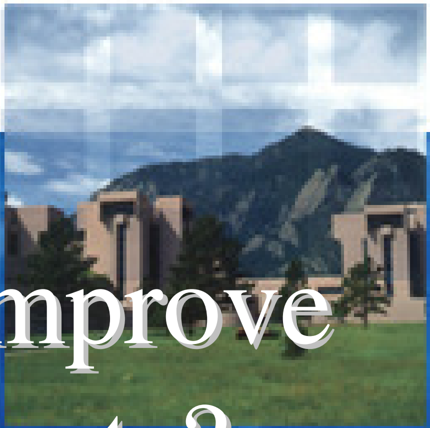
NCAR



Can turbulence information improve contrail susceptibility forecasts?

John K. Williams, Bob Sharman, Dave Duda,
David Johnson, and Pat Minnis

AMS 15th Conference on Aviation, Range and Aerospace Meteorology
Los Angeles, CA
August 3, 2011

National Center for Atmospheric Research

Impact of contrails

- Contrails and contrail cirrus alter the Earth's radiation balance
- IPCC (2007): aviation may contribute 2-8% of all anthropogenic radiative forcing, with 35-70% from contrails and associated cirrus

- Accurate contrail forecasts could facilitate decision-making to mitigate climate change
- NextGen Integrated Work Plan (2008) calls for a "consolidated probabilistic environmental forecast … of the sensitivity of atmospheric volumes to exhaust emissions"

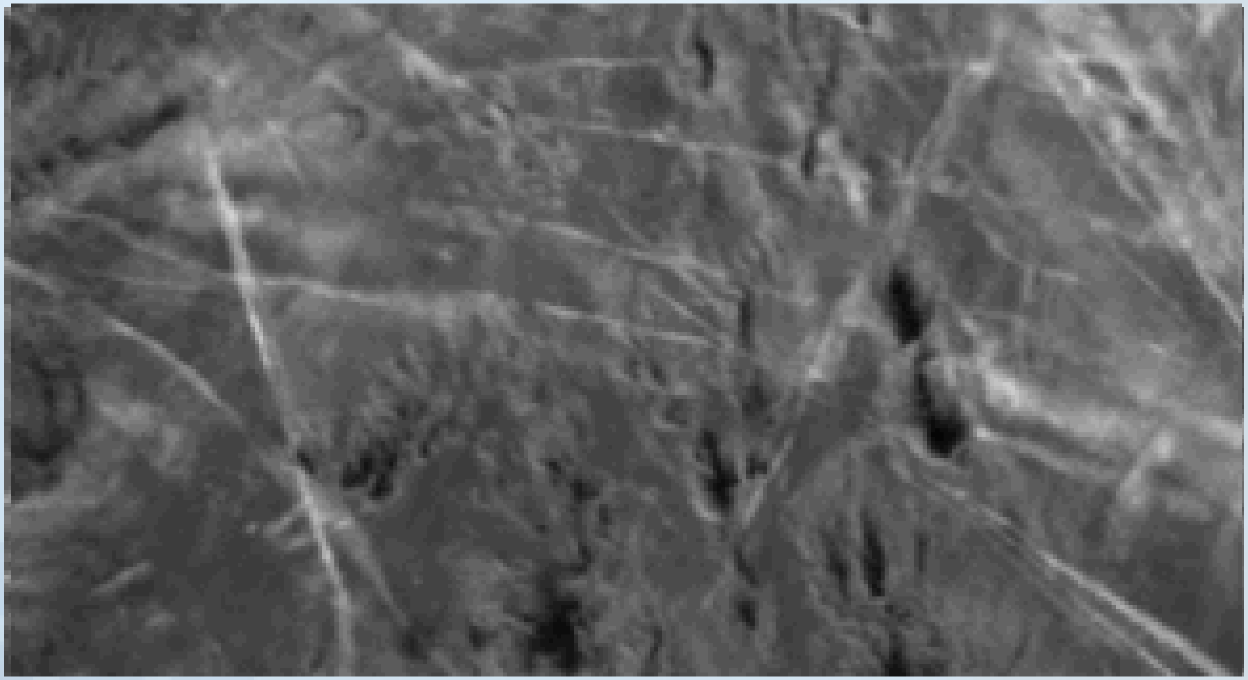
Hypothesis

NCAR

- **Atmospheric turbulence influences formation and longevity of contrails and contrail cirrus**
  - Low turbulence may inhibit mixing of exhaust CCNs with the surrounding atmosphere
  - High turbulence may accelerate breakup of contrails via vertical mixing
- **Adding turbulence variables to NWP-based contrail forecast models may improve their skill**

