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A new approach to forecasting mountain wave induced Clear Air Turbulence

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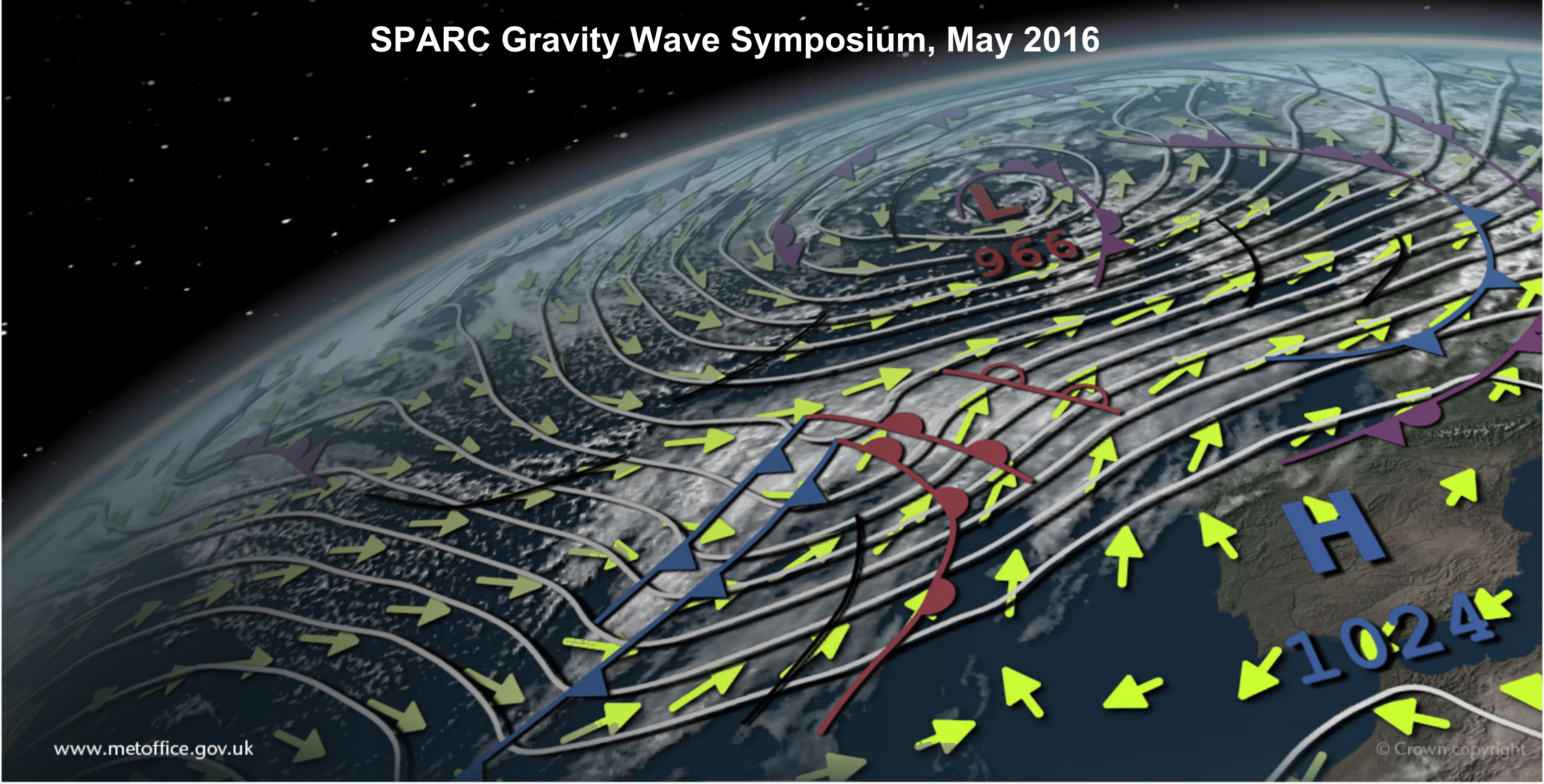

