Topic 2.4

ADVANCES AND CHALLENGES IN SUBJECTIVE INTENSITY ESTIMATION

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Abstract: This report reviews the status of subjective tropical cyclone intensity estimation. Particular focus is placed on recent advances to improve intensity estimation, reviewing the factors responsible for ongoing differences between agencies and also general challenges.

The first International Workshop on Satellite Analyses of Tropical Cyclones (IWSATC) in 2011 highlighted differences in the use of Dvorak technique. While the essence of the Dvorak technique remains, the various differences highlight the opportunity to conduct more verification and calibration research to benchmark the most appropriate way forward.

As objective techniques are refined and developed and new satellite sensors are available, it is important to provide guidance on the strengths and limitations of each technique. Integrating the different estimates continues to be a challenge to forecasters emphasising the need for ongoing training.

2.4.0 Introduction

An accurate intensity estimate is a critical element of the forecast process. A poor analysis jeopardises the forecast and consequently the expected impacts that people need to appropriately prepare for. There are a number of inputs used to determine the intensity including the Dvorak technique, surface observations, scatterometry, the Advanced Dvorak Technique (ADT), microwave sounders (e.g. AMSU), SATCON, and subjective interpretation of passive microwave patterns. Consideration of the previous intensity estimate for forecast intensity. These are summarised in Figure 1.

There is considerable ongoing efforts to improve the objective guidance for determining the intensity e.g. ADT, SATCON, JMA’s Cloud Grid Information Objective Dvorak Analysis (CLOUD) (Kishimoto et al. 2013), JMA’s microwave intensity methods using TRMM and AMSU (Sakuragi et al., 2014, Oyama 2014). These advances in objective guidance are addressed in a separate IWTC session.

However forecasters are required to combine the various intensity methods to determine a single intensity estimate. This requires a good knowledge of the individual techniques including their strengths and weaknesses and an understanding of the relative skill of the techniques so have appropriate weightings in the process of determining the final estimate.

The fact that different agencies can vary in their intensity estimates of the same circulation using essentially the same sources of information indicates that further work is required by agencies to share and benchmark their processes for determining the uncertainty. The discrepancy
is most apparent in the northwest Pacific basin where multiple agencies conduct their own analyses on the same system as recently documented by Schreck et al. (2014). For example when Super Typhoon Rammasun made landfall over Hainan Island in July 2014, JMA estimated the intensity at 90 knots, CMA 120 kn and JTWC 135 kn. A central pressure of 899 hPa was recorded (data to be verified) but there wasn't a concurrent measurement of Vmax.

This report outlines recent progress to improve the subjective elements of determining the intensity and summarises the inherent challenges.

![Diagram](image)

**Figure 1.** Intensity inputs to determine Tropical Cyclone intensity. Observations include those from surface, aircraft and via radar. Credit: BoM / The COMET Programme

### 2.4.1 International Workshop on Satellite Analysis of Tropical Cyclones (IWSATC)

The first IWSATC held at the Central Pacific Hurricane Center and University of Hawaii gathered operational forecasters of the major warning centres and researchers together to share the latest knowledge and techniques being used (Velden et al. 2012). This highlighted similarities and differences in the methodologies to determine the intensity. Primarily this focused on the application of the Dvorak technique and the conversion of the Dvorak CI number to Vmax as well as advances in objective guidance.

### 2.4.2 Application of the Dvorak Technique

IWSATC provided the opportunity for agencies to share their approach to using the Dvorak technique. These are available at the WMO/TCP website: [http://www.wmo.int/pages/prog/www/tcp/IWSATC.html](http://www.wmo.int/pages/prog/www/tcp/IWSATC.html)

A degree of scatter in reported CI values between agencies is expected given the subjective nature of the Dvorak technique, and variations of 0.5 are common. However biases between agency estimates is of concern.
Ongoing differences occur because of different use of wind averaging periods and CI to Vmax tables. USA-based agencies use a 1-minute averaging period, Chinese Meteorological Agency reports a 2-minute wind, and the Indian Meteorological Department (IMD) reports a 3-minute wind while other agencies report a 10-minute average wind speed. The Japanese Meteorological Agency (JMA) uses the Koba et al. (1991) table for converting CI to Vmax while other agencies use the Dvorak (1984) table.