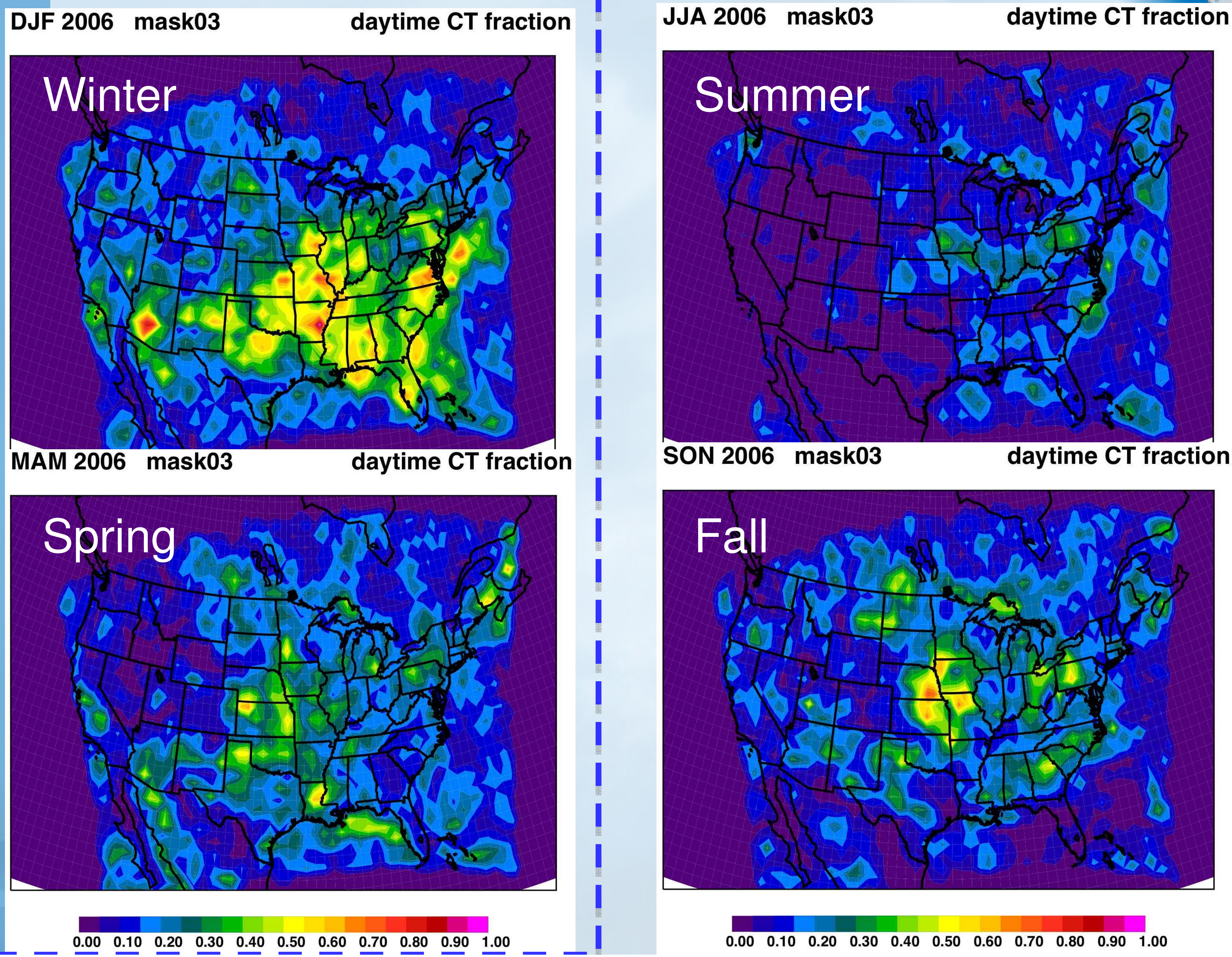
Contrail Detection Algorithm (CDA)

