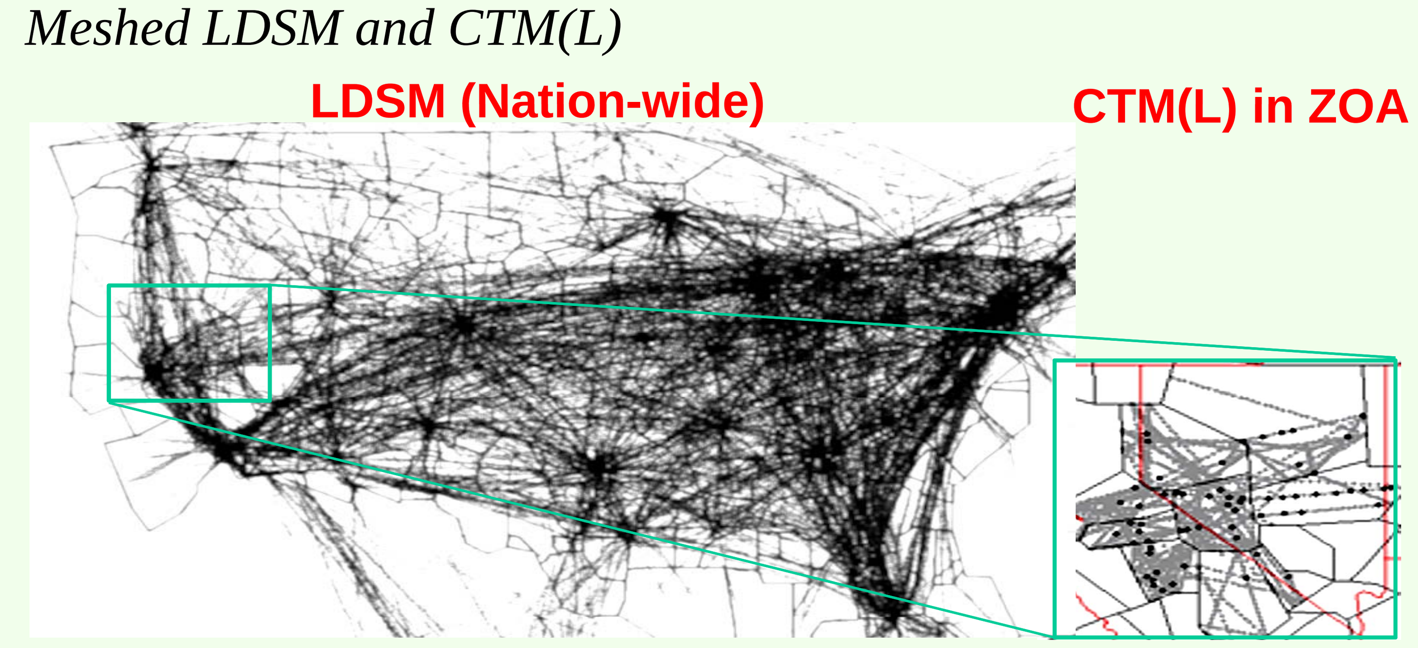


Tractable analysis of performance statistics in the presence of stochastic weather (from left to right: impact of stochastic weather on the number of aircraft delayed, obtained using Monte Carlo simulation, average weather info. not sufficient to predict delay, validation of the jump-linear analysis.



Focus and Core Outcome at Purdue University: The Linear Dynamics System Model (LDSM) is now integrated with the Large Capacity Cell Transmission Model, CTM(L), as a starting point for design of strategic-to-tactical Traffic Flow Management strategies. Using historical air traffic data and jetway information, a nation-wide air transportation network at a Center level is built for the LDSM, and inside each Center, a detailed subnetwork is built for the CTM(L). The two models are meshed together and the performance of the meshed model, in terms of comparing the predicted aircraft counts with historical data, is also validated.

Meshed LDSM and CTM(L)



Meshed Validation