P2-126

A Prototype Method for Diagnosing High Ice Water Content in Near-Real-Time Using Passive Satellite Imagery

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Introduction

At least one hundred jet engine power loss events have occurred since 1990 at altitudes where conventional airframe icing is extremely unlikely. Recent research suggests that these events may be triggered by ingestion of high concentrations of small ice particles into the engine. This phenomenon, now dubbed ice crystal icing (ICI), typically happens in the vicinity of convective clouds which can loft large amounts of small ice crystals into the upper troposphere. Because the particles can be very small (~40 microns), they go undetected by onboard weather radar and hence conditions can appear benign at flight level. The High Altitude Ice Crystals – High Ice Water Content (HAIC-HIWC) field experiments in Darwin, Australia, and Cayenne, French Guiana, were organized to collect in-situ measurements of ice water content in order to better understand how these events are triggered and how they may be avoided. This paper presents a method to identify high ice water content conditions using multi-spectral imagery from passive geostationary satellites, cloud property retrievals from the NASA Langley Satellite ClOud and Radiative Property retrieval System (SatCORPS), and a satellite-derived database of overshooting top (OT) detections over the Darwin and Cayenne regions. The satellite observations and in-situ total water content measurements from the HAIC-HIWC experiments were used to develop a probabilistic indicator of HIWC and the method is demonstrated using rapid scan imagery from the Multi-Functional Transport Satellite (MTSAT-1R). Although HIWC, i.e., IWC > 1-2 g m^{-3}, encounters were relatively uncommon during the experiments, most occurred within ~60 km of significant convection. Future application to next-generation imagers with high temporal resolution such as Himawari-8 and GOES-R is anticipated.

Satellite and Aircraft Data

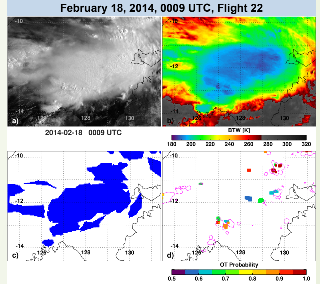
During the HAIC campaigns, in-situ cloud total water content (TWC) was measured by an isokinetic evaporator probe (IKP2*; Davison et al. 2012, *AIAA*) mounted on the Falcon-20, and additional aircraft and atmospheric state parameters were provided by SAFIRE (Service des Avions Francais Instrumentés pour la Recherche en Environnement). MTSAT-1R and GOES-13 provided multi-spectral imagery of the Darwin and Cayenne domains, respectively. Cloud property retrievals (e.g., cloud boundaries, optical depth, water path) were derived from the satellite imagery using the SatCORPS (Minnis et al. 2011), and an automated overshooting top (OT) detection algorithm (Bedka and Khlopenkov, 2016) was used to identify locations of cirrus anvils and deep convective updrafts.

The OT detection algorithm is a set of statistical, spatial and frequency analyses of IR and VIS imagery and consists of two main components:
(1) IR-based detection of anvil clouds and brightness temperature (BTW) minima within these regions. OT candidates are assigned an "OT Probability" score.
(2) Quantification of cloud texture in 1-km visible imagery via a unitless rating. Values greater than 5 are indicative of strong vertical motions and gravity waves, and larger values correspond to classic OT "cauliflower-like" texture.

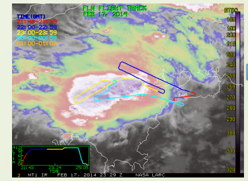
Spatial/temporal collocation:
Assuming a typical airspeed of 180 m/s, the 1-Hz aircraft measurements were averaged to 45-s intervals in order to approximate the relatively coarse satellite spatial resolution. The four nearest satellite pixels were matched to each segment of the flight tracks and the mean cloud properties were computed. Temporal differences between the observations were restricted to less than 10 minutes.

*Strapp, W. 2014. French Falcon Isokinetic Evaporator Probe (IKP2) Data, Darwin, Version 1.0. UCAR/NCAR - Earth Observing Laboratory. http://data.eol.ucar.edu/dataset/384.011. Accessed 21 Oct 2015.
*Strapp, W. 2016. French Falcon Isokinetic Evaporator Probe (IKP2) Data, Cayenne, Version 3.0. UCAR/NCAR - Earth Observing Laboratory. http://data.eol.ucar.edu/dataset/486.001. Accessed 21 Oct 2015.