- Extends Mannstein et al. (1999) 2-channel algorithm to detect linear contrails in AVHRR IR imagery
- To reduce false detections, additional MODIS IR channels (6.7, 8.6, 13.3 μm) are added to the 11 and 12 μm channels



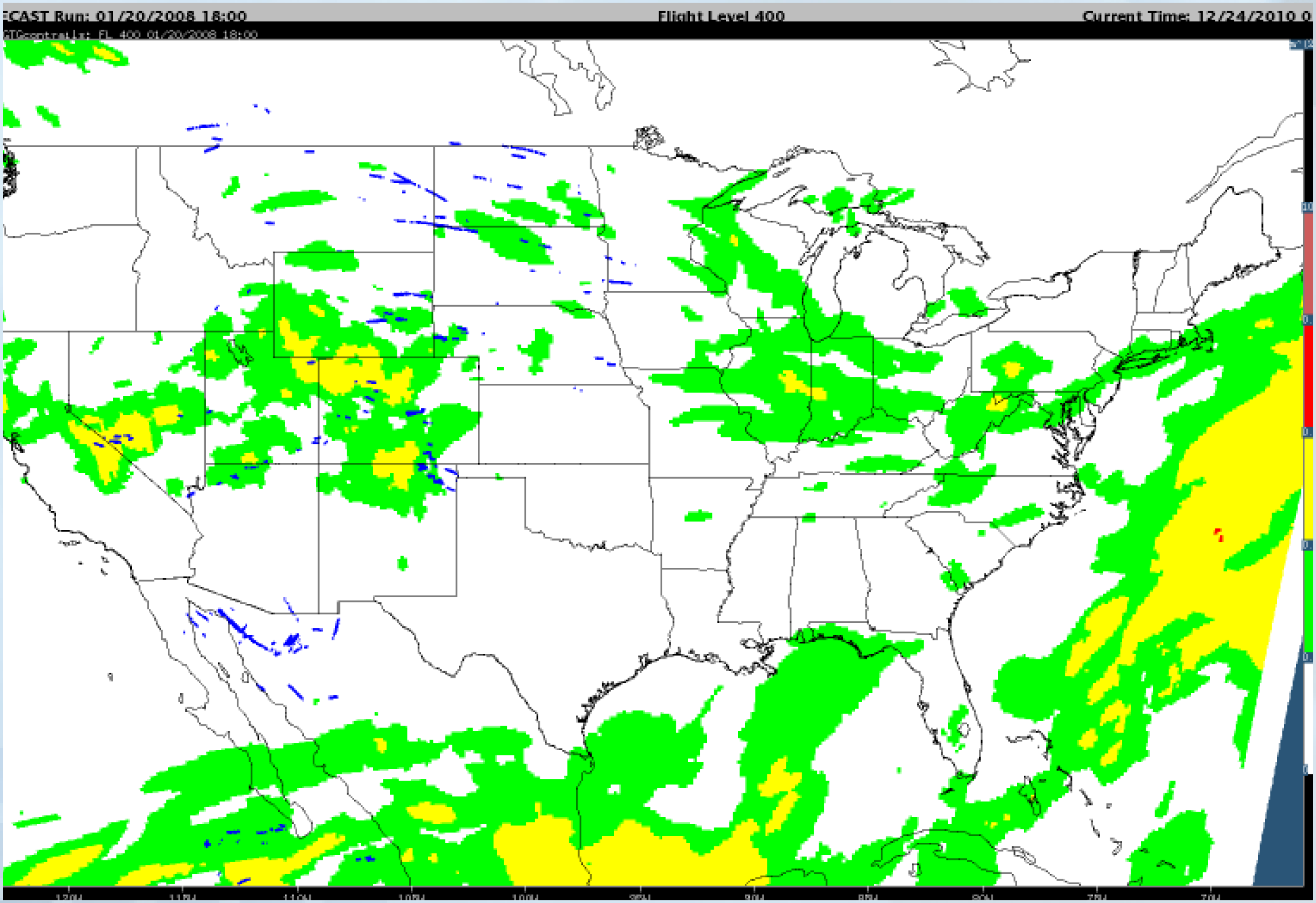
$$\mathbf{BTD_{11\text{-}12}} + BTD_{8.6\text{-}12} + BTD_{8.6\text{-}13.3}$$