Some of the variations in application of the Dvorak technique identified include:

**CMA:** use of a ‘simplified Dvorak Technique’ that only uses Vis imagery and is quite different from the original (1984) technique. Following IWTC, CMA introduced Dvorak (1984) into operations in 2012 (Yinglong Xu, pers, comm.).

**IMD:** preference given to Vis imagery as the EIR analyses have a high bias in the NIO. Also do not increase intensity during the diurnally favourable period (early morning) for convection but wait for cloud signatures to persist during the less favourable hours following sunrise. These lead to IMD indicating weaker intensities than other agencies.

**JMA:** in addition to adopting the Koba et al. (1989) CI to Vmax relationship, they do not use the Vis method at all. Have a specific Early Stage Dvorak Analysis (ESDA) derived from elements of the Dvorak initial classification rules.

**BoM:** Dvorak (1984) has been augmented with notes clarifying the application in Burton (2005). Included is the emphasis on taking a 3-hour average approach in determining the data-T no. given the fluctuations in convective signatures. This will become more significant as higher temporal resolution of satellite imagery becomes available such as Himawari-8 and CMA’s FY-4.

**NESDIS:** Like BoM adheres to suggestions made by Burton (2005). For example the importance of reanalysis of previous fixes is highlighted during periods of rapid intensification when Dvorak constraints appear to be broken. Once this has been done the constraint should be broken when the average DT calculated once each hour for a 6 hour period to the analysis time exceeds the FT constraint value.

**NHC:** A study of aircraft-based best track intensity estimates showed the Dvorak intensity change constraints were only broken in only about one per cent of the cases for 6, 12, 18 and 24 hour intensity changes.

**Rapid intensification:** Some agencies report breaking the FT change constraint of Rule 8.4. NHC have reduced the threshold 4.0 to 1.5. BoM have since followed this guideline but generally only for small systems.

**Weakening rules:** Many agencies have made variations to Rule 9 that states the final CI should be held for 12 hours. La Reunion and BoM have applied a 6-hour rule while other agencies also occasionally broke this rule when rapid weakening was obvious. JMA conducts analyses without holding CI for 12 hours after landfall until redevelopment stage.

**Shear pattern:** JTWC and La Reunion generally only use the shear pattern for weakening patterns finding that it overestimates the intensity during the development phase.

**Embedded Centre pattern:** Application of this pattern is inconsistent across agencies. BoM and La Reunion find that it overestimates the intensity, potentially related to low-latitudes in the Southern Hemisphere.
**Landfall:** Some agencies (e.g. HKo, JMA) continue to perform analyses after landfall, and refer to the results when appropriate.

**‘Pure’ Dvorak Vs adjustments:** While the Dvorak analysis is based purely upon EIR and Vis imagery it is apparent that agencies occasionally adjust their Dvorak analysis based upon additional data and observations especially microwave imagery. This is the practice at NESDIS for example. This further contributes to inter-agency discrepancies that will be confusing to users without associated metadata to explain the estimate.

**A colour EIR scale:** Despite the longevity of the Dvorak Technique, the use of the grey shade temperature scale for the EIR is the source of ongoing confusion especially for those new to the technique. The original BD scale was based on monochrome technology available at the time of the technique but has withstood the test of time as it is the only international standard. Various colour enhancements have been used for local applications without getting to the stage of international co-operation. La Reunion has been using a colour scale since the early 90s as shown in Figure 2. This passes colour blindness checks JMA also developed a colour scale that has been operationally applied since the late 80s. It was also incorporated into the Satellite Animation and Interactive Diagnosis (SATAID) by JMA in 1996. SATAID has been available through the JMA’s WIS service (http://www.wis-jma.go.jp/cms/sataid/), and widely used by National Meteorological Services of Southeast Asia.

It would be helpful for the international community to agree to a standard colour version to enable the transition to be as smooth as possible.

