# *Air Force Weather Agency*

*Integrity - Service - Excellence*


U.S. AIR FORCE

# Supporting Transport & Dispersion Modeling with Stochastic Weather

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# Overview

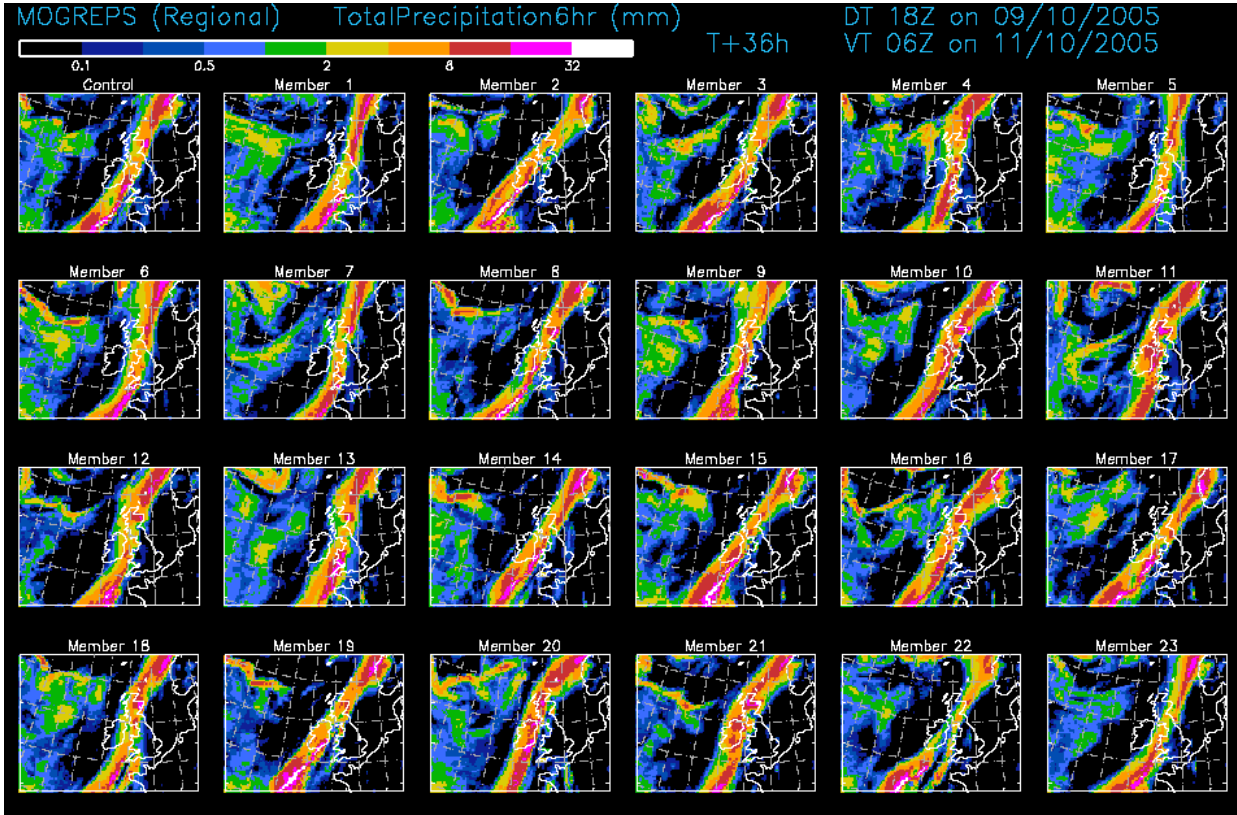
- **Background**
  - Definitions
  - Why ensembles?
- **Theory**
  - Deterministic vs. Stochastic Weather
  - Limitations
- **Development**
  - Joint Ensemble Forecast System (JEFS)
  - Ensemble Prediction System (EPS)
- **Application & Education**
  - Forecast Process
  - Warfighter Decision Making

# Background

# Definitions

- **Stochastic Weather:** Description of the spectrum of possibilities for the state of the atmosphere
- **Ensemble Forecast:** (General) Multiple, unique forecasts for the same event
  - (Rigorous) Multiple, unique numerical weather prediction runs (*members*) for same valid period, capturing all sources of uncertainty

Sample Rigorous Ensemble
UK Met Office Global and Regional Ensemble Prediction System (MOGREPS)
- 25km Grid
- 36h Forecasts
- 24 Members
- Varied Analyses (EtKF)
- Varied Model (Stoch. Phys.)



**Ensemble Startup**

# Operational Center / Current Ensemble ...as of Dec 2007

***1992*** **The National Center for Environmental Prediction (NCEP)**

- **Global**: 30 members, 4/day, T126/L28 (~110 km), 15-day forecast
- **Limited Area**: 21 members, 32 km, 60-hour forecast

***1992*** **The European Centre for Medium-Range Weather Forecasts (ECMWF)**

- **Global**: 51 members, 2/day, T399/L40 (~ 35 km ), 14-day forecast

***1995*** **Fleet Numerical Meteorology and Oceanography Center (FNMOC)**

- **Global**: 18 members, 1/day, T119/L24 (~120 km), 10-day forecast

***1996*** **Canadian Meteorological Center (CMC)**

- **Global**: 16 members, 2/day, 10-day forecast

***1996*** **China Meteorological Agency (CMA)**

- **Global**: 21 members, 1/day, T213/L31 (~ 65 km ), 10-day forecast

***2000*** **Australian Bureau of Meteorology (BoM)**

- **Global**: 33 members, 2/day, T119/L19 (~ 120 km ), 10-day forecast

***2001*** **Japan Meteorological Agency (JMA)**

- **Global**: 51 members , 1/day, T159/L40 (~ 90 km ), 9-day forecast

***2001*** **Korean Meteorological Administration (KMA)**

- **Global**: 32 members, 1/day, T213/L40 (~ 65 km ), 8-day forecast

***2007*** **United Kingdom Meteorology Office (UKMet)**

- **Global**: 24 members, N114/L38 (~120 km), 72-hour forecast
- **Limited Area**: 24 members, 25 km, 36-hour forecast

# Why Ensembles for USAF?

- **Ensemble Forecasting (EF) provides objective, high quality *stochastic weather* to enable optimal decision making for:**
  - **<u>Effectiveness</u>: Maximize Mission Capability**
  - **<u>Efficiency</u>: Conserve Resources**

- ***<u>Letter to Airmen: Air Force Smart Operations 21</u>* (SECAF, Mar06)**
  ***"…a dedicated effort to maximize value and minimize waste in our operations."***

  **"*AFSO 21 signifies a shift in our thinking…innovative ways to use our material and personnel more effectively*."**

- **<u>AF Policy Directive 90-9</u> – *"All Air Force personnel will apply ORM principles, concepts, and techniques to assess the risks associated with their daily mission and duty-related activities."***

# Deterministic Wx vs. Stochastic Wx Application

**Mission:** C17 needed to deliver urgent equipment and supplies from CONUS to Pakistan for covert, special ops anti-terrorism operation. Air Refueling required.

## Current Scenario
**(deterministic wx support)**

**Wx fcst for primary AR track:**
Sky: CLR
Vis: 7+ miles
Turb: MDT-SVR FL180-300
Icing: Neg
TSTMS: ISOLD

**Action:** C17 plans to use alternate refueling track. Refueling successful.

**Result:** Mission accomplished

**Cost:** Supplemental KC10 costs due to alternate track
- flight time: 2.5 hr (crew stress)
- fuel: 42,000 lbs ($27K)

## Future Scenario
**(stochastic wx support)**

**Wx fcst for primary AR track:**
Sky: CLR
Vis: 7+ miles
Turb: 25% chance > MDT
Icing: Neg
TSTMS: 15% chance

**Action:** C17 plans to use primary track (accept known risk). Refueling successful.

**Result:** Mission accomplished

**Cost:** Maximized efficiency and minimized cost through enabling of ORM

# Theory

# Causes of NWP Uncertainty

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## Source Data

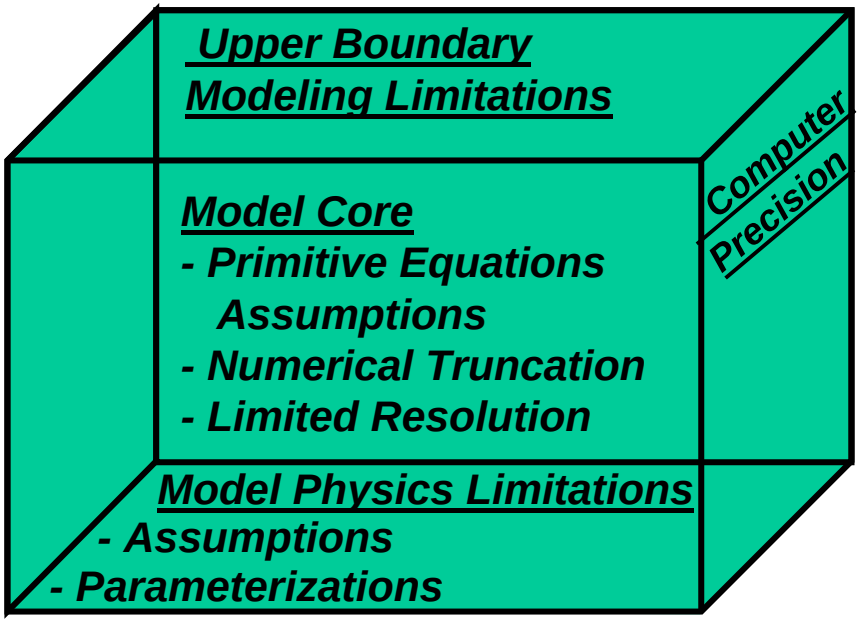
***Initial Conditions***
- *Erred Observations*
- *Incomplete Observations*
- *Limitations to Data Assimilation*