Seasonal CDA Analysis Results: Daytime 2006, 1030 LT



Comparing contrails with GTG

NCAR



20 January 2008 1800 UTC, MODIS contrail detections (blue) and GTG 30,000 – 39,000 ft maximum (colored contours)

Statistical Evaluation Methodology #1

NCAR

- Selected four seasonal months (Jan, Apr, Jul, Oct) of 2008
- Grid point locations within two pixels (37 km) from *Terra* MODIS contrail detection are “contrail”, those more than 100 km away are “no contrail”
- Only cloud-free areas were used
  - 10.8 μm brightness temperature > 255 K
  - 10.8 μm minus 12.0 μm BTD between -0.5 and 5 K (eliiminates cold, thick clouds)
  - local standard deviation of BTD between 0.0 and 0.05 (eliminates regions of possible cloud cover)
- Trained and evaluated logistic regression models

Contrail frequency analysis

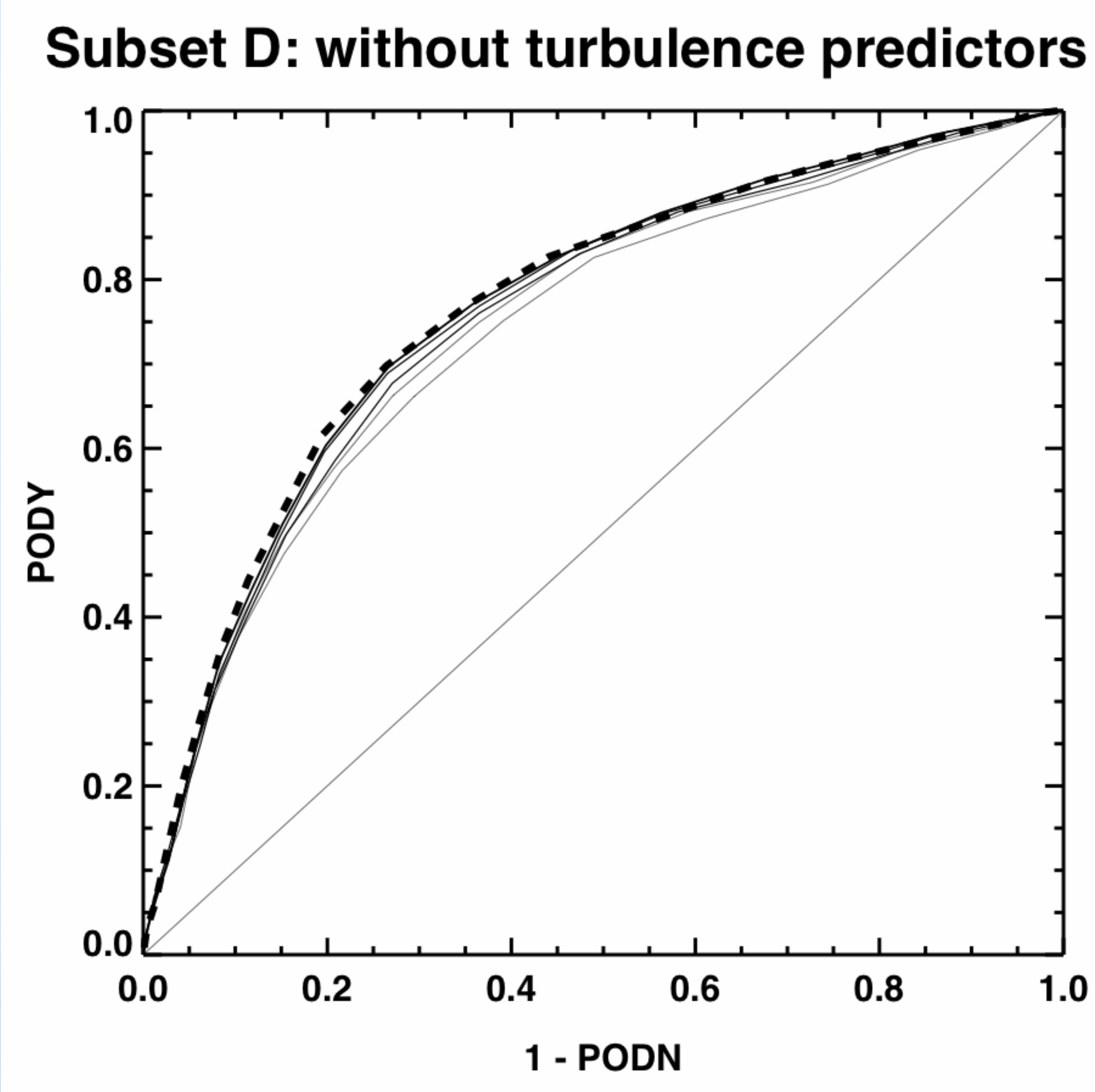
NCAR

- **Subset B:** RHI > 57, TEMP < 219 K
  - **58%** of 50,000 profiles have contrails
- **Subset C:** RHI > 57, TEMP < 219 K, GTG > 0.06
  - **60%** of 8,000 profiles have contrails
- **Subset D:** RHI > 57, TEMP < 219 K, GTG < 0.01
  - **50%** of 13,000 profiles have contrails

- ***Small* values of GTG may inhibit formation and maintenance of visible contrails**

Logistic regression performance (1)