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Overview

Background: Forecasting mountain wave induced turbulence for aviation

A new diagnostic for predicting Mountain CAT

Verifying the new Mountain CAT predictor

Conclusions

Forecasting mountain wave turbulence for aviation

- **Atmospheric turbulence encountered in commercial aviation** – cause of most weather-related aircraft incidents
- **Mountain wave breaking** in the lower stratosphere is **one of the major causes** of it
- For **clear air turbulence** (CAT), there are **no visual clues** – pilots reliant on
    - **operational forecasts**
    - reports from other aircraft.
- Mountain waves typically sub-grid-scale in global forecast models
- Due to recent developments some NWP models (e.g. UK Met Office Unified Model; MetUM) **now able to resolve mountain wave activity explicitly**
    - **allows forecasts of mountain wave induced turbulence with greater accuracy** and confidence than possible before.

Mountain CAT predictors in the MetUM: **Parameterized to resolved**

Previously: "WAFC CAT predictor" – diagnose **mountain wave turbulence** from **subgrid GW stress** diagnosed from **orographic drag parameterization scheme**. Not ideally fit for purpose as:

- Stress realism limited by simplifications used in drag scheme
- Stress divergence, rather than stress, is associated with wave dissipation and turbulence

Proposed new method:

- latest version of MetUM dynamical core (ENDGame) **and** increased operational global model resolution (N768 ~17km at mid-latitudes)
- allows significantly improved representation of gravity waves
- Consequent possibility now of turbulence prediction based on model-resolved fields.

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Mountain CAT predictors in the MetUM: **A new diagnostic**

- Propose a **modified TKE diagnostic** using **model-resolved** fields

- Despite the improvements, the characteristically **fine-scale** phenomenon of mountain wave **breaking** is still unlikely to be resolved by global models

- Grey zone? – likely to resolve waves but under-predict dissipation

- To account for this, the modified TKE diagnostic
  - uses a long tail stability function
  - gives greater mixing (κ_m) at higher stabilities than unmodified.

Mountain CAT predictors in the MetUM: **A new diagnostic**

Diagnostic derived via bulk formula based on **eddy diffusivity for momentum**, κ_m, as:

$$TKE = \left(\frac{\kappa_m}{lC} \right)^2 ,$$

where C is a tuneable constant (set to 0.5) and ***l*** is **mixing length**.
Modified TKE uses a diagnosed eddy diffusivity which assumes a **long tail stability function**:

$$f(Ri) = \frac{1}{1+10Ri} ,$$

where Ri is gradient Richardson number. κ_m is then defined as

$$\kappa_m = l^2 S f(Ri) ,$$

where S is **modulus of vertical wind shear**.

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Methodology for verifying new diagnostic

Use automated commercial aircraft turbulence reports as observations (**Global Atmospheric DataSet – GADS**)

