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Adverse Weather Representation Using a Spatio-Temporal Risk Characterization Model

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Motivation

- **Adverse Weather Significantly Impacts Flight Operations**
  - Safety -- 22. 5% All US Accidents
  - Efficiency -- 17% / $1.7B per year Avoidable Weather Delays (Source: FAA)

Thunderstorms & Microbursts

In-Flight Icing

(Courtesy of NASA)

Turbulence & Clear Air Turbulence

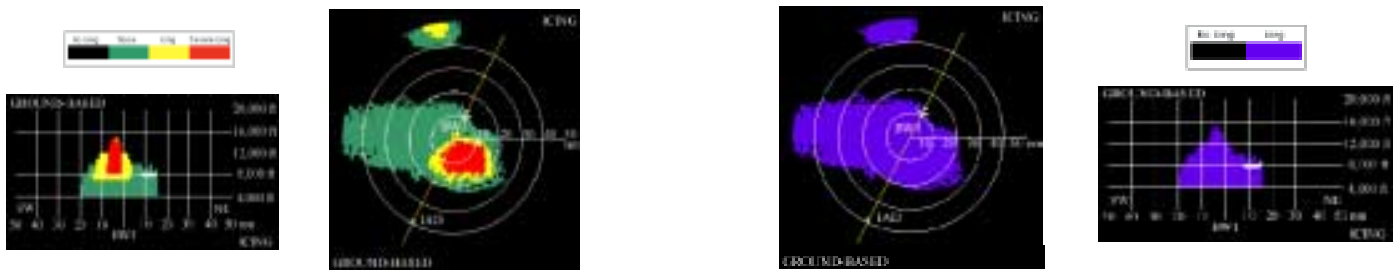
- **Several Efforts to Improve Weather Information**
  - NASA Aviation Safety Program
  - National Weather Service
  - National Center for Atmospheric Research

Challenges

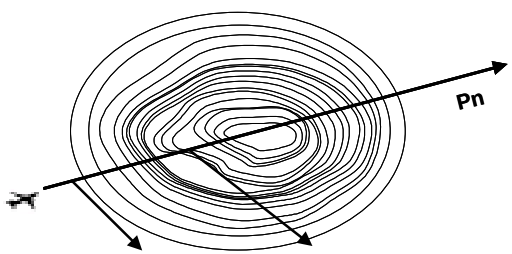
- **Fundamental Challenges for Effective Dissemination of Weather Information**
  - Atmospheric Surveillance Limitations -> Imperfect and Incomplete Model
    - Spatial Coverage
    - Resolution
    - Sampling Rate
    - Sensor Integration
  - Complexity of the Weather Field Model -> Multi-Dimensional Information Field
    - Spatially Distributed
    - Time-Varying
    - Probabilistic
    - Aviation Impact Variable
    - Phenomena Intensity
    - Need to Forecast
  - Humans Ability to Make Routing Decisions in Probabilistic Spatio-Temporal Weather Field
    - Need to Assess Risk
    - Need to Project Into Future
    - Need to Select Routing

Objectives

1. **Study and Improve Efficacy of the Presentation of Information on Spatially Distributed and Temporally Varying Hazards to Flight Crews**



2. **Propose a Formalism for Operational Risk Assessment of Spatio-Temporal Threat Fields**