***Lateral Boundary Conditions (for LAM)***
- *Inaccuracies*
- *Discontinuous*

*NWP Model*

***Lower Boundary Conditions***
- *Incomplete and Erred Surface Temperature, Soil Moisture, Albedo, Roughness Length, …*

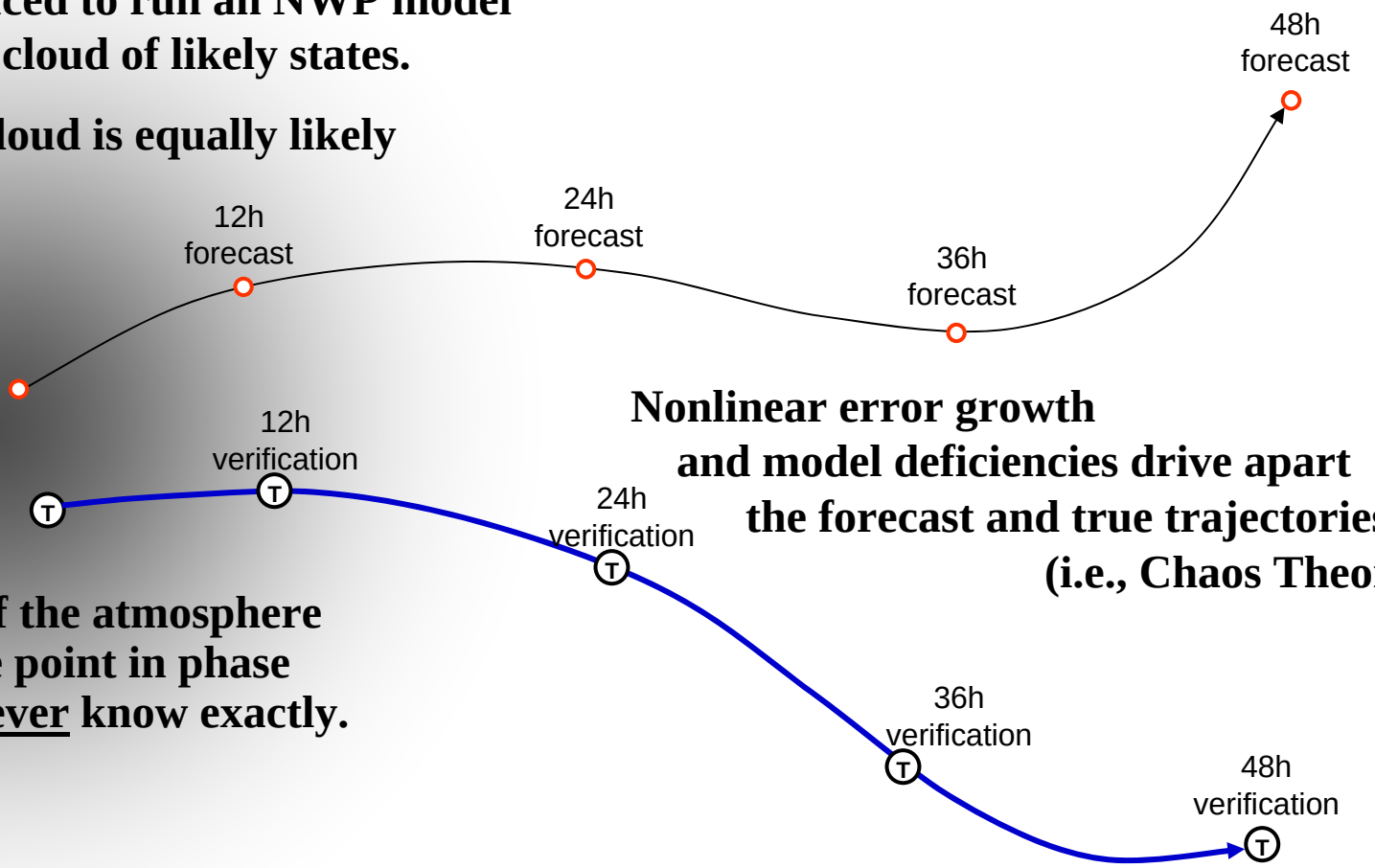
## Computational



# Deterministic Forecasting Limitations

**An analysis produced to run an NWP model is somewhere in a cloud of likely states.**

**Any point in the cloud is equally likely to be the truth.**




**Nonlinear error growth and model deficiencies drive apart the forecast and true trajectories (i.e., Chaos Theory)**

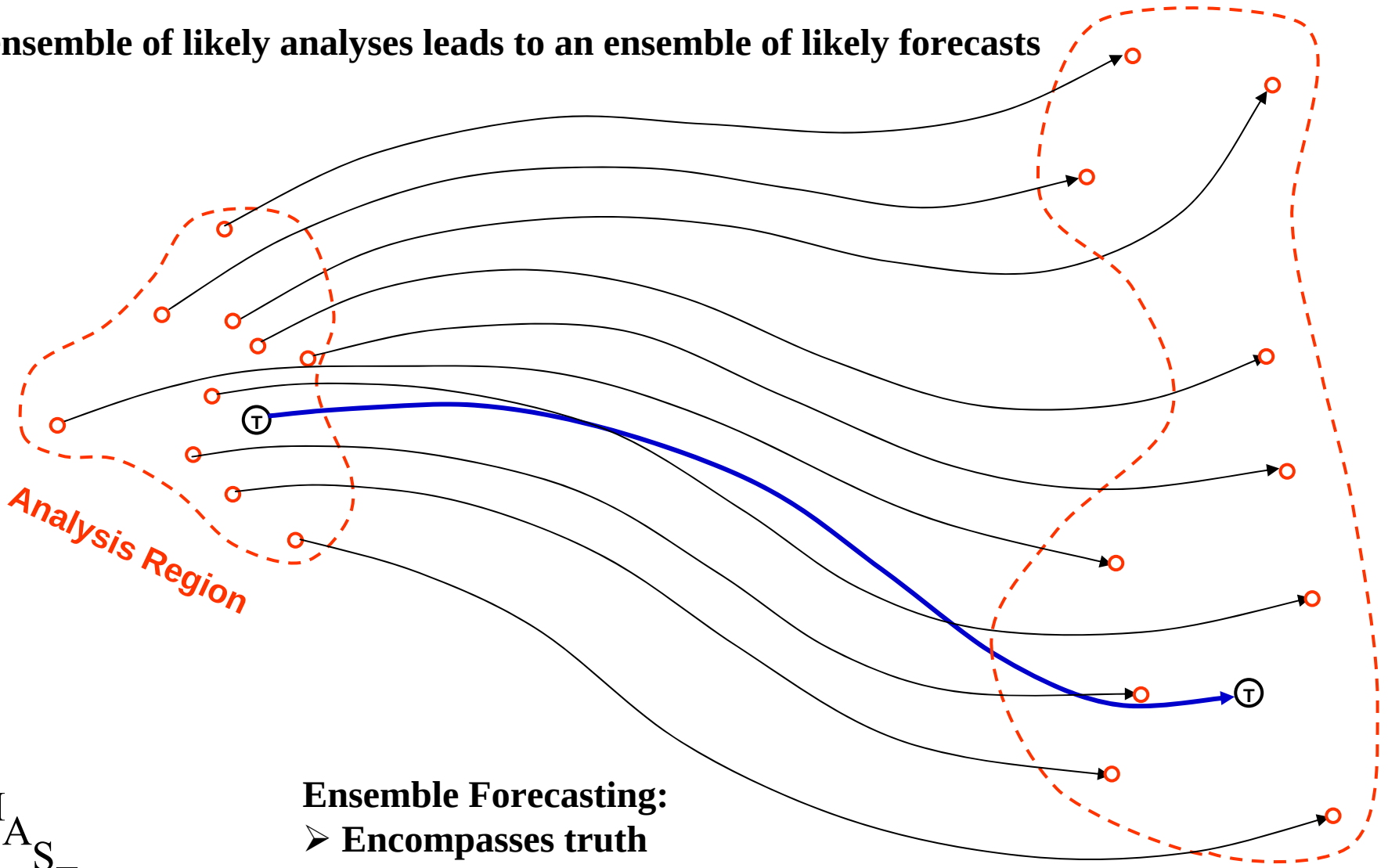
**The true state of the atmosphere exists as a single point in phase space that we <u>never</u> know exactly.**

PHASE SPACE

***A point in phase space completely describes an instantaneous state of the atmosphere. (pres, temp, etc. at all points at one time.)***

# Ensemble Forecasting, a Stochastic Approach

**An ensemble of likely analyses leads to an ensemble of likely forecasts**




PHASE SPACE

**Ensemble Forecasting:**

- **Encompasses truth**
- **Reveals flow-dependent uncertainty**
- **Yields objective stochastic forecast**

