SATELLITE SIGNATURES ASSOCIATED WITH SIGNIFICANT CONVECTIVELY-INDUCED TURBULENCE EVENTS

Kristopher Bedka*, Wayne Feltz*, John Mecikalski#, Robert Sharman@, Annelise Lenz*, Jordan Gerth*

* Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison

University of Alabama in Huntsville

@ Research Applications Laboratory, National Center for Atmospheric Research

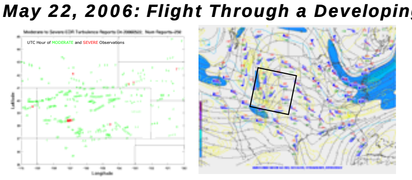
Project Description

Convectively-induced turbulence (CIT) represents a significant hazard for the aviation industry. For aviation interests between 1983-1997, all turbulence sources contributed to 664 accidents (609 fatal), in addition to 239 serious and 584 minor injuries, for an estimated annual societal cost of $134 million (Eichenbaum, 2000). Studies have shown turbulence in and around thunderstorms to be responsible for over 60% of turbulence-related aircraft accidents. (Cornman and Carmichael, ICAO, 1993)

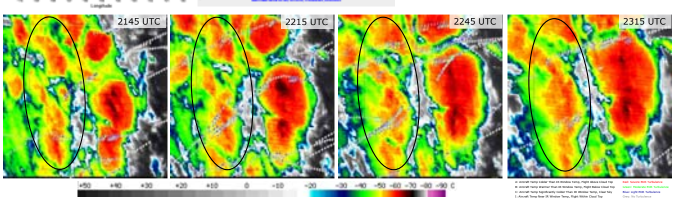
This project represents a collaborative effort between UW-CIMSS, NCAR, and UAH to enhance aviation safety by providing better diagnostics and forecasts of CIT using satellite and radar imagery. Unlike clear-air turbulence forecasts which can be developed to a large extent from NWP model output, CIT forecasts can benefit from the use of higher temporal and spatial resolution cloud observations provided by satellite and ground-based weather radar.

The goal of this effort is to develop satellite-derived interest fields using objective pattern recognition techniques that can be included for testing within the FAA-supported Next-Generation Graphical Turbulence Guidance (GTG-N) at NCAR. Improved GTG-N guidance will aid aviation meteorologists, dispatchers, and pilots in making strategic and tactical decisions for avoiding turbulent convection.

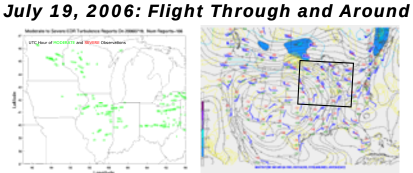
May 22, 2006: Flight Through a Developing Convective Cloud Line



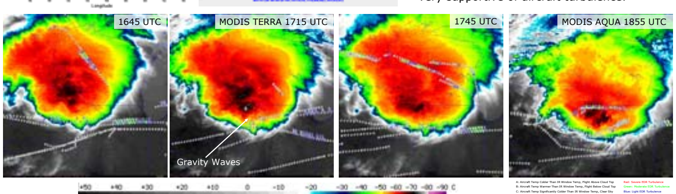
Numerous moderate to severe EDR observations are found in association with a developing convective line in western CO. Convective development occurred across CO ahead of a negatively-tilted trough in a region of strong upper-tropospheric divergence. Scale interaction between the synoptic trough and mesoscale convection causes difficulty in determining the exact forcing for the turbulence that occurred.



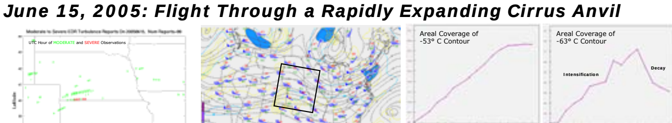
July 19, 2006: Flight Through and Around an MCS



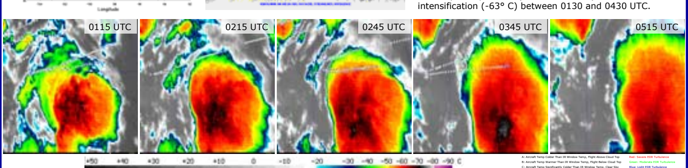
Light to moderate EDR observations were found near and within a long-lived mesoscale convective system over the U.S. Upper Midwest. Numerous out of cloud turbulent EDR were found within the southeast quadrant of the system. Analysis of 13 km RUC model data indicates that vertical wind shear induced by convective outflow reduced the Richardson number in the upper troposphere. This environment is very supportive of aircraft turbulence.



June 15, 2005: Flight Through a Rapidly Expanding Cirrus Anvil



An objective anvil expansion product (R. Rabin) reveals that numerous turbulence observations were associated with rapid expansion (-53° C contour) and overal MCS intensification (-63° C) between 0130 and 0430 UTC.



Conclusions

• Results of the climatological analysis shows that the Rocky Mountain region (100-110° W) exhibited a significantly higher frequency of MOD to SVR turbulence incidents than any of the other three regions. 99.65% of all EDR observations were either light or null in the Rocky Mountain region. The regions from 70-100° W exhibit near equal relative percentages of MOD to SVR observations.

• Satellite imagery reveals that the following phenomena are often found in association with highly turbulent convective events:
1) Developing, near-mature convection
2) Rapidly expanding anvil clouds indicating strong outflow/divergence
3) Banded cirrus outflow structures (i.e. transverse bands)
4) Convective gravity waves
5) Orographically-generated convection and/or possible mountain waves

• Objective satellite-derived products are being developed to identify rapidly expanding cirrus anvils, convective cloud top growth, overshooting tops, and turbulent mountain wave structures in support of current and future generation aviation turbulence nowcasting.