$$R = R_{Pn} \times \rho_{O|i} \times R_{Po} + R_{Pn} \times (1-\rho_{O|i})$$

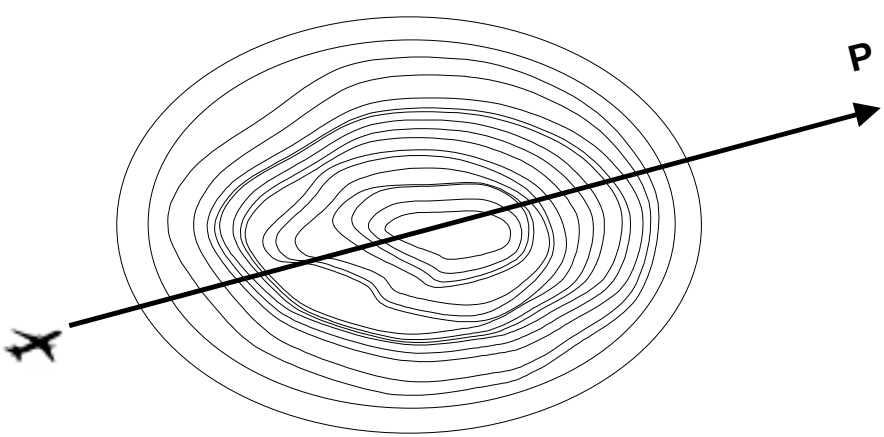
$$R_P = \int_P \rho(x, y, z, t)\, ds$$

3. **Support Integrated Development of Weather Information Systems**
   - Icing, Turbulence, Convective Weather

Risk Characterization Model

- **Characterizes a Subset of Aviation Weather Problems as**
  - Spatially Distributed Field
  - Temporally Varying Field
  - Risk Density Field
    - Probability of a Loss Event is a Function of the Integration of the Exposure to the Spatio-Temporal Field

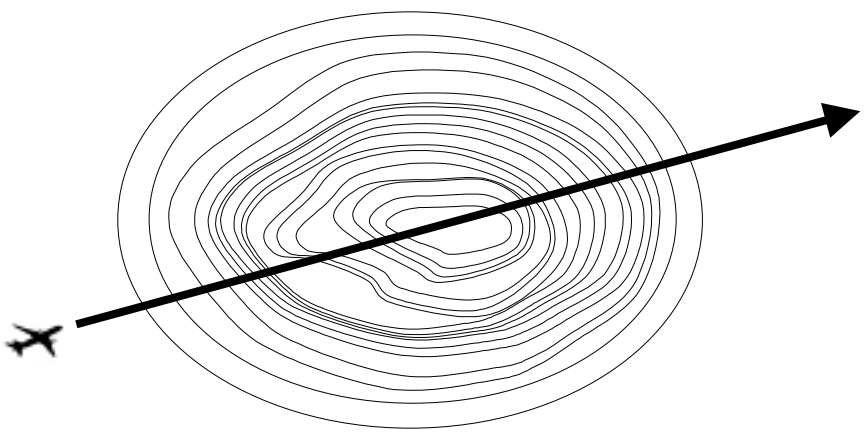
- **Definitions**
  - Path Risk = Probability of a Loss Event Along a Specified Path (R_P)



$$R_P = \int_P \rho(x, y, z, t)\, ds$$

	$\rho(x, y, z, t)$	**Risk Density**
where	P	**Specified Path**
	s	**Path Length**