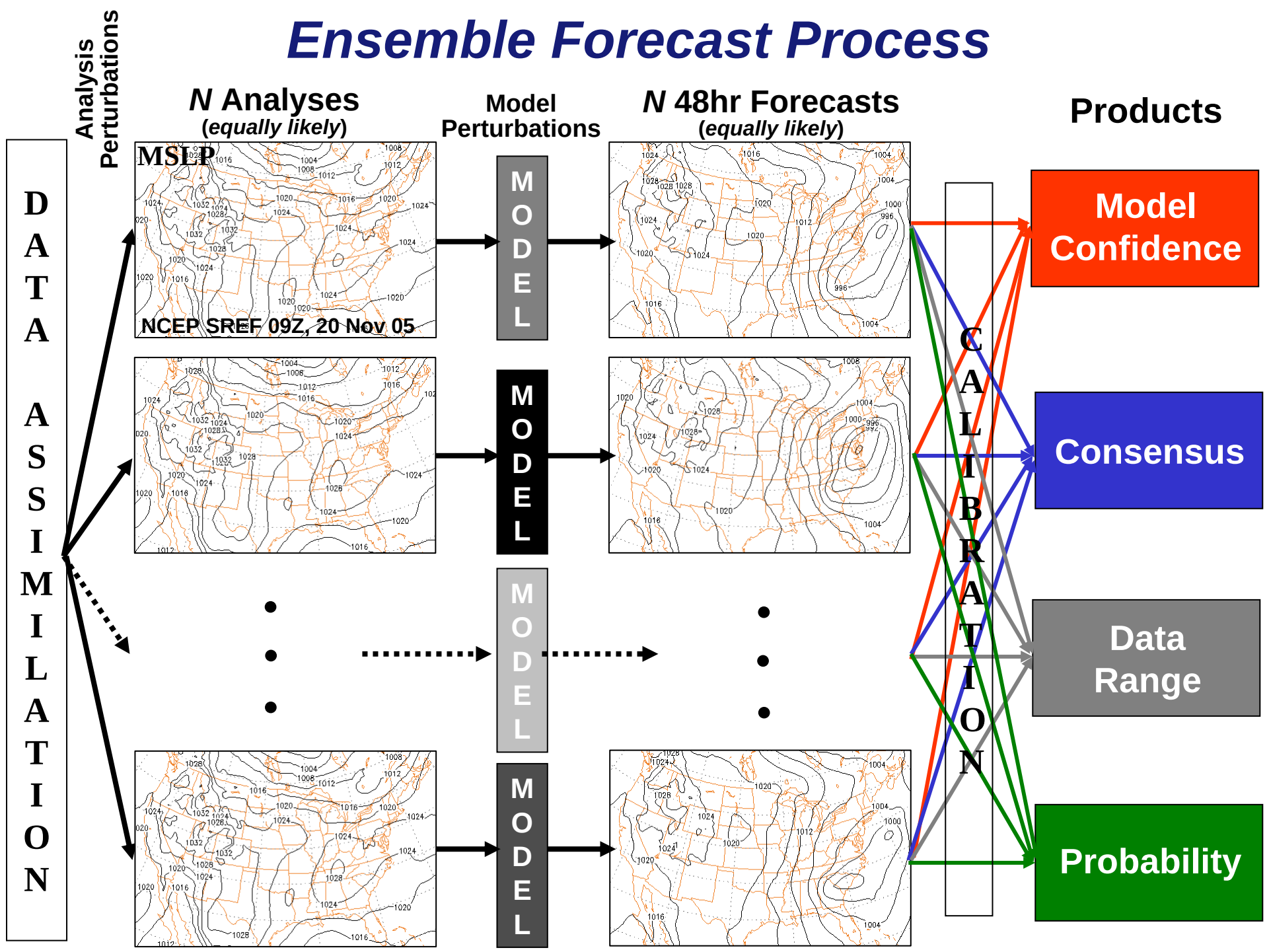
# Limitations

- Stochastic Weather is not a panacea
  - Only required when *uncertainty* exceeds operational *sensitivity*
  - Ensembles quantify uncertainty…doesn't ELIMINATE it !
  - Operator still susceptible to unfavorable outcomes
  - KEY: Minimize impact from unfavorable outcomes

- Short Falls of raw ensemble (*or deterministic*) output
  - Limited # of members
  - Model bias
  - Insufficient accounting for initial and model error
  - Insufficient model resolution
  - ANSWER: Calibrate to adjust raw output

# Development

# Ensemble Forecast Process

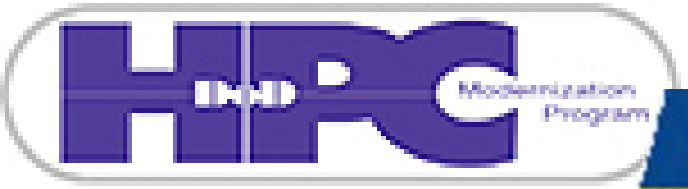


# The Joint Ensemble Forecast System

# JEFS

**GOAL: Prove the value, utility, and operational feasibility of EF to DoD operations.**

**FOCUS: How to best exploit EF output within forecasting and decision processes.**

















NCAR

# Joint Global Ensemble (JGE)

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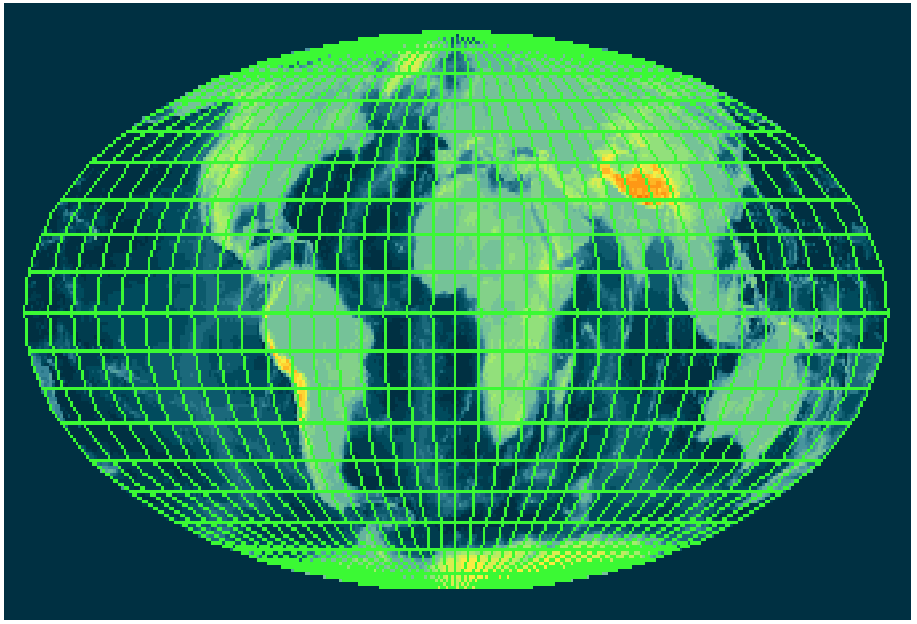
- *Description*: **Combination of current GFS and NOGAPS global, medium-range ensemble data. Possible expansion to include ensembles from CMC, UKMET, JMA, etc.**
- *Initial Conditions*: **Ensemble Transform (GFS) and Breeding Modes[1] (NOGAPS)**
- *Model Variations/Perturbations*: **Two unique models, but no model perturbations**
- *Model Window*: **Global**
- *Grid Spacing*: **1.0°× 1.0° (~80 km)**
- *Number of Members*: **46 at 00Z**
  **30 at 12Z**
- *Forecast Length/Interval*: **10 days/6 hours**
- *Timing*
  - **Cycle Times: 00Z and 12Z**
  - **Products by: 07Z and 19Z**



[1] Toth, Zoltan, and Eugenia Kalnay, 1997: Ensemble Forecasting at NCEP and the Breeding Method. *Monthly Weather Review*: Vol. 125, No. 12, pp. 3297–3319.

# Joint Mesoscale Ensemble (JME)

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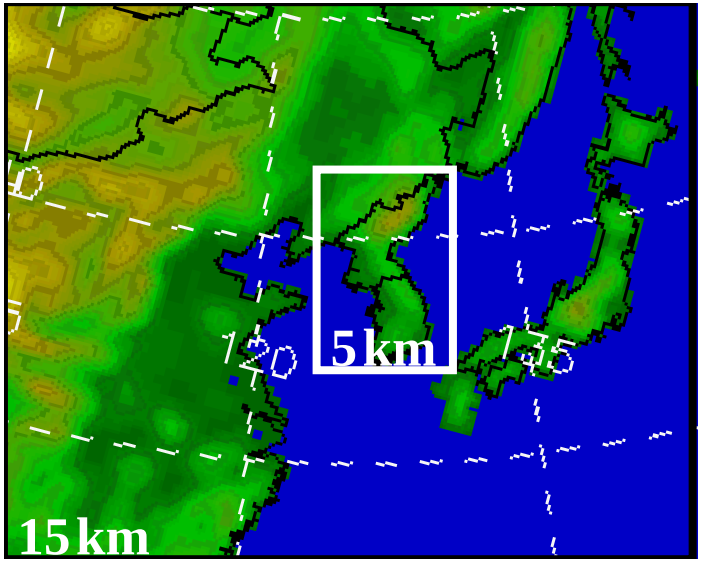
- *Description*: Multiple high resolution, mesoscale model runs at FNMOC and AFWA
- *Initial Conditions*: Ensemble Transform Filter[2] run on short-range (6-h), mesoscale data assimilation cycle driven by GFS and NOGAPS ensemble members
- *Model variations/perturbations*:
  - Multimodel: WRF-ARW, COAMPS
  - Varied-model: various configurations of physics packages
  - Perturbed-model: perturbed surface boundary conditions (e.g., SST)
- *Model Window*: East Asia (COPC directive, Apr '04)
- *Grid Spacing*: 15 km for baseline JME (fall '06)
  5 km nest (in summer '07)
- *Number of Members*: 20-30 (½ AFWA, ½ FNMOC)
- *Forecast Length/Interval*: 60 hours/3 hours
- *Timing*
  - Cycle Times: 06Z and 18Z
  - Products by: 11Z and 23Z

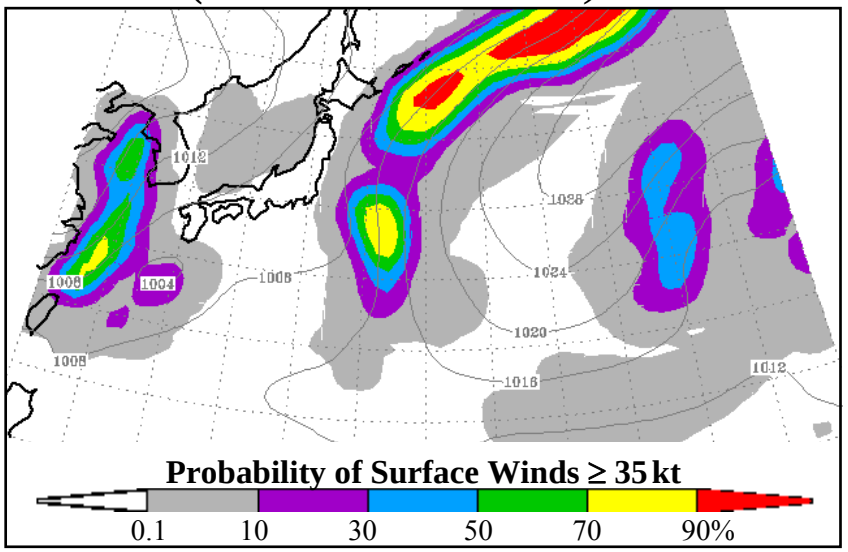
  } ~5 h production /cycle




[2] Wang, Xuguang, and Craig H. Bishop, 2003: A Comparison of Breeding and Ensemble Transform Kalman Filter Ensemble Forecast Schemes. *Journal of the Atmospheric Sciences*: Vol. 60, No. 9, pp. 1140–1158.