February 18, 2014, 0009 UTC, Flight 22



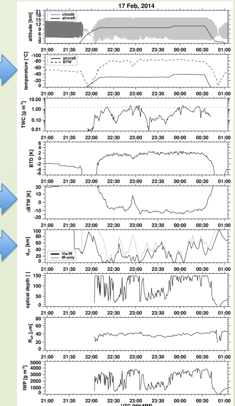
Visible (a) and IR (b) imagery of the Darwin flight domain on February 18, 2014, and the corresponding anvil cloud detection product (c), and visible texture detection (d, magenta contours) and IR-based OT probability rating (color shading).



Pixel IR BTs were differenced with the regional anvil mean BT (denoted ΔBTW) to identify the coldest cloud tops in the imagery.

All TWC measurements were characterized by their distance to the nearest OT (denoted d_{OT}).

During this flight, TWC of ~1.5 was observed at the -35 to -40°C level for periods corresponding to large negative ΔBTW, positive BTD, d_{OT} < 40 km, and COD > 50. Effective ice particle radius R_{eff} showed little trend with TWC during this flight.

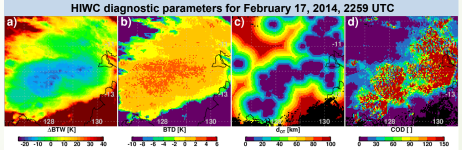


Methodology

The goal of the HIWC probability product (PHIWC) is to optimally combine a set of satellite-derived products to identify:

(a) Storms with cloud tops that are higher and presumably more intense than others in the region (via ΔBTW)
(b) The presence of deep convection (via BT differences in the water vapor and IR channels, denoted BTD)
(c) Active updraft regions where HIWC is likely generated (via d_{OT})
(d) Microphysical variability at cloud top indicative of HIWC below cloud top (via cloud optical depth COD)

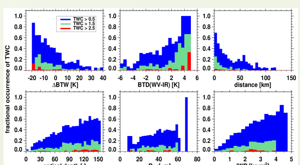
HIWC diagnostic parameters for February 17, 2014, 2259 UTC



A random subset (66%) of the matched aircraft/satellite dataset was used to compute the fractional occurrence of high IWC as a function of these four parameters. Within the research community, there is not yet a consensus on one particular threshold to delineate high IWC from low IWC, but values greater than 1.5 g m^{-3} have generally been considered high enough to warrant concern. Here we consider three different TWC thresholds of 0.5, 1.5, and 2.5 g m^{-3}.

Single-variate distributions of TWC fractional occurrence show a noticeable trend with ΔBTW, BTD, d_{OT}, and COD. There is no significant trend with effective ice particle radius R_{eff}. Since IWP is a function of both COD and R_{eff}, it is reasonable to use COD rather than IWP as a HIWC predictor.

Most instances of TWC > 1.5 g m^{-3} occurred within ~60 km of evident convection identified by the automated OT detection algorithm.

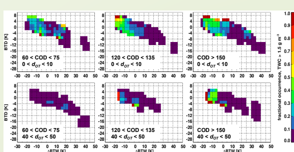


Single-variate distributions of TWC fractional occurrence. Figure uses Cayenne IKP2 draft dataset Version 3.

Multi-variate distributions of TWC fractional occurrence were computed to estimate HIWC probability (PHIWC) given ΔBTW, BTD, d_{OT}, and COD. Smoothing was performed to reduce the number of empty bins and reduce noise due to small sample sizes.

Fractional occurrence tends to increase with increasing COD and decreasing d_{OT}.

A 3-parameter IR-only model utilizing ΔBTW, BTD, and d_{OT} was generated to estimate PHIWC when COD and visible texture detection are unavailable.

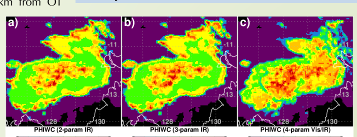


Multi-variate distributions of TWC fractional occurrence. Figure uses Cayenne IKP2 draft dataset Version 3.

A 2-parameter "background" model was developed and used for pixels that are greater than 50 km from OT detections.

Additional spatial smoothing was performed to reduce noise due to small sample sizes.

The use of VIS texture detection and COD help accentuate only those areas near organized convection which likely produce HIWC.

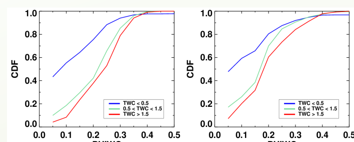


HIWC probability fields for February 17, 2014, 2259 UTC, using the 2-parameter (a), 3-parameter (b), and 4-parameter (c) models

Results and Examples

The remaining 33% of the matched aircraft/satellite dataset was reserved for validation of the model described in the previous section.