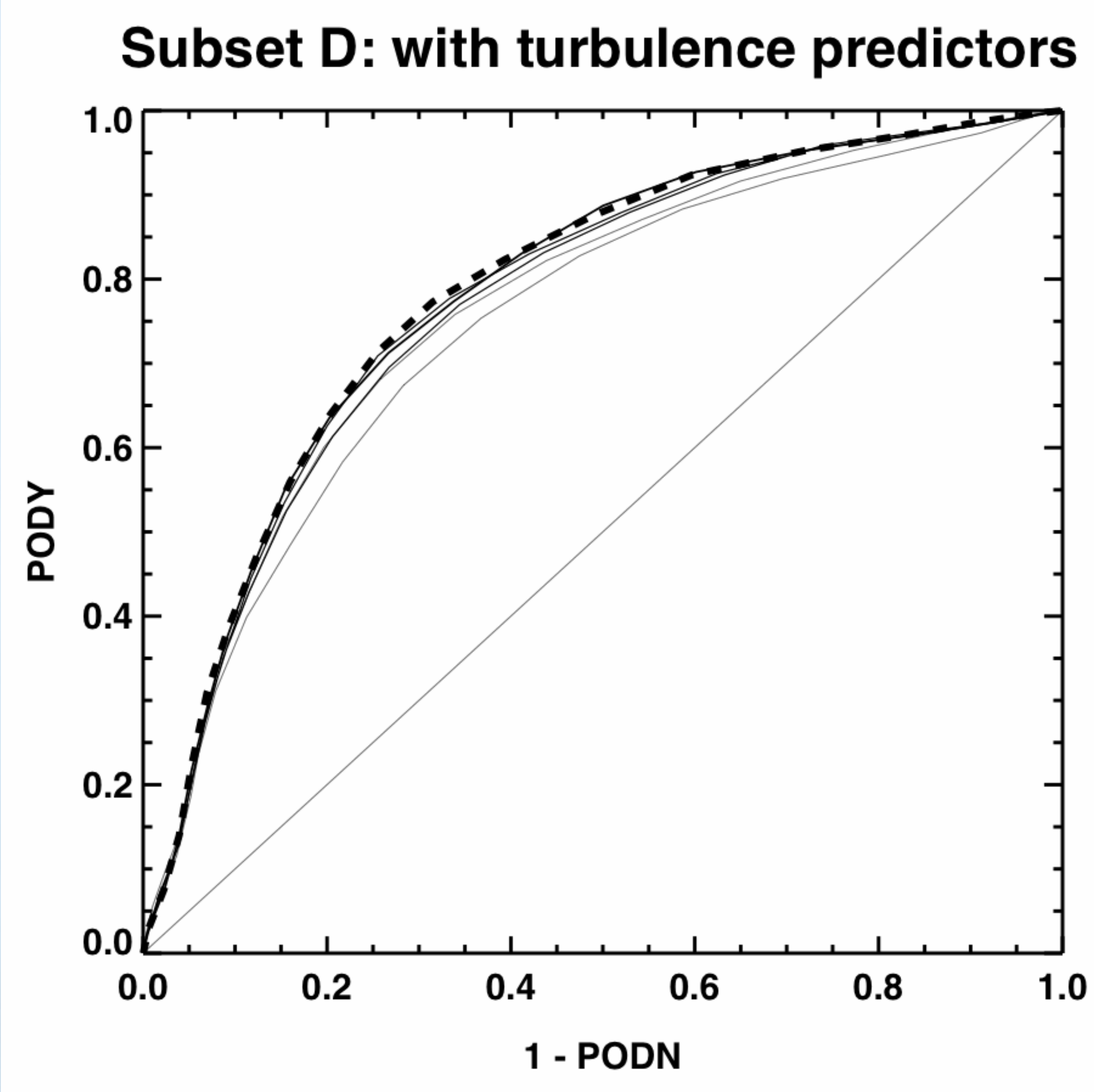
NCAR



D without turbulence predictors: performance

N	*AUC*
3	0.70
4	0.75
5	0.75
6	0.76
7	0.77
8	0.77

Logistic regression performance (2)