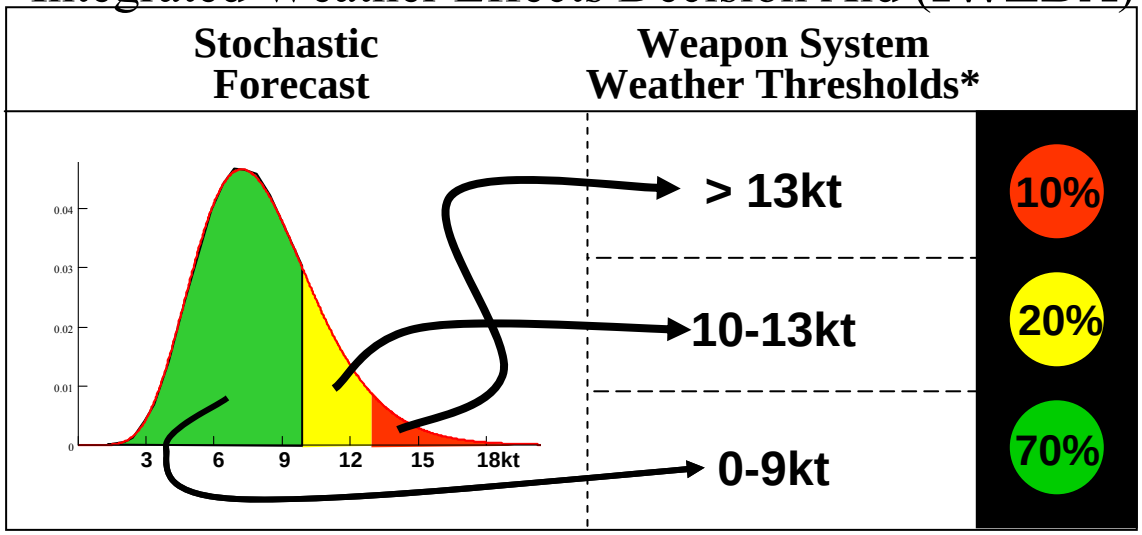
# Need Tools to Bridge the Gap

## Characterize the Environment
*(Stochastic Forecast)*




## Integrate and Exploit
*(Binary Decisions/Actions)*


## Integrated Weather Effects Decision Aid (**IWEDA**)

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# Application
# &
# Education

# Weather Risk Analysis and Portrayal (WRAP)

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*Given uncertain weather, lower acceptable risk means less certainty in the desired outcome.*

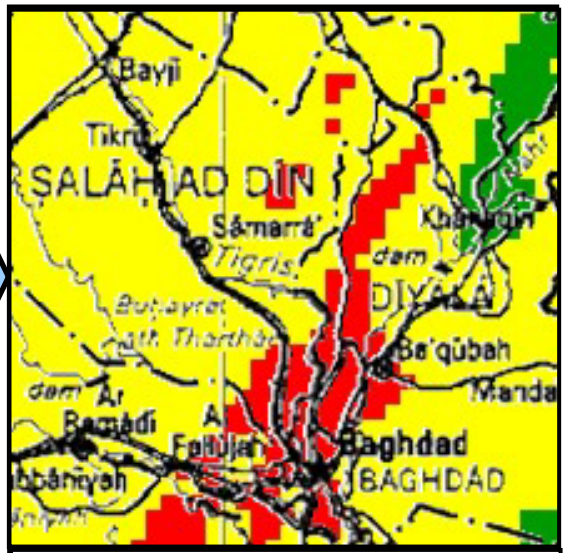
Stochastic Weather Data

Warfighter Risk Tolerance

IWEDA Rules

## WRAP

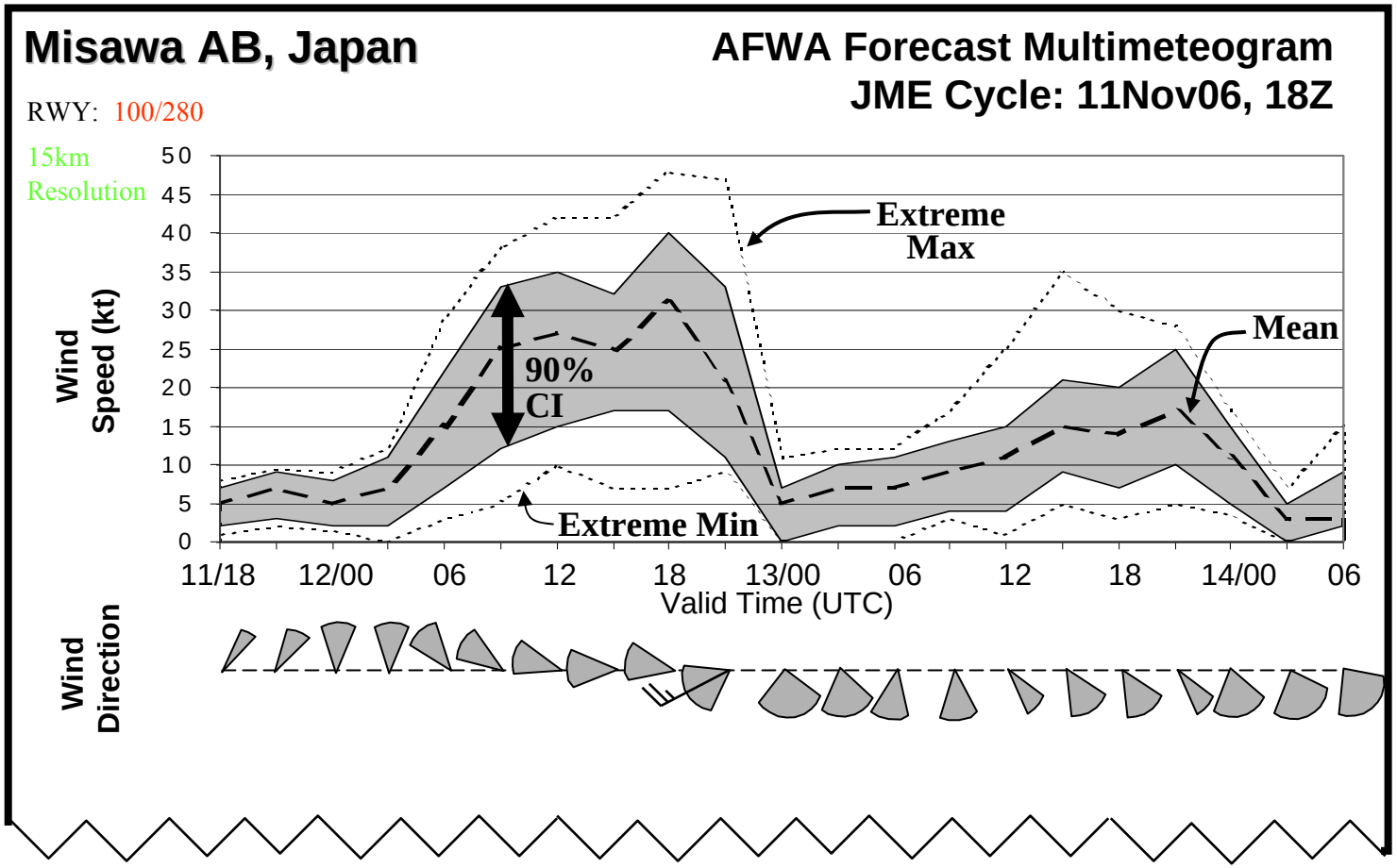
- ORM calculations
- Stop-light style decision inputs
- Portrayal Techniques