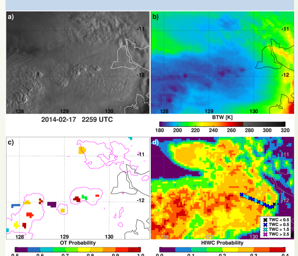
Cumulative distribution functions (CDF) of PHIWC from the the Vis/IR (left) and IR-only (right) methods were generated using the validation dataset. Most moderate and high TWC, i.e., TWC > 0.5 g m^{-3} have PHIWC > 0.2. There is slightly better separation between low and high TWC (blue and red curves, respectively) with the Vis/IR model.



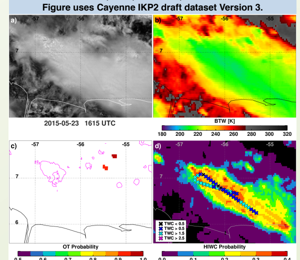
Cumulative distributions of PHIWC obtained from the Vis/IR (left) and the IR-only (right) methods.

Automated OT detection and PHIWC products are illustrated below with example imagery from the Darwin (MTSAT-1R) and Cayenne (GOES-13) campaigns. In-situ IKP2 TWC observations are plotted over the PHIWC graphic in the lower right of each example. High TWC tends to be located near areas of VIS texture and/or high OT probability ratings. MTSAT-1R 10-minute rapid scan imagery was critical for capturing quickly developing or decaying areas of convection. Some OTs likely formed and decayed between the 30-minute GOES-13 scans.

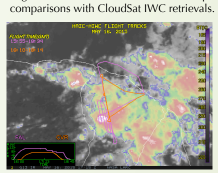
FEBRUARY 17, 2014, 2259 UTC, FLIGHT 22



MAY 23, 2015, 1615 UTC, FLIGHT 19
Figure uses Cayenne IKP2 draft dataset Version 3.



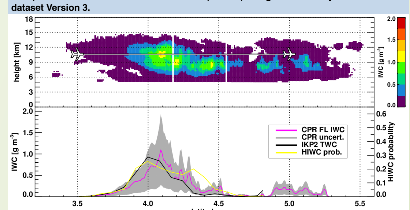
Flight coordination with an A-Train overpass on May 16, 2015 of the Cayenne campaign (Flight 15) presented an opportunity for comparisons with CloudSat IWC retrievals.



An area of moderate IWC (~1.0 g m^{-3}) was encountered by the Falcon-20 aircraft during this CloudSat overpass (top).

IKP2 TWC (black line) falls within CloudSat IWC retrieval uncertainty (magenta line and gray shading). PHIWC (yellow, right y-axis) follows trends in in-situ and retrieved IWC.

CloudSat overpass of Cayenne flight domain on May 16, 2015. IWC retrievals from the CloudSat 2B-CWC-RO product are shown here (top). Flight-level IWC was extracted and plotted with in-situ TWC and PHIWC (bottom). Figure uses Cayenne IKP2 draft dataset Version 3.**



**CloudSat Standard Data Products are distributed by the CloudSat Data Processing Center located at the Cooperative Institute for Research in the Atmosphere at Colorado State University in Fort Collins.

Summary

High concentrations of ice particles, i.e., HIWC, have been linked to aircraft engine power loss events at cruise altitudes where the existence of supercooled water droplets is extremely improbable.

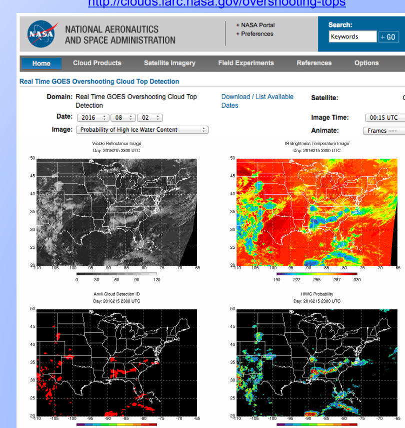
In-situ ice water content measurements were matched to satellite cloud property retrievals in order to develop an algorithm to estimate the probability of high ice water content PHIWC in satellite imagery. Most observed HIWC had PHIWC greater than 0.2.

HIWC frequently occurs within 60 km of overshooting cloud tops (OTs). Therefore, a database of OT detections from high temporal resolution satellite imagery is extremely valuable. Next-generation sensors such as the Advanced Baseline Imager (ABI) on GOES-R and the Advanced Himawari Imager (AHI) on Himawari-8 offer the necessary capabilities for such a database.

Doppler Radar System Airborne (RASTA) IWC retrievals from the HAIC campaigns will be used for additional analyses and validation. This additional dataset should help mitigate problems due to small sample sizes.

The OT and HIWC detection algorithms are currently run in real-time over the CONUS using GOES imagery (sample imagery shown below).

http://clouds.larc.nasa.gov/overshooting-tops



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