D with turbulence predictors: performance

N	*AUC*
3	0.75
4	0.77
5	0.77
6	0.78
7	0.78
8	0.79

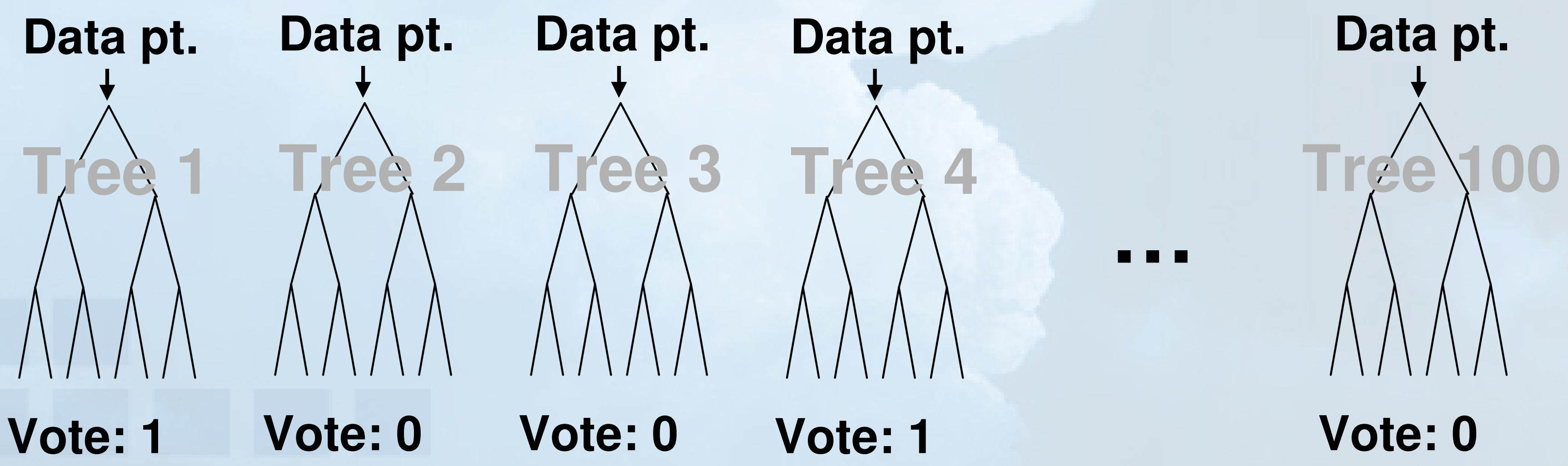
Statistical Analysis #2

NCAR

- Logistic regression model assumes monotonic relationship between predictors and probability
  - The hypothesized relationship to turbulence is more complex
  - **Could a more general modeling framework show a larger impact?**
- The previous analysis focuses on the layer with highest RHI
  - **Could using flight densities derived from Aircraft Situation Display to Industry (ASDI) data to choose the target layer refine the results?**

Random Forest (RF) analysis

- RF is a non-linear data mining technique used to analyze a retrospective database and
  - Create a **non-parametric** (makes no assumptions about functional form), probabilistic empirical predictive model via an ensemble of decision trees
  - Produce estimates of variable importance



=> 40 votes for “0”, 60 votes for “1” can be translated into a probability

Methodology

NCAR

- Collect instances of contrail pixels (< 2 km) and "no contrail" pixels (>100 km away from MODIS detections)
  - Use GOES cloud products to eliminate natural clouds; use only pixels > 40 km away from cloud top < 255 K
- Find "most likely" altitude layer based on air traffic
  - Analyze ASDI track density within 100 km radius, and find the level for which the total +/- 2,000 ft "cylinder" contains the highest overall density
- Sample collocated RUC-13 3-D model quantities, turbulence diagnostics, and GTG values
- Randomly resample sets of "true" and "false" pixels from dataset
- Use even Julian days for training, odd for testing

Variable importance analysis

NCAR

Table 1: RUC and ASDI

Rank	Importance	Variable
1	20.8	MIXR
2	18.8	VPTMP
3	15.9	ASDI 200 km mean
4	15.0	HGT
5	14.3	SPEED
6	13.4	UGRD
7	11.8	ASDI 100 km mean
8	10.8	VGRD
9	10.5	Appleman
10	7.9	PRES
11	7.9	ICMR
12	7.9	ASDI 50 km mean
13	4.6	VVEL
14	2.7	NCIP