![Image of colour EIR scale](credit-La-Reunion-RSMC)

**Figure 2. A colour Dvorak EIR scale used in La Reunion for consideration for more widespread use. Credit La Reunion RSMC**

### 2.4.3 Definitions of intensity

Regional differences in the definition of Vmax and a TC can also lead to discrepancies. For example, La Réunion RSMC require the maximum wind to extend more than half way around the circulation. While BoM also require gale force winds to extend more than half way around the circulation near the centre for tropical cyclone classification, they do not require the defined Vmax to extend this far. This can result in different interpretations of surface observations and scatterometry in particular.
So for the case when scatterometry shows gales in one or two quadrants BoM Vmax may be 35 kn but not name it as a tropical cyclone, whereas La Reunion would indicate Vmax as 30 kn.

2.4.4 Interpreting passive microwave and scatterometry imagery

In addition to being very useful for positioning passive microwave imagery can assist in intensity determination from the degree of convective organisation. For example, an eye is typically evident on microwave imagery ahead of IR and Vis so will be a definite indicator of development. Similarly changes in eye structure often evident on microwave imagery (see 2.4.10 for discussion on secondary eye formation). La Reunion will routinely use microwave imagery for determining the Dvorak DT for curved band patterns. Nevertheless the understanding and subjectivity in applying this information continues to cause discrepancies between agencies as discussed by Edson (2014) since IWTC VII, Ascat-B has become available to augment Ascat-A, although Quickscat and Oscat have failed. The NASA RapidScat instrument on board the International Space Station is expected to be online by 2015.

2.4.5 Aircraft

NASA and HRD have been developing new methods relevant to surface wind determination. These include:

- Wind speed algorithms for the Stepped Frequency Microwave Radiometer (SFMR) have been updated (Klotz and Uhlhorn, 2014)
- Creation of 2-D wind maps using P-3 Doppler radar (HRD)
- HIRAD: 2-D swath of the SFMR (NASA)
- HIWRAP and HIWRAP Airborne Doppler radar (NASA) Guimond et al. 2014
- HAMSR: airborne microwave sounder which aims to deliver intensity estimates similar to those from AMSU instruments (NASA)
- COYOTE: an unmanned drone is dropped out of the dropsonde tube then deploys wings and a propeller to fly around for about 30 minutes after release (HRD)

2.4.6 Subjectively combining different intensity methods

While the Dvorak technique remains the primary intensity technique when direct observations are unavailable, the process of combining this with other data from surface observations, scatterometry, the Advanced Dvorak Technique (ADT), microwave sounders (e.g. AMSU), SATCON, passive microwave patterns, Doppler radar, aircraft reconnaissance data and even NWP output to derive the final intensity estimate remains a subjective process. While the majority of this information is shared between agencies, the different weightings further accounts for discrepancies between agencies.

The COMET module on intensity analysis (refer 2.4.7) describes the general approach used by many agencies including BoM, NHC, Fiji, La Reunion, JTWC and NESDIS.

IMD’s current process of using a consensus based intensity estimation takes into consideration (a) satellite (Dvorak), (b) Radar and (c) synoptic analysis is described in Mohapatra et al, 2014.

Figure 3 shows the subjective best track plotted with the range of intensity methods for Hurricane Nadine by NHC. It is not uncommon for different methods to give widely varying intensities that the forecaster has to assess.
2.4.7 Metadata
Some agencies provide technical descriptions of how the intensity was derived e.g. NHC advisories, La Reunion technical descriptions, BoM Technical Bulletin, JTWC Warning Text and Satellite Fix Bulletins. This is useful for other agencies and any technical user to better interpret the situation. Ideally this type of metadata is also made available in best track datasets. NHC have a ‘fix’ file to contain all the inputs that are considered for creating the final best track. BoM have a field denoting how the intensity estimate was derived augmented by a comments field that can be used to describe certain cases. For example when the intensity was based on scatterometry that is higher than the Dvorak estimate would indicate.

BoM now routinely store in their best track database all the relevant Dvorak T-numbers with comments to provide better metadata on the intensity determination. They have also embarked upon a project to ensure that a more homogeneous record of the CI and Vmax is available for each fix in their historical best track back to the early 1970s. The experience has highlighted the considerable variations in methods used historically.