No “Option” Case



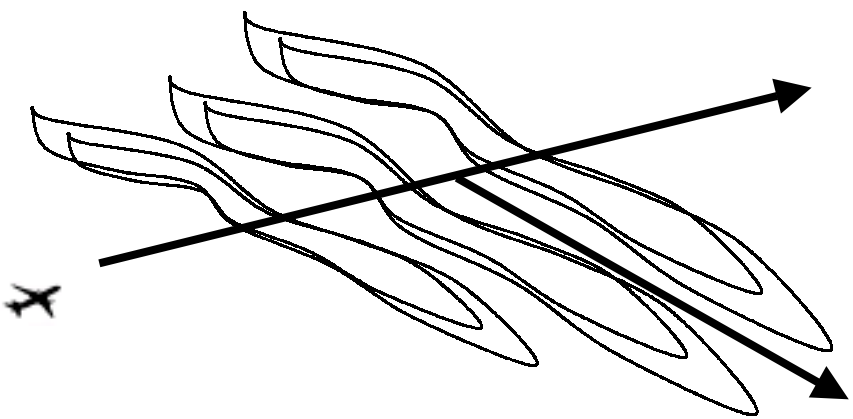
Nominal Path Risk

$$R_{P_n} = \int_{P_n} \rho(x, y, z, t)\, ds$$

Total Risk = Nominal Path Risk

Available “Option” Case

Risk Density Field



Nominal Path Risk

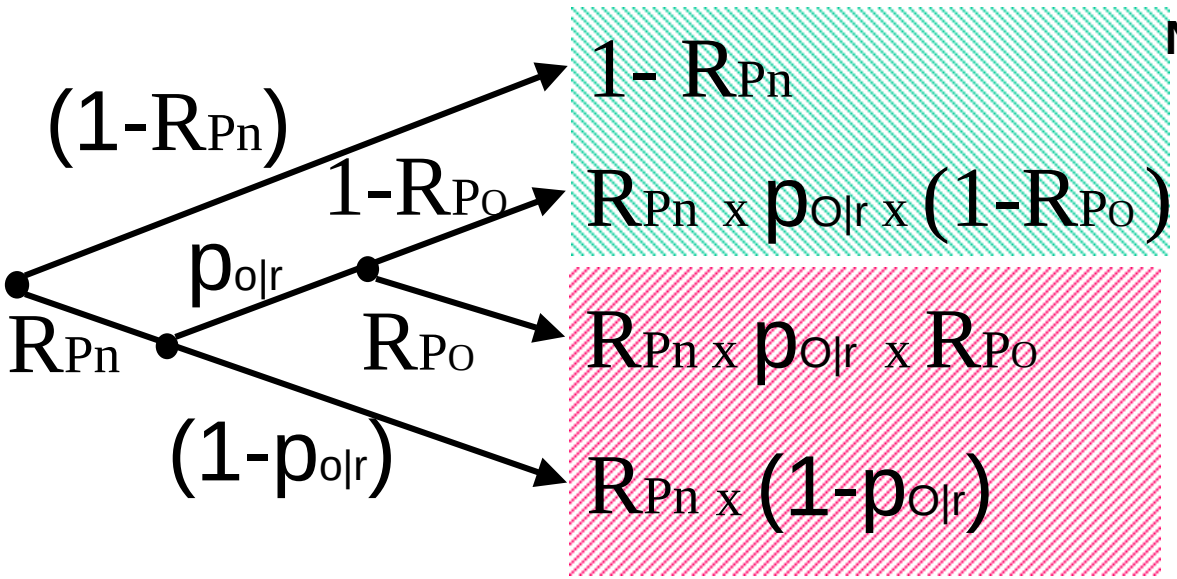
$$R_{P_n} = \int_{P_n} \rho(x, y, z, t)\, ds$$

Lumped “Option” Path Risk

$$R_{P_o} = \int_{P_o} \rho(x, y, z, t)\, ds$$

$p_{O|r}$: Probability of “Options”
Given the Nominal Path Risk

Total Risk is Function of "Options" Availability



No Dangerous Exposure

Dangerous Exposure Along Nominal Path but Successful "Option" Use

Dangerous Exposure and No Successful Use of "Option"

Dangerous Exposure Along Nom. Path and No "Option" Available

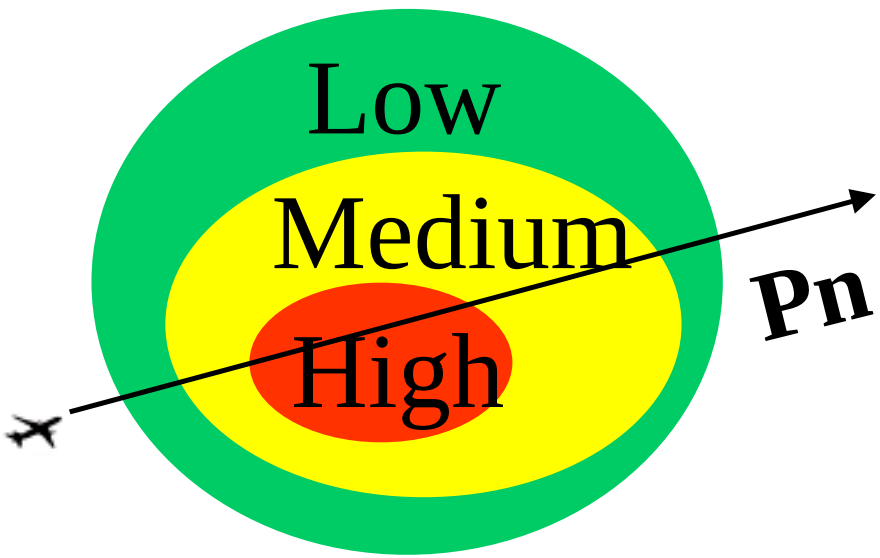
$$\text{Total Risk} = R_{Pn} \times p_{o|r} \times R_{Po} + R_{Pn} \times (1-p_{o|r})$$