**Wx Risk Visualization**
(**low** risk tolerance)

# Sample JME Product:

## Multimeteogram



# Sample JME Product: Probagram *(Probabilistic Meteogram)*

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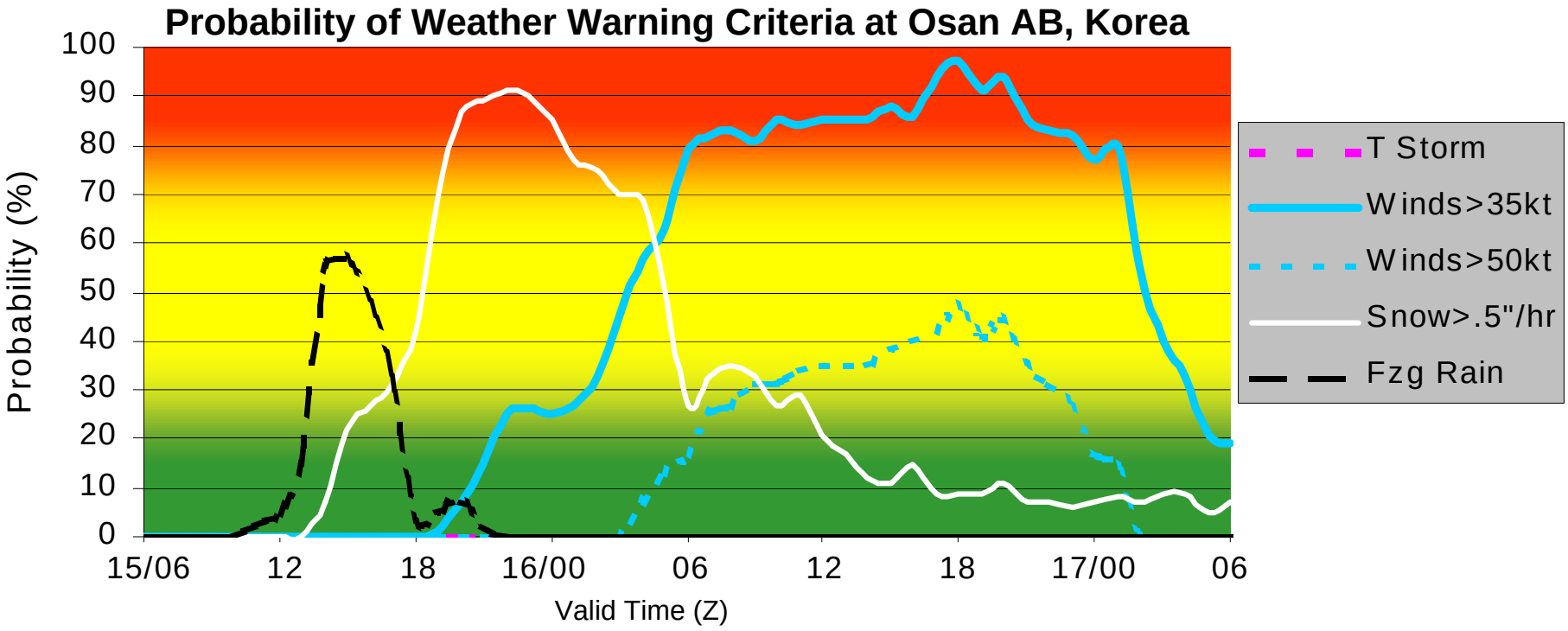
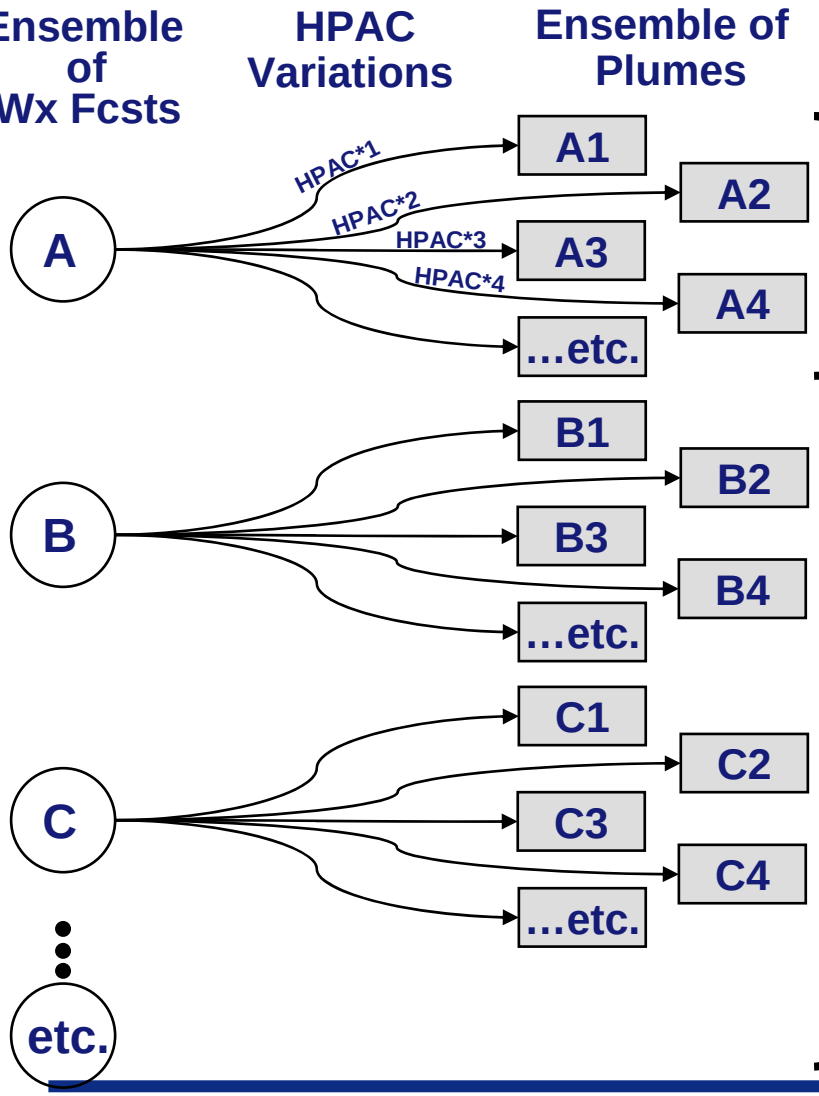
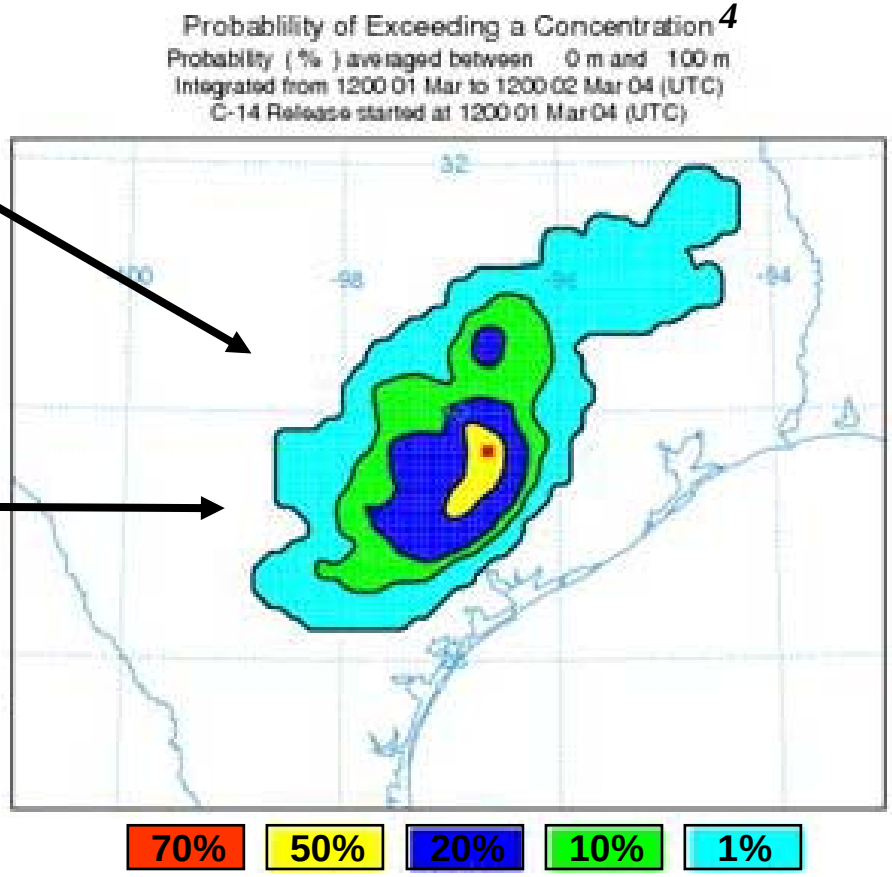



- **Probability of Lethality for Several Agents**
- **Probability of Threshold Concentration for Several Agents**

# Application to Dispersion Modeling



# Application to Dispersion Modeling

Ensemble of Wx Fcsts

A

B

C

D

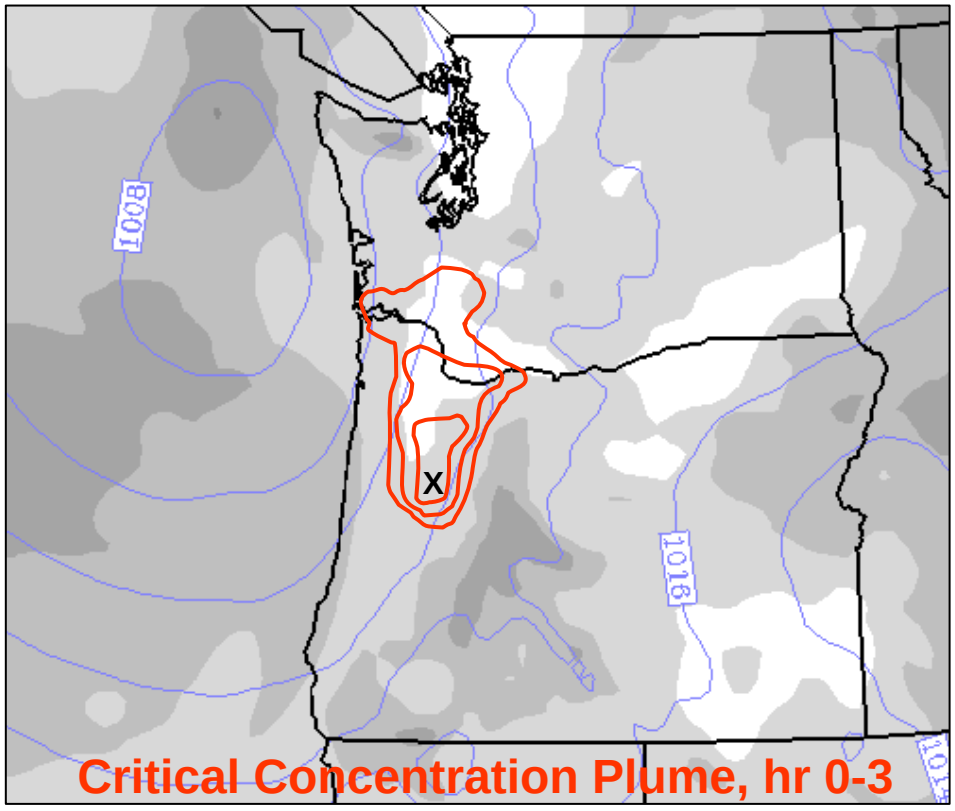
E

F

etc.