To address agency differences in the Dvorak analyses, in 2014 CMA, HKO, JTWC and JMA exchanged their historical record of CI numbers from 2004 to 2013 and JMA will report preliminary outcomes to the 47th Typhoon Committee in 2015.

2.4.8 Training
A key recommendation from IWSATC was to expand the training material focused on helping forecasters making optimal use of the available satellite-based intensity estimates. There have been many training initiatives by the various RSMC/TCWCs including some under the auspices of WMO such as the Typhoon Committee of Asia-Pacific.

One particular initiative has been an online training material developed by BoM in conjunction with COMET on intensity analysis. The COMET lesson is freely available at: https://www.meted.ucar.edu/training_module.php?id=1083
This provides guidance for forecasters needing to combine different intensity methods to determine the intensity of a tropical cyclone. Each of the intensity methods is summarized, focusing on both strengths and weaknesses. These methods include the Dvorak technique, surface observations, scatterometry, the Advanced Dvorak Technique (ADT), microwave sounders (AMSU), SATCON, and subjective interpretation of passive microwave patterns. Consideration of the previous intensity estimate and forecast is also examined. The lesson uses case studies to highlight the importance of weighting the methods according to the situation. Appendix 1 is a summary of tropical cyclone intensity techniques.

As new satellite sensors and updates to methods emerge there is a requirement for training and time for acceptance in order to be fully integrated into the forecast process. Since IWTC VII there have been a number of new sensors available. ASCAT-B now complements ASCAT-A, but OceanScat (OScat) data is no longer available. New passive microwave sensors include AMSR2 and GMI although AMSRE is no longer available and TMI may not continue for much longer.

![Tropical Cyclone Intensity Analysis](https://www.meted.ucar.edu/training_module.php?id=1083)

Figure 4. The COMET intensity analysis lesson available at: [https://www.meted.ucar.edu/training_module.php?id=1083](https://www.meted.ucar.edu/training_module.php?id=1083)

Credit: COMET

### 2.4.9 Uncertainty

Quantifying the intensity uncertainty is important just as determining the position accuracy. While this is not part of traditional forecast products, it is required as an input into the forecast intensity uncertainty needed to assess the likelihood of possible outcomes. For example while a particular forecast may not indicate a system at typhoon/hurricane-force intensity, decision-makers such as emergency managers want to know what the likelihood of this will be in order to make the most informed decisions. Furthermore quantifying uncertainty in best tracks is important as discussed in Torn and Snyder (2012).
A potential reason why intensity uncertainty is not recorded is that it is very difficult to do. The lack of accurately determined intensity makes verification difficult reinforcing the need to better measure the intensity. A study by NHC showed that when the best track estimate had aircraft reconnaissance information was available, 50 per cent of the corresponding Dvorak intensity estimates were within 6 knots, 75 per cent were within 12 knots and 90 per cent within 18 knots as shown in Figure 5.

![Figure 5. Dvorak error distribution when aircraft reconnaissance is available. Credit: NHC, NOAA](image)

### 2.4.10 Challenging cases

Some types of systems are not handled well by the Dvorak Technique.

**Monsoonal, hybrid and extra-tropical transitioning systems**

The Dvorak technique does not cater to monsoonal, hybrid and extra-tropical transitioning systems. The intensity is typically stronger than the Dvorak estimates indicate. There are often variations in the intensity of such systems from different agencies.

Some systems can evolve from being a broad monsoonal low into a large system at gale, storm or even hurricane force intensity. Severe Tropical Storm Nakri in the northwest Pacific in July 2014 emerged from a monsoon gyre.
Figure 6 shows the broad monsoon structure of the developing system Man-yi in the northwest Pacific. Man-yi was difficult to classify using the Dvorak technique even though Man-yi was at gale force intensity.

![Image of Tropical Storm Man-yi](image.png)

Figure 6. Modis visible image of Tropical Storm Man-yi, 13 September 2013
Credit: NASA

**Small (midget) tropical cyclones**

Traditional intensity analysis tools under-estimate the true maximum winds for the small or 'midget' tropical cyclone. This includes Dvorak technique, microwave (AMSU), scatterometry and surface observation interpretation.

Sampling the maximum wind is difficult because the radius of maximum winds is small making the chances of an observing site sampling the true maximum winds unlikely. Winds can vary a lot over small distances, another reason that historically small TCs were underestimated in TC databases.