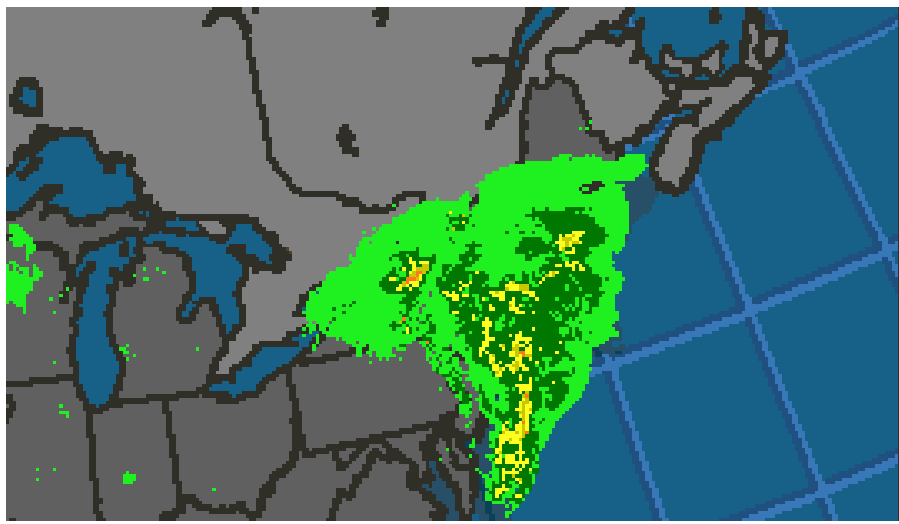
Implications for Risk Assessemen

- **Information Need on Risk Density Field**
  - Should Be Relevant to Specific Weather Phenomena
    - Icing
    - Convective Weather
    - Volcanic Ash
    - Turbulence
    - Continued VFR Into IMC
  - It May Be Desirable to Reduce the Threat Field Representation to a Discrete Set of Risk Density Levels, Due to:
    - Limitations of Weather Surveillance
    - Evidence that People Do Not Assess Probabilities Well
    - Need for Operationally Meaningful Information
- **Availability of Options Given the Risk Density Field**

Discretized Risk Density Field

$$R_{Pn} = \rho_{low}\Delta s_{low} + \rho_{medium}\Delta s_{medium} + \rho_{high}\Delta s_{high}$$