"Best Guess" Forecast Winds + Variance

HPAC With Uncertainty Information [5]




HIGH — LOW

Forecast Confidence

# Application to Dispersion Modeling

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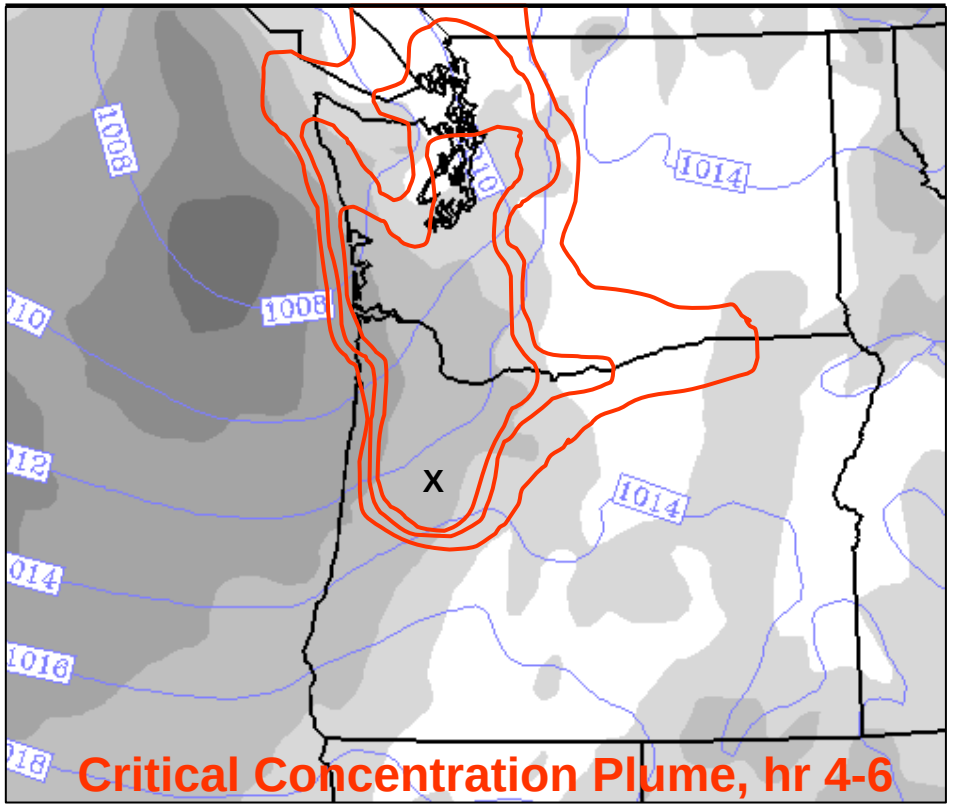
Ensemble of Wx Fcsts

- A
- B
- C
- D
- E
- F
- ...
- etc.

"Best Guess" Forecast Winds + Variance

HPAC With Uncertainty Information [5]



# Currently Available Forecaster Training

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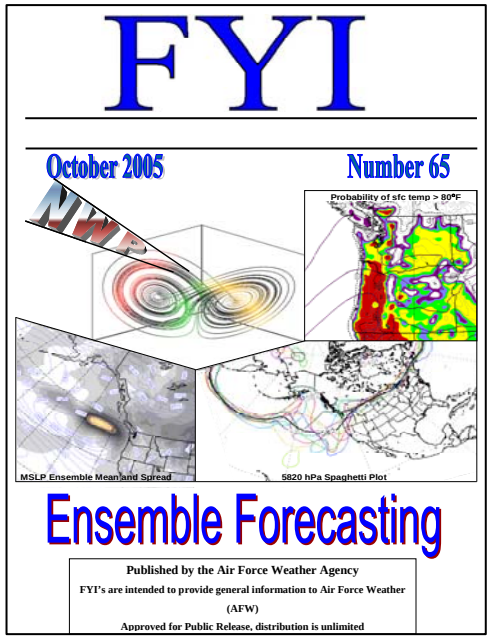
## Strengths

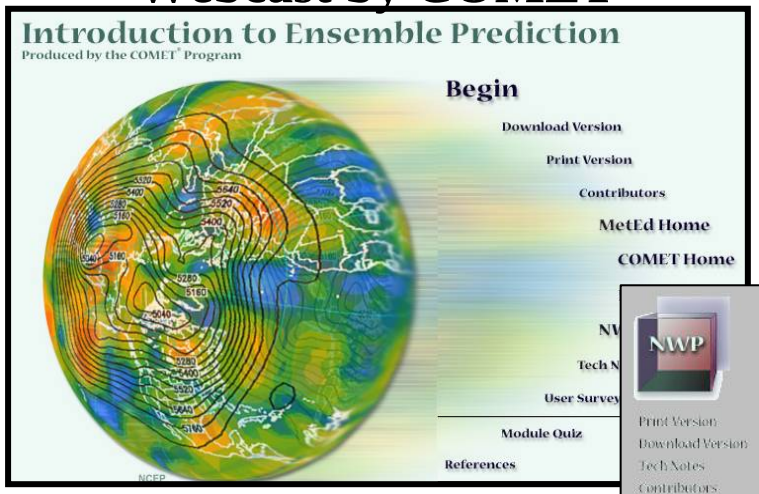
- Good for initial exposure
- Starts brainstorm for products and applications ideas
- Available, accessible, free...

## Weaknesses

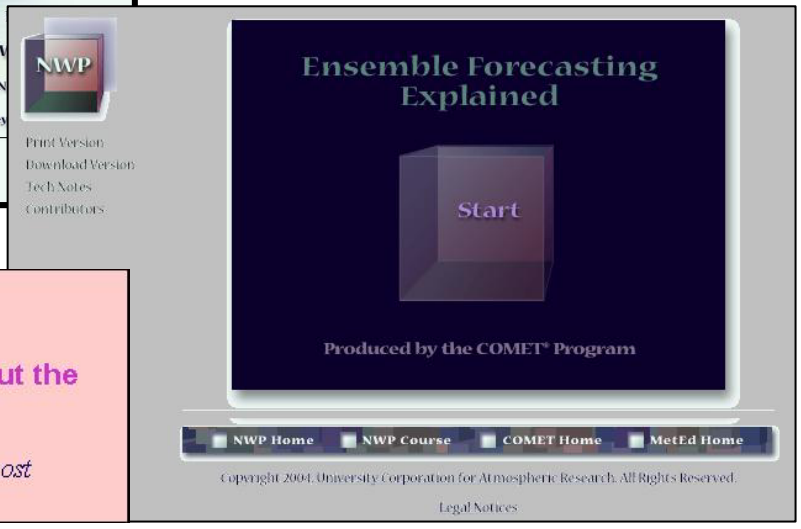
- Too scientific in places
- Weak on some key concepts
- Leaves forecaster hanging…
  - Limited application to today's forecast process
  - Missing customer interface



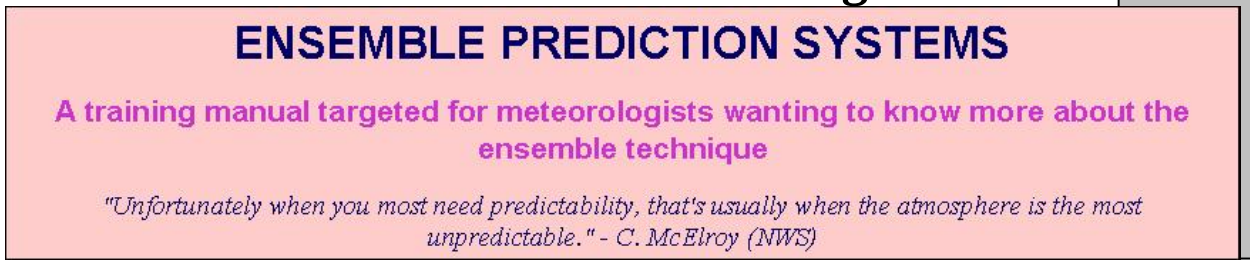

**Webcast by COMET**




**COMET module**




**National Weather Service training manual**



This ensemble stuff is useless!
Last time they said 80% chance of snow we didn't get a flurry
This time they said only 40%!

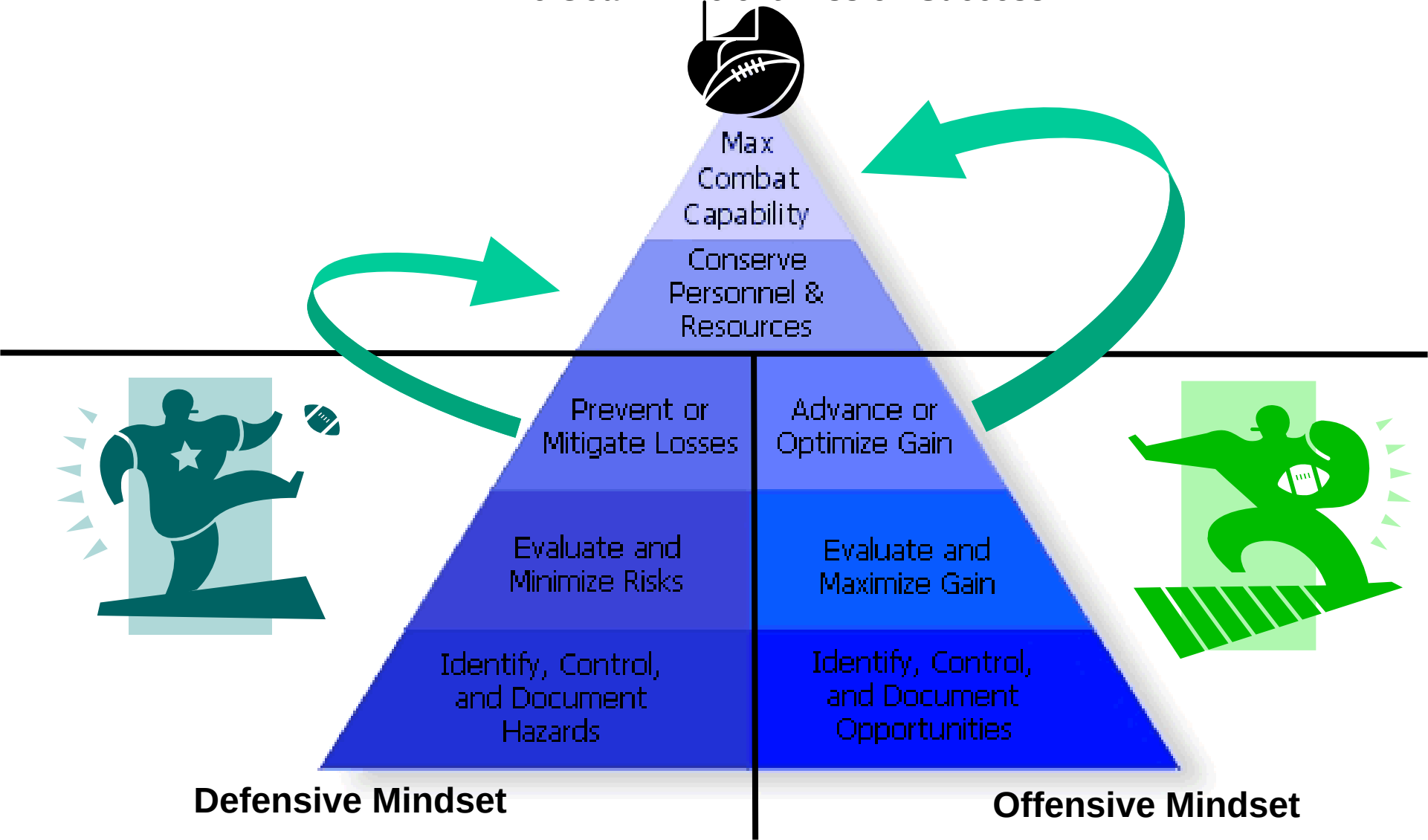
# Warfighter Education on using Stochastic WX