Contact Info: Kristopher Bedka, Email: krisb@ssec.wisc.edu

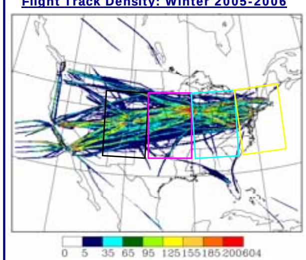
Data and Methodology

A climatology has been developed using experimental Eddy Dissipation Rate (EDR) observations to identify highly turbulent convective events from January 2005 to June 2007. This EDR database, collected by United Airlines (UAL) Boeing 757 aircraft, represents an objective measure of the vertical accelerations induced by turbulent atmospheric phenomena. The objective nature and continuous reporting of turbulent + null EDR observations are essential to this effort, and provide a distinct advantage of the subjective and spatially disparate pilot reports (PIREPS) of turbulence. Peak EDR observations are normalzed to values ranging from .05 to .95 (in .1 increments), with moderate turulence (MOD) estimated from .25-.45 and severe (SVR) being ≥ .55.

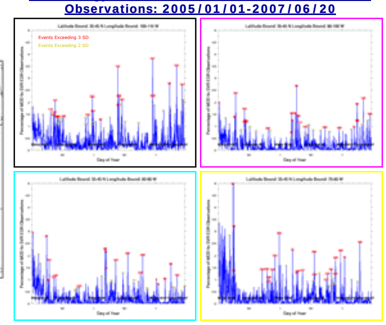
EDR observations are plotted upon GOES, MODIS, and AVHRR VIS, IR window, and WV imagery to identify thunderstorm signatures frequently associated with moderate to severe turbulence. Flight tracks for EDR-equipped UAL aircraft are shown below, with warm colors representing the highest data density. Some examples shown here highlight events with MOD to SVR EDR turbulence observations exceeding 2 SD from the seasonal mean. EDR observations in the climatology below are compiled from 1200 UTC on the day listed to 1159 UTC the following day. This is done to capture the full evolution of a convective event over the U.S., as daytime storms often evolve into turbulent Mesoscale Convective Systems (MCS) during the nighttime hours.

EDR Turbulence Climatology

United Airlines EDR-Equipped Boeing 757 Flight Track Density: Winter 2005-2006



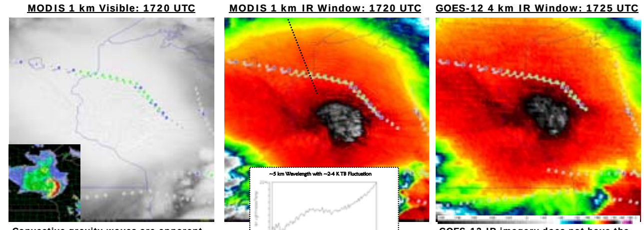
Climatology of Moderate to Severe EDR Turbulence Observations: 2005/01/01-2007/06/20



Statistics Computed Per Day During Convective Seasons	Mean # of Null + Turbulent EDR Observations Per Day	Mean % (Number/Day) of Moderate or Greater Turbulence	Median % (Number/Day) of Moderate or Greater Turbulence	Max % of Moderate or Greater Turbulence, 2.5 Convective Seasons	Max % of Moderate or Greater Turbulence, Entire Database
Region 1: 100-110 West	8162	0.35% (29 per day)	0.24% (20 per day)	3.5% (JD 2007123: May 3)	3.8% (JD 2006347: Dec 13)
Region 2: 90-100 West	8110	0.19% (15 per day)	0.10% (8 per day)	1.8% (JD 2007125: May 5)	2.7% (JD 2006096: April 6)
Region 3: 80-90 West	6745	0.20% (14 per day)	0.11% (7 per day)	2.0% (JD 2006200: July 19)	3.0% (JD 2005005: Jan. 5)
Region 4: 70-80 West	3433	0.22% (8 per day)	0.12% (4 per day)	2.6% (JD 2007105: April 15)	6.1% (JD 2005087: Mar 28)

July 23, 2005: Aircraft Encounter Convective Gravity Waves

MODIS 1 km Visible: 1720 UTC — MODIS 1 km IR Window: 1720 UTC — GOES-12 4 km IR Window: 1725 UTC

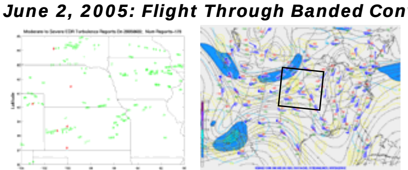


Convective gravity waves are apparent in both MODIS 1 km Visible and IR Window imagery. Wave signatures are apparent nearly 200 km from the coldest cloud tops

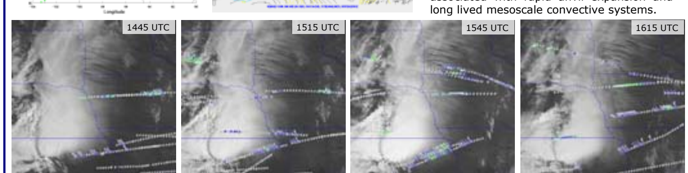
Comparison to nearby sounding indicates that a ~4 K T_B fluctuation corresponds to a 500 m wave amplitude

GOES-12 IR imagery does not have the necessary spatial resolution to observe these turbulent gravity waves

June 2, 2005: Flight Through Banded Convective Cirrus Clouds



Banded cirrus, sometimes called "transverse bands", have been welll recognized as a turbulence signature in satellite imagery. Transverse bands are found within a variety of phenomena such as convective storms, tropical cyclones, and strong upper level streaks. Little documentation is available describing the forcing mechanism for this banding. Cases studied by the authors here noted banding associated with rapid anvil expansion and long lived mesoscale convective systems.



Other Assorted Turbulence Events