Although Severe Tropical Cyclone Tracy passed right over the top of Darwin providing an accurate estimation of the surface pressure (950hPa), it is likely the airport did not sample the highest winds as the damage along Darwin's northern suburbs sustained greater damage than around the airport.

From an impact point of view, the small footprint of the maximum winds reduces the chances of a community being affected by the peak winds. But try telling the residents of Darwin that!

There is growing reliance on subjectively assessing the 85-91GHz microwave imagery pattern but this is highly subjective. Figure 7 shows the 85GHz microwave image of Tropical Cyclone Rosie. The operational estimate was 45 kn when this image arrived showing an eye and while the intensity was revised up to 50 kn, forecasters were unsure just how strong the cyclone was. There is a distinct lack of reliable maximum wind data from these types of systems to enable calibration of methods.
Figure 7. An eye is apparent on the 95GHz view of Tropical Cyclone Rosie in the southeast Indian Ocean when the operational estimate was at 45kn.
Credit: NRL

**Systems over land**

Traditional satellite-based methodologies can’t be used over land. Once a system moves over land, intensity estimates rely more upon surface observation, standard inland decay rates, radar, and increasingly upon NWP surface wind depictions. Overland the relationship between the intensity and the cloud pattern changes and while Dvorak can be still be used to derive a Current Intensity, the maximum wind estimate should be biased towards other methods. Topographical variations and the changing structure of the circulation add to the complexity of the analysis especially when interpreting surface observations.

**Secondary eyewall formation (SEF) and replacement cycles (ERC)**

Kossin and Sitkowski (2012) discuss the intensity changes associated with secondary eye wall formation (SEF) and eye wall replacement cycles (ERC). Of particular value is the intensity change depiction associated with 85-91GHz microwave imagery as demonstrated in the case of Hurricane Floyd in Figure 8.

The process to adjust intensity estimates based on this pattern is subjective and while some agencies may incorporate this into their process. At BoM, the recognition of SEF/ERC may lead to a slight adjustment to Dvorak estimates and consideration of short term intensity changes.
2.4.11 Conclusions and Recommendations

Although there are advances in objective intensity aids, the process of determining the intensity remains a subjective one based upon the assessment of the different methods including the Dvorak technique. The first IWSATC was extremely useful for sharing and documenting the way different agencies go about determining the intensity.

Many of the issues raised at IWSATC remain. Differences arising from the use of wind averaging periods, application of the Dvorak technique, and conversion from Dvorak CI to wind speed (e.g. Koba table), and weighting of other sources such as ADT, SATCON, and aircraft data will continue to be a source of differences in intensity.

Nevertheless the understanding of how to combine information in a range of different situations is now better established especially as objective techniques become more established.
Recommendations
Sharing of techniques: The efforts of IWSATC I should be followed up with further work to exchange information and to benchmark techniques. This is particularly significant for when new data streams and objective techniques are updated or developed.

Calibration: Further work should be undertaken to more accurately measure the intensity and compare this with Atlantic data when recon data is available.

Agencies should record metadata of how the intensity is estimated for each fix and ideally shared with other agencies. This information should ideally be stored in the best track archive.

Agencies should consider routinely determining and recording the uncertainty of their intensity estimate.

Colour EIR scale: That agencies collaborate to consider adopting a standard colour Dvorak temperature scale.

Data sharing: Agencies should consider sharing more observational data with assured quality such as SYNOP and AWS reports for better analysis.

Acknowledgements
Thanks go to the WMO for the opportunity to contribute to this report, and to Liz Ritchie and Chun-Chieh Wu for keeping us on task.