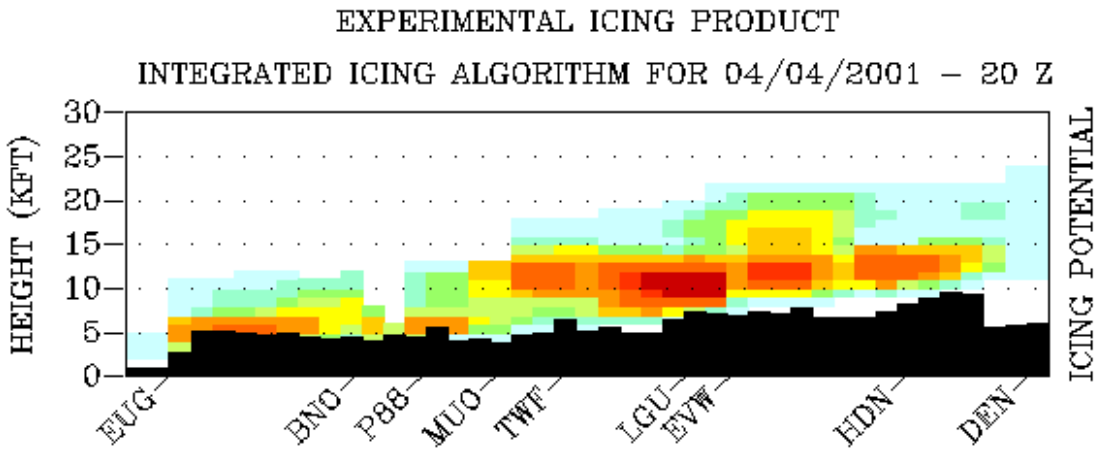


E.g., Pencil-Beam Radar Reflectivity (dBZ) Found to Be a Successful Classifying Variable for Predicting Aircraft Penetration versus Deviation in Convective Weather (MIT Lincoln Lab, 2000)

Approach Applied to Icing Collaboration with NCAR

- **No Direct Risk Density Surrogate Available**
  - Necessary to Combine Several Atmospheric Variables to Assess Icing Environment Threat Field
    - Temperature
    - Liquid Water Content or Humidity Measurements
    - Droplet Size Distribution

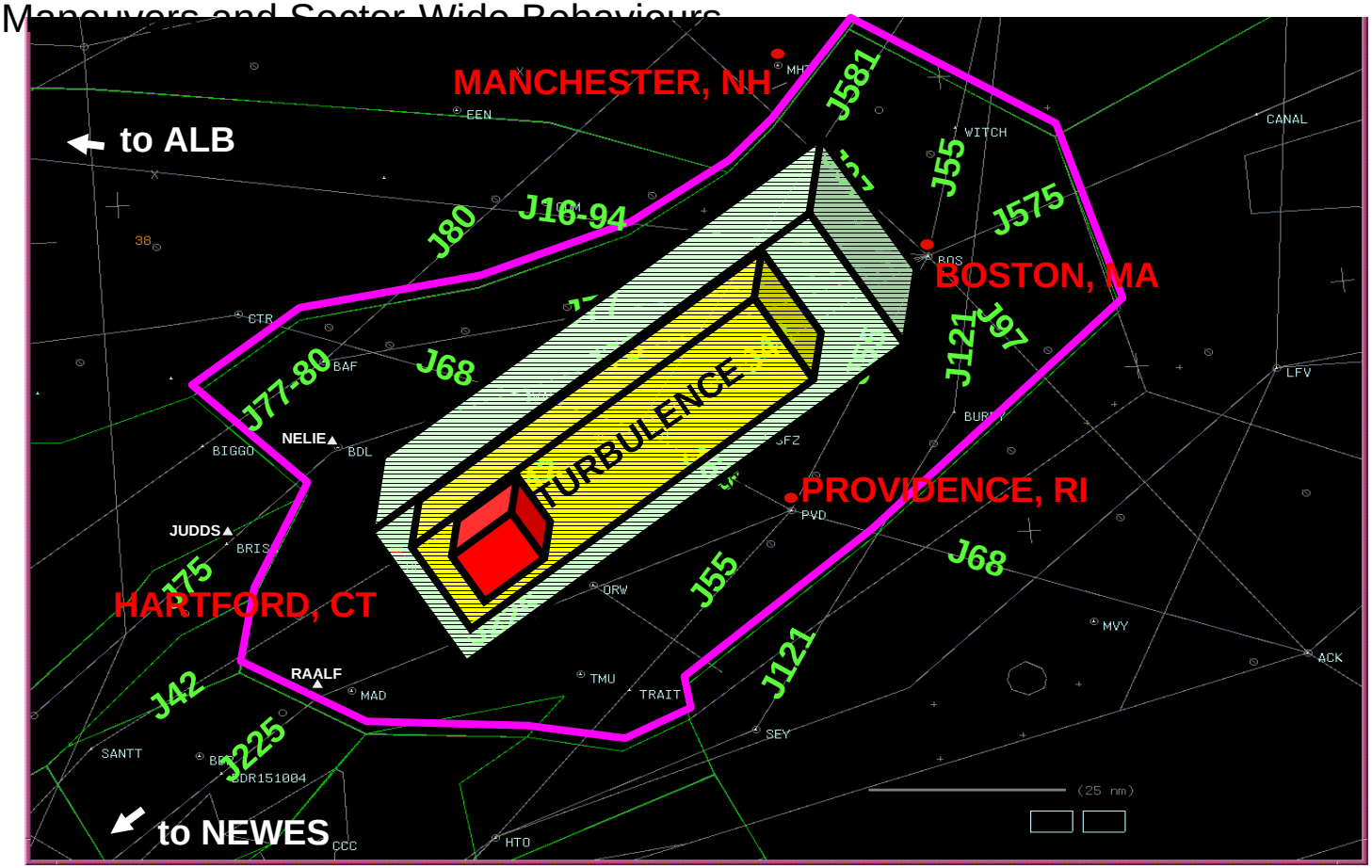
- **NCAR Objective: Risk Density Field that Integrates**
  - Probability (Likelihood)
  - LWC Intensity?
  - Icing Type
  - Intermittency
  - Hazard-Free Areas / “Options”