- **Warfighters should understand :**
  - **Benefits of stochastic vs. deterministic weather to ORM decision making**
  - **Optimal use of stochastic weather in both M2M and human decision making**

- **Recommend integration with warfighter training (i.e. schools, exercises, etc.)**

# Stochastic WX Optimizes ORM

**The Goal: Efficient Mission Success**




**Defensive Mindset**

**Offensive Mindset**

# Defensive ORM: Resource Protection

**Scenario – *Typhoon Approach at Kadena AB, Japan***

Critical Event: Surface Winds ≥ 50kt -- **Damaging to aircraft parked on the apron**

Loss (if damaged): $1M

Cost (of protecting): $150K -- Redeployment (fuel, TDY costs, etc.)

***Example Expense Over 2 Year Period**

| Typhoon Approach | Deterministic Operator (Decision Threshold = 50kt) | | | Stochastic Operator (Decision Threshold = 15%) | | |
|---|---|---|---|---|---|---|
| | Forecast Wind (kt) | Observed Wind (kt) | Cumulative Expense ($K) | Forecast Wind > 50kt | Observed Wind (kt) | Cumulative Expense ($K) |
| 1 | 12 | 20 | 0 | 9% | 20 | 0 |
| 2 | 36 | 44 | 0 | 17% | 44 | 150 |
| 3 | 77 | 81 | 150 | 99% | 81 | 300 |
| 4 | 43 | 62 | 1150 | 25% | 62 | 450 |
| 5 | 52 | 41 | 1300 | 33% | 41 | 600 |
| 6 | 28 | 29 | 1300 | 24% | 29 | 750 |
| 7 | 20 | 27 | 1300 | 1% | 27 | 750 |
| 8 | 32 | 23 | 1300 | 7% | 23 | 750 |

*Generated by computer simulation

# Defensive ORM: Resource Protection

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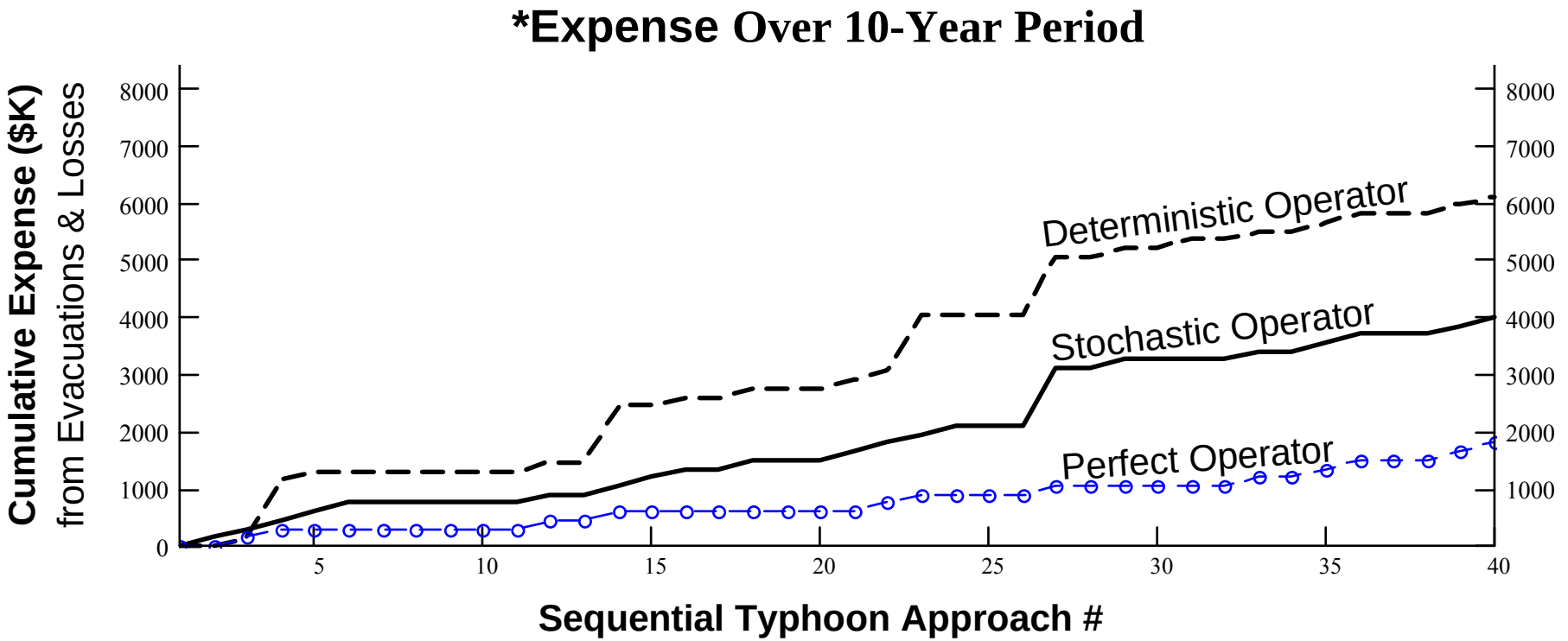


*Generated by computer simulation

# Summary

- **Ensemble forecasting provides objective stochastic weather**
  - **Technology well advanced, and can enable ORM…not just in a military setting**
- **Ensemble Capability is Coming…**
  - **JEFS results late 2008 will pave the way for future operational EPS**
  - **Joint prototype with Navy will create a DoD asset**
- **Education and training required to fully realize advantages**
  - **Forecaster – retrain to stochastic thinking**
  - **Warfighter – foster integration and exploitation of stochastic weather**

***"Stochastic weather allows us to exploit uncertainty, …rather than being at its mercy."***

***--- F. Anthony Eckel, Maj (PhD)***

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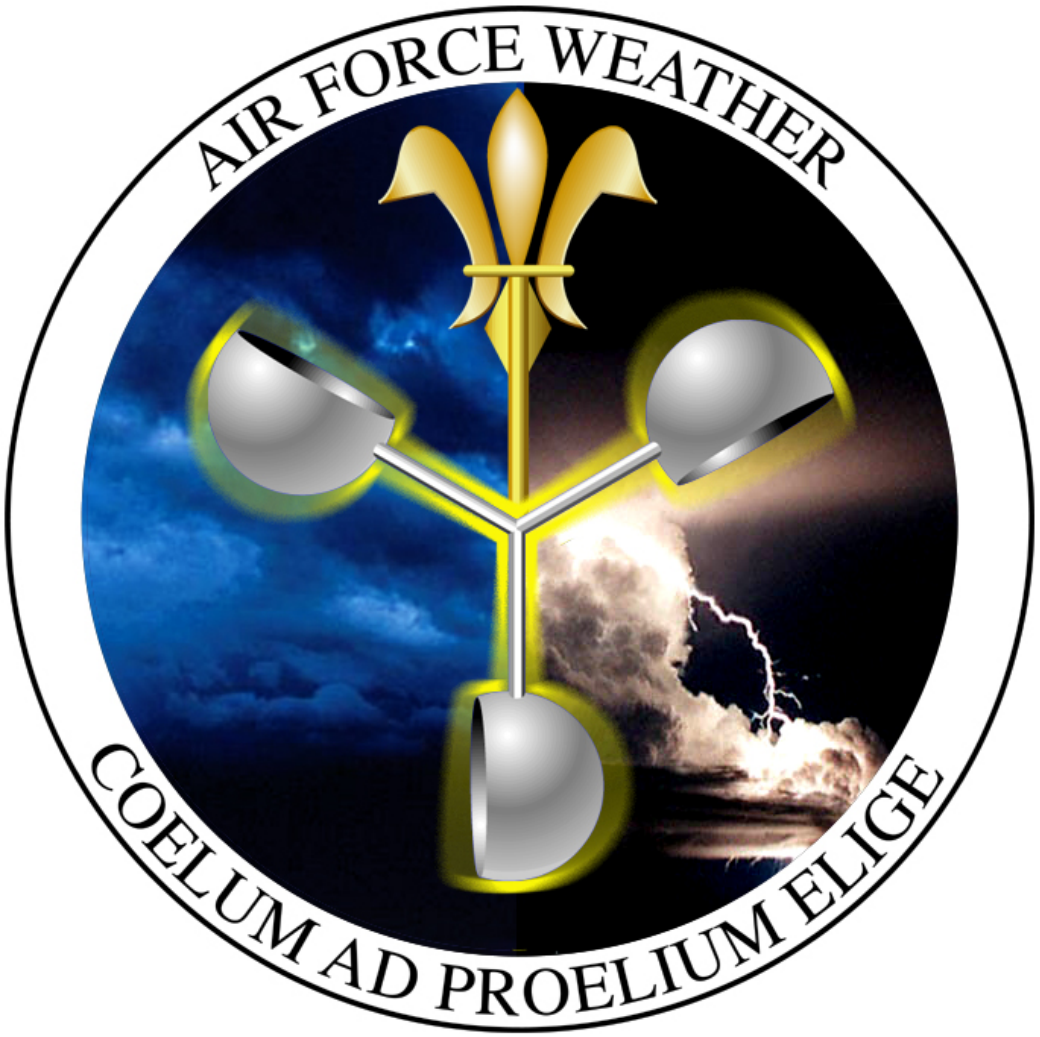