Acronyms used in the report
ADT Automated Dvorak Technique
AMSU Advanced Microwave Sounding Unit
AOR Area Of Responsibility
BoM Bureau of Meteorology (Australia)
CI Current Intensity number (Dvorak)
CMA Chinese Meteorological Agency
Cp Central Pressure
HRD Hurricane Research Division
IMD Indian Meteorological Department
JMA Japanese Meteorological Agency
JTWC Joint Typhoon Warning Center (US)
MSLP Mean sea level pressure
NCEP National Centers for Environmental Prediction (US)
NCMRWF National Centre for Medium Range Weather Forecasting (India)
NESDIS National Environmental Satellite, Data, and Information Service (U.S.)
NHC National Hurricane Center (U.S.)
NOAA National Oceanic and Atmospheric Administration (U.S.)
NRL Naval Research Lab (U.S.)
NWP Numerical Weather Prediction
RSMC Regional Specialized Meteorological Center
SFMR Stepped Frequency Microwave Radiometer
SH Southern Hemisphere basin
TC Tropical Cyclone
TDO Typhoon Duty Officer (US)
TCWC Tropical Cyclone Warning Center (Australia)
Vmax Maximum sustained wind
WP Western North Pacific Basin
References
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Mohapatra,M. B. K. Bandyopadhyay and Ajit Tyagi, 2014, Construction and Quality of best tracks parameters for study of climate change impact on Tropical Cyclones over the North Indian Ocean during satellite era, In 'Monitoring and prediction of tropical cyclones over the Indian Ocean and climate change', Ed Mohanty UC, Mohapatra, M., Singh, OP., Bandyopadhyay, BK. And Rathore, LS. And o-published by Springers and Capital publishers, New Delhi, India, pp.1-17


## Summary of Tropical Cyclone Intensity Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Limitations</th>
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<tbody>
<tr>
<td><strong>Dvorak Technique</strong></td>
<td>Used globally as the primary intensity technique since 1970s (when no direct measurements available). Provides an intensity estimate across all intensity ranges. Verified to have robust skill – difference between analysts should be +/- 0.5 T-number. Dvorak best between 80-110 knots.</td>
<td>High uncertainty when cloud features are not clear cut and when DT is much different from MET. MET requires previous estimates of FT to be accurate so it is recommended to review these estimates if time permits. Limited use for monsoonal, hybrid, sub-tropical, and post-tropical systems; and for systems over land. Subjectivity means lower accuracy for inexperienced analysts. Underestimates between 30-50 knots. Overestimates between 65 and 85 knots.</td>
</tr>
<tr>
<td><strong>Curved band patterns</strong></td>
<td>Curved band is more obvious on vis imagery than on IR. Higher accuracy achieved with good band definition, consistency in time, having similar estimates on Vis and IR.</td>
<td>Can be hard to define the band esp. overnight – can use 85-91GHz microwave image to help define the band.</td>
</tr>
<tr>
<td><strong>Shear patterns</strong></td>
<td>Shear pattern more obvious on visible imagery than on IR. Some agencies consider it more useful for weakening rather than developing situations.</td>
<td>Discretion in assigning DT in the range of 2.5-3.5 when distance &lt; ¾ degree. Uncertainty bias towards model expected T-no (MET) for defining Final-T. Often high variation from hour to hour so important to use 3-hour average to determine DT.</td>
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<td><strong>Covered Centre pattern</strong></td>
<td>Works best when eye has just disappeared or evident on microwave imagery.</td>
<td>Accuracy dependent on centre location. Vis CDO under-estimates intensity for small strong TCs. DT estimates may be biased high at low latitudes.</td>
</tr>
<tr>
<td><strong>Eye patterns</strong></td>
<td>Enhanced IR eye method most objective of all patterns.</td>
<td>Visible method will underestimate intensity for small systems. Won’t detect eyewall fluctuations – use microwave.</td>
</tr>
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### Appendices