- **Establishing Relationships Between Measurable Parameters May Call Upon Fuzzy Logic Approaches**
  - Enables Correlating Perceived Risk with Different Levels of Measurable Parameters

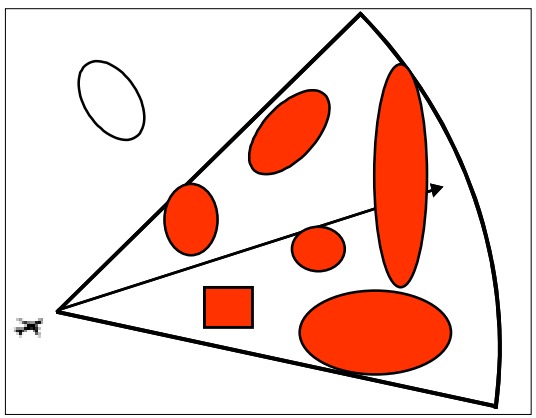
On-Going Study on Information Needs on Range to Support Avoidance

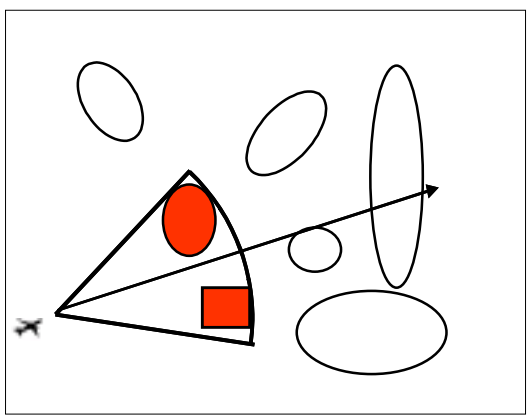
- **Fast-Time Simulation of Clear Air Turbulence (CAT) with NASA Safety-Simulation Group (NASA Ames, ATAC, UC Berkeley, Georgia Tech, SJSU, NASA GRC)**
  - Measure Impact of Airborne CAT Sensor Range & PIREP Information on Avoidance Maneuvers and Sector-Wide Behaviours



On-Going Studies on Information Needs on Range to Support Avoidance

- **Abstracted Probabilistic Spatio-Temporal Risk Field Experiment**
  - Hypothesis
    - Identification of minimal useful sensor range for detecting adverse weather phenomena (e.g., convective weather, aircraft icing, clear air turbulence, volcanic ash, etc.), in relation to the phenomena's scale (e.g., line versus air mass thunderstorms)
  - Independent Variables
    - Range of a look-ahead sensor
    - Effective size of distributed threat targets (described in a 2D reference frame using polar coordinates)
    - Position accuracy of the distributed threat targets beyond the look-ahead sensor range





Summary

- Risk Characterization Model Transforms Observable Variables of Adverse Weather Field Into Spatio-Temporal Risk Density Field
- Probability Assessment of Model Indicates Needs to Incorporate Information on Availability of “Options”
- It is Hypothesized that the Model Can Serve as Conceptual Basis for Identifying Key Features of Information for Operational Risk Assessment
- The Model Will Be Further Developed and Tested with Weather Examples (I.e., Icing, Clear Air Turbulence)