"Anticipate and Exploit the Weather for Battle"

# Backup Slides

# Notional Requirements for NWS Ensemble Data (by 2010)

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| | CONUS (WRF) Limited Area Ensemble | Global Mesoscale Ensemble |
|---|---|---|
| Model Domain | 1) CONUS (20N-55N, 135W-60W<br>2) Alaska (55N-73N, 170W-130W) | Global |
| Grid Spacing | 10 km | 25 km or spectral equivalent (~T565) with step down resolution beyond 48-h forecast lead time |
| Number of Levels | 60 | 40 |
| Ensemble Size | 20 Members | 20 Members |
| Cycle Frequency | 4 per day | 4 per day out to 72 h, with 2 of those cycles out to 240 h |
| Forecast Length/Interval | 48 h / 3 h | 72 h & 240 h / 6 h |
| Delivery Schedule | Incremental delivery starting NLT 3h after initialization time, complete NLT 5h after initialization time | *same* |
| Analysis Perturbations | Robust initial conditions (Ex: Ensemble Transform Kalman Filter) | *same* |
| Model Perturbations | Robust accounting for model uncertainty using single model framework with multiple physics combinations, physics perturbations, and/or stochastic physics. | *same* |
| Calibration | Robust correction for systematic errors, both 1$^{st}$ moment (bias correction) and 2$^{nd}$ moment (spread correction) of the ensemble distribution | *same* |

# WRAP Decision Input Processing

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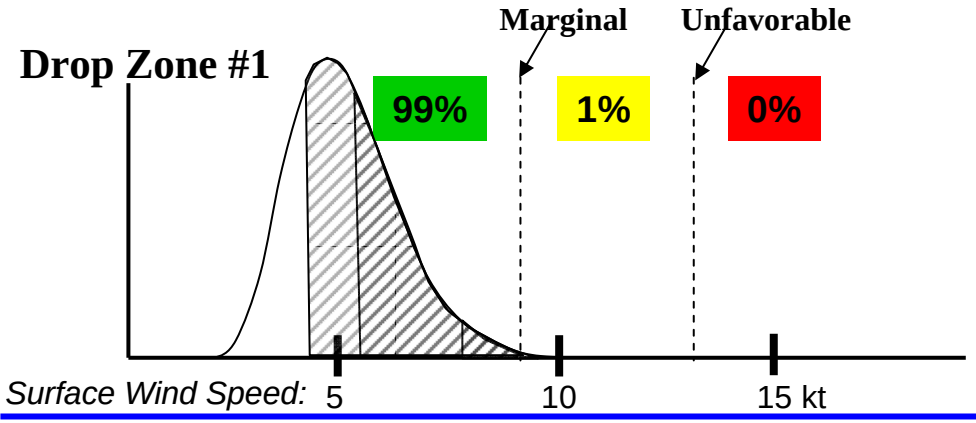
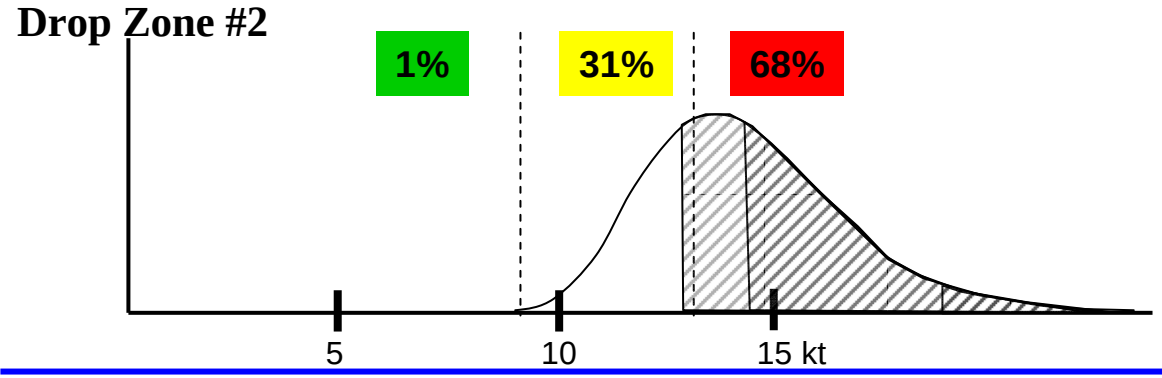
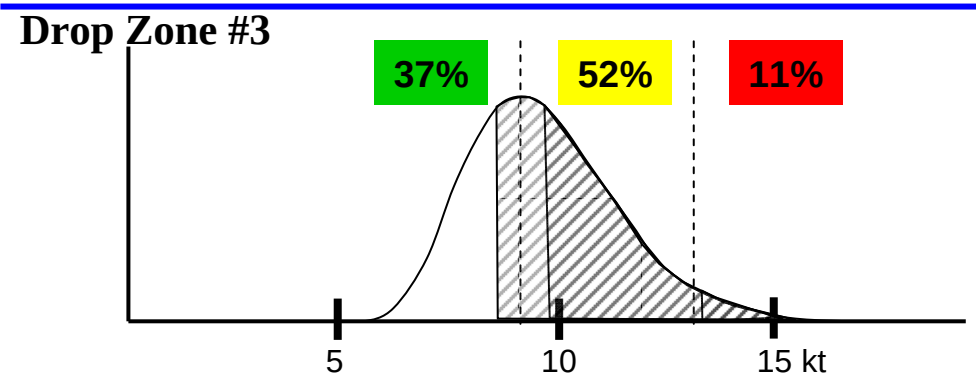


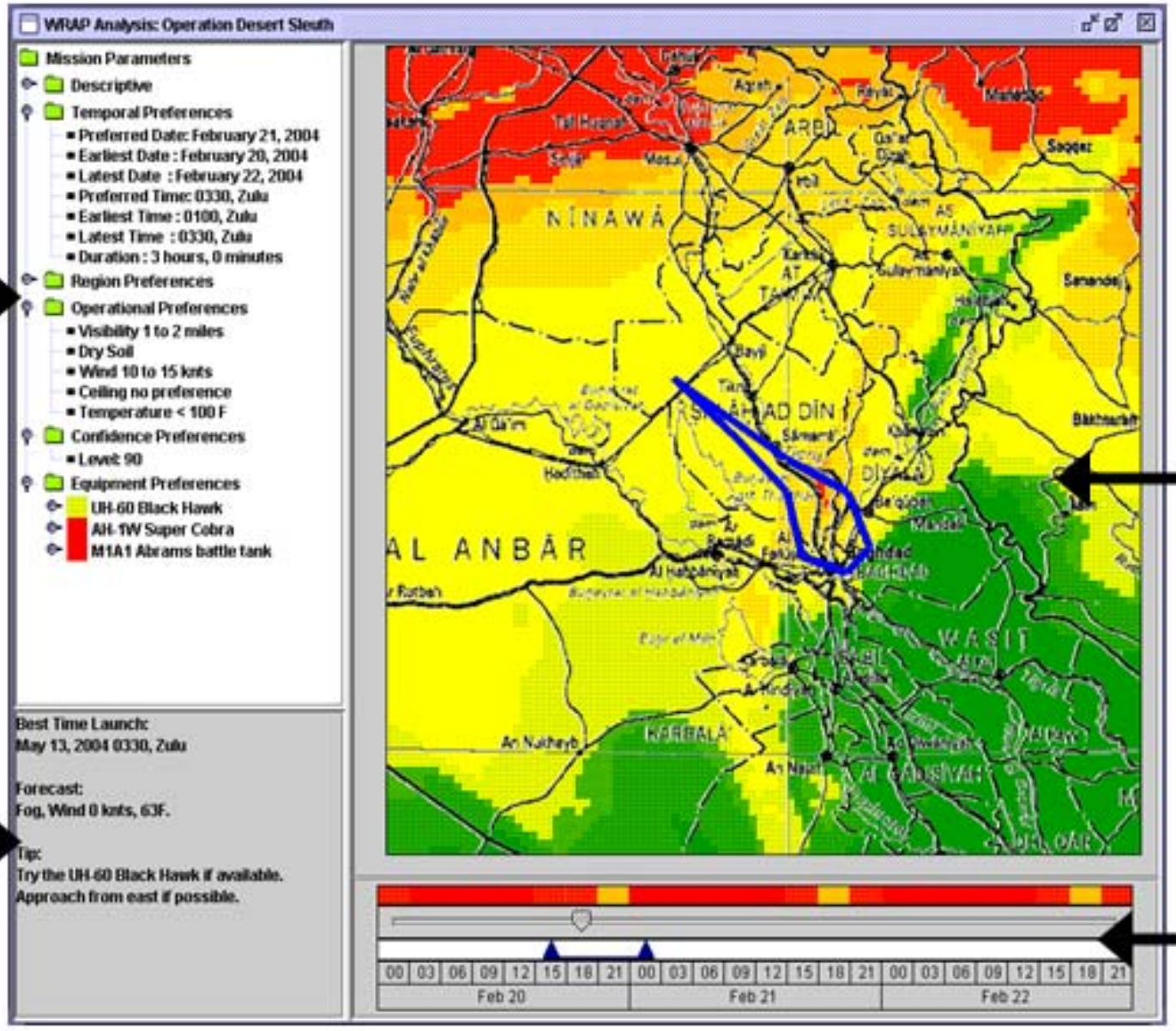




| Acceptable Risk | Decision Input |
|---|---|
| Low (Accept 10%) | |
| Med (Accept 40%) | |
| High (Accept 70%) | |

| | |
|---|---|
| Low | |
| Med | |
| High | |

| | |
|---|---|
| Low | |
| Med | |
| High | |

# WRAP Interface




Parameters and Preferences

Info Window

Map View

Temporal Controls

# Long Term EF Vision (2020)

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