**Appendix**

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**Note:**

- **Table:** Summary of Tropical Cyclone Intensity Techniques
- **Technique:** Dvorak Technique, Curved band patterns, Shear patterns, Covered Centre pattern, Eye patterns
- **Advantages:** Worldwide usage, robust skill, intensity estimates across all ranges.
- **Limitations:** High uncertainty, cloud feature clarity, time constraints, subjective accuracy.
- **Methods:** Used globally, robust skill, intensity estimate, verification.
- **Data Sources:** Vis and IR cloud patterns, T-number, T4.0 and higher, Strong systems.
<table>
<thead>
<tr>
<th><strong>Surface Observations</strong></th>
<th>Surface observations are the most objective measure of surface winds at the location.</th>
<th>Obs usually underestimate the intensity as it is difficult for a single obs site to capture the max winds given the small zone of maximum winds near the centre. Siting and quality of anemometer can result in reported winds being unrepresentative of standard 10m surface winds. Elevation, terrain, anemometer height and obstructions are factors that can enhance or reduce reported winds. Ship wind reports may be unrepresentative because of quality, location and height of anemometers and flow variations because of the ship’s bulk. There are so few automatic weather stations in tropical ocean areas that it is infrequent to get a reliable report near the centre to use to estimate the intensity.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface Observations cont.</strong></td>
<td>Pressure observations near the centre can be used to derive maximum winds.</td>
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<td></td>
<td>Automatic sites reporting continuously are more likely to provide an accurate representative maximum wind.</td>
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<tr>
<td><strong>Scatterometers</strong> measure the roughness of the ocean surface to estimate wind speed.</td>
<td>Valuable technique for determining intensity of weaker TCs of 50 kn or less. Calibrated against known wind speeds.</td>
<td>Not useful for winds over 50 knots. Limited coverage both spatial and number of passes/day. Resolution insufficient to detect inner core of max winds. Accurate to ~ 50 knots. Slight under-estimation ~35-50kn. Narrow swath means path may miss the cyclone’s region of maximum winds.</td>
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<tr>
<td><strong>ASCAT</strong> On METOP-A and B satellites.</td>
<td>Retains accuracy in heavy rain so is the most accurate of scatterometers for tropical cyclones.</td>
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<tr>
<td><strong>Advanced Dvorak Technique (ADT)</strong> Uses IR imagery to objectively determine intensity using algorithms based on Dvorak principles. Developed at CIMSS – <a href="http://tropic.ssec.wisc.edu/real-time/adt/adt.html">ADT web page</a> <a href="http://tropic.ssec.wisc.edu/real-time/adt/adt.html">NOAA operational ADT</a></td>
<td>Objective technique calibrated against storms of known intensity. Available for every system globally via the web and updated at least hourly using latest IR image. Can identify periods of rapid intensification. Versions are updated regularly with improved algorithms. Includes microwave imagery to overcome known biases in covered centre patterns when intensity reaches 55 kn.</td>
<td>Sensitive to location accuracy. Struggles when the IR cloud signature is poorly defined. Overestimates for shear patterns especially during weakening.</td>
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<tr>
<td><strong>Microwave Sounders</strong> Intensity measured from upper-level temperature anomalies. AMSU, SSMIS</td>
<td>Independent of Dvorak. Calibrated against Atlantic and East Pacific systems of known intensity. Available for all TCs via the web. Improved algorithms as new sounders with higher resolution becoming available: SSMIS, ATMS.</td>
<td>Overestimates intensity of weak systems &lt; 50kn when there is convection but the vortex has not yet responded. Can underestimate intensity of small strong systems and when TC is towards the edge of the swathe because of lower resolution, especially for small systems. Eyewall diameter from JTWC&amp;ARCHER may be in error.</td>
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<tr>
<td>SATCON</td>
<td>Microwave Patterns</td>
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<tr>
<td>Consensus of ADT and microwave sounder techniques (CIMSS and CIRA). Developed at CIMSS. <a href="http://tropic.ssec.wisc.edu/real-time/satcon/">http://tropic.ssec.wisc.edu/real-time/satcon/</a></td>
<td>More accurate than each members – considers known weaknesses and 'intelligently' combines information. Automatically available globally via the web. Versions are updated with improved algorithms and potentially new techniques (e.g. SSMIS sounder).</td>
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<tr>
<td>Weaknesses of individual members (see ADT and AMSU). May miss ingesting CIRA AMSU estimates.</td>
<td>Indicates storm structure – sees through the high cloud. Can detect intensity changes more easily than conventional imagery esp. with eyewall variations.</td>
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<td>Limited number of sensors on polar orbiting satellites availability is less frequent.</td>
<td>Subjective without a defined answer; this may change in future as techniques such as ARCHER improve intensity techniques.</td>
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Microwave Patterns
Subjective view of microwave imagery at 85-91GHz for changes in convective structure, and 37GHz for low level circulation development.