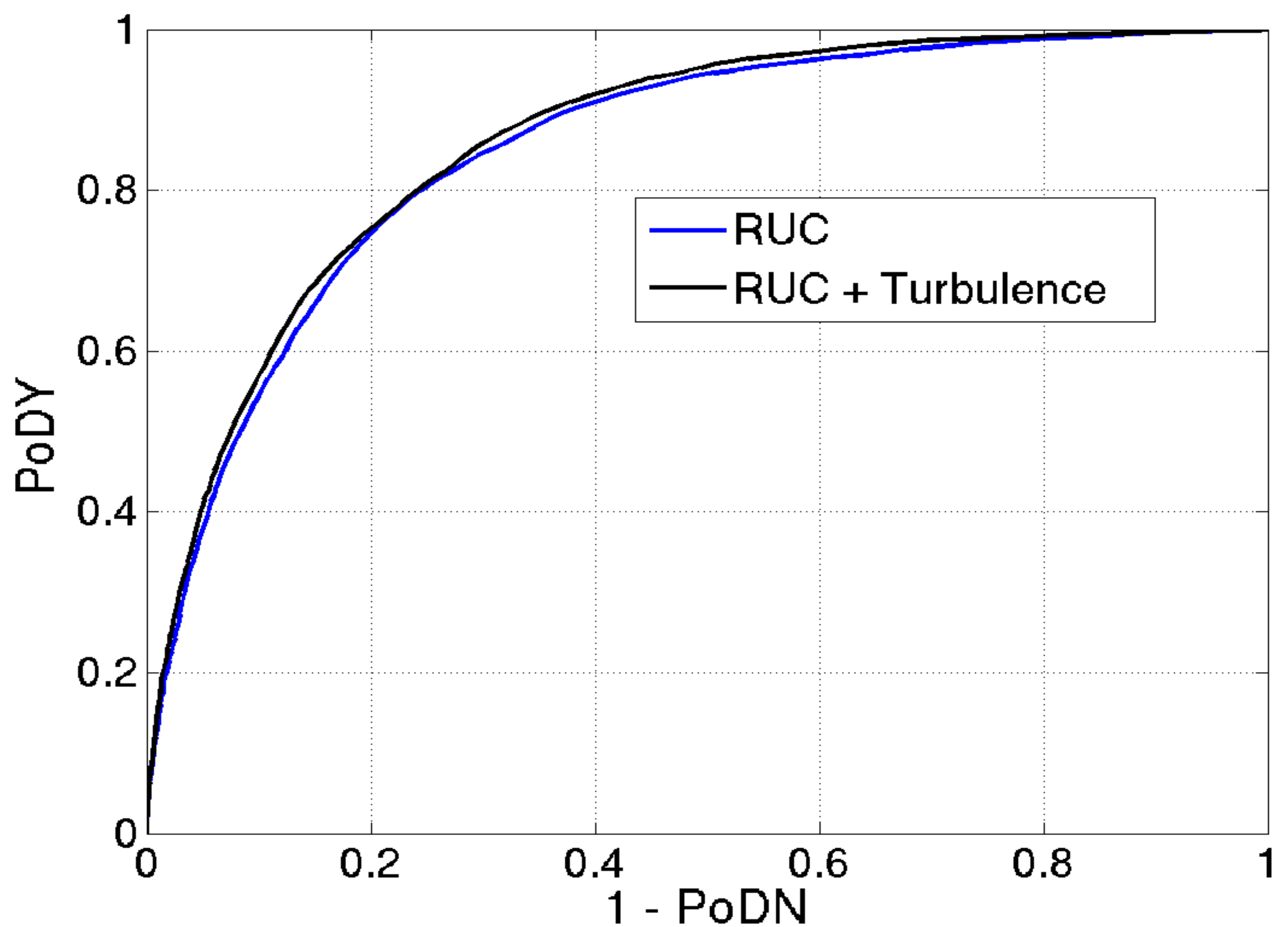
Table 2: RUC, ASDI, and Turbulence

Rank	Importance	Variable
1	17.0	MIXR
2	14.7	VPTMP
3	11.6	ASDI 200 km mean
4	11.2	**BROWN1**
5	11.0	UGRD
6	10.7	SPEED
7	10.4	HGT
8	9.28	ASDI 100 km mean
9	8.33	ICMR
10	8.03	**MoG CLIMO**
11	7.64	**TEMPG**
12	7.45	VGRD
13	7.40	**VWS**
14	7.31	Appleman
15	6.82	**NGM1**
16	6.82	**SoG CLIMO**
17	5.82	ASDI 50 km mean
18	4.82	PRES
19	3.29	VVEL
20	1.82	NCIP

Performance comparison

NCAR

	AUC	MaxCSI	MaxTSS
RUC	0.85	0.79	0.57
RUC + Turbulence	0.86	0.80	0.56



Conclusion

NCAR

- Analysis shows only weak evidence that RUC NWP model turbulence information can contribute to improved contrail forecasts
  - The GTG combination did not appear to provide the most relevant turbulence information
- The RF empirical model does appear to perform relatively well
  - May facilitate enhancement of existing contrail prediction models

Future work

- **Turbulence often comes in thin layers, so pinpointing contrail altitudes may be important**
- Perform more detailed analysis of the present dataset
  - Cross-validation to establish error bars, significance
  - Focus on regions where air traffic density is not as widely distributed vertically
  - Focus on levels which RUC variables indicate are susceptible to contrails
- Provide better height identification of contrails
  - Alternative detection methods?
  - Associate contrails with the generating flight, and track them over time?

Acknowledgement

NCAR

This presentation is based upon work supported by NASA under ROSES-2008 award No. NNH08ZDA001N. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

Contact information

John K. Williams

National Center for Atmospheric Research

jkwillia@ucar.edu

303-497-2822