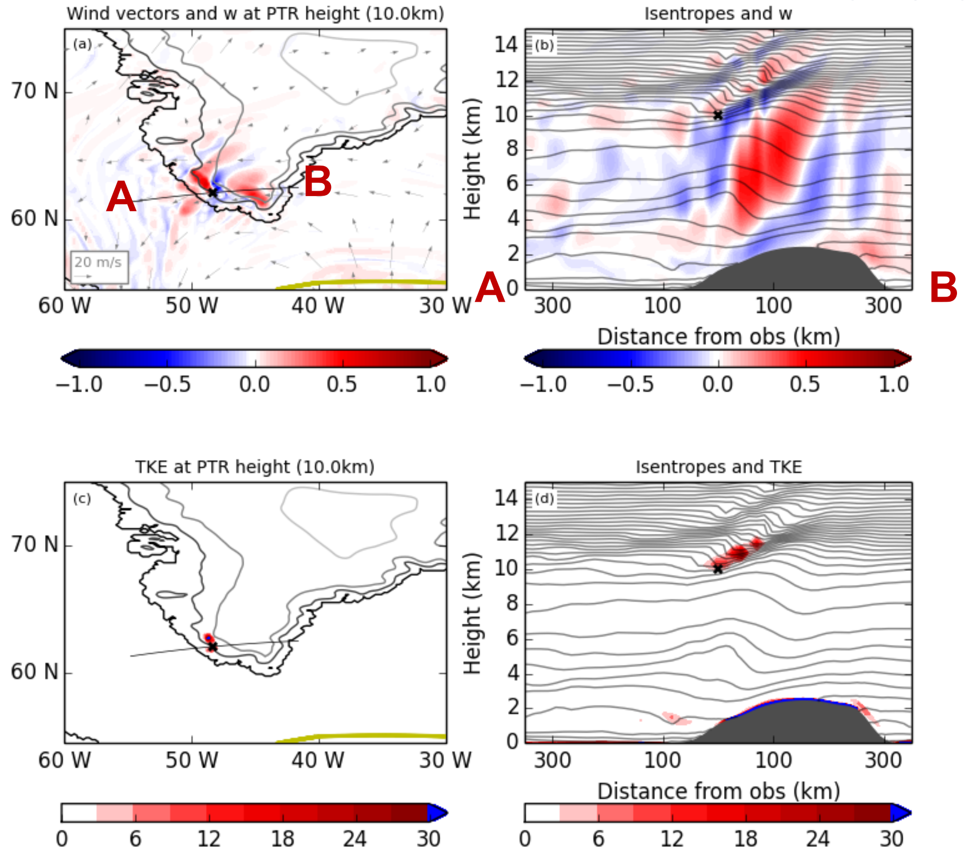
- over Greenland (mountain wave induced turbulence an identified hazard in this region)
- Derived Equivalent Vertical Gust (DEVG) metric
- Light / Moderate / Severe turbulence categories

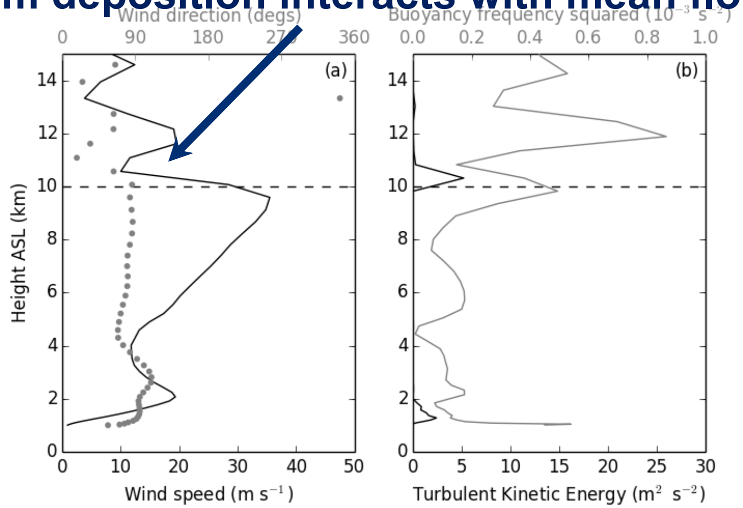
Two approaches:

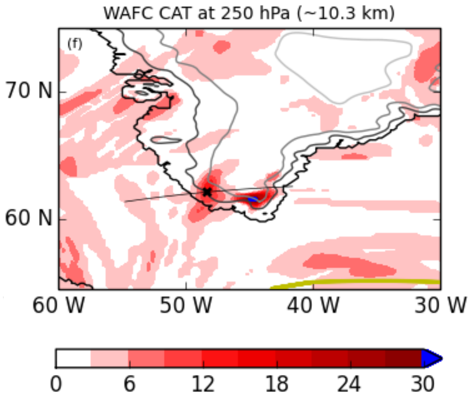
- **Case studies**
  - May 2010 Severe (Sharman et al. 2012)
  - GADS Moderate, widespread
  - GADS Severe, strong shear
- **Long-term verification** (17-month)

Severe Localised Turbulence Case study

Wave-induced critical level breaking -- momentum deposition interacts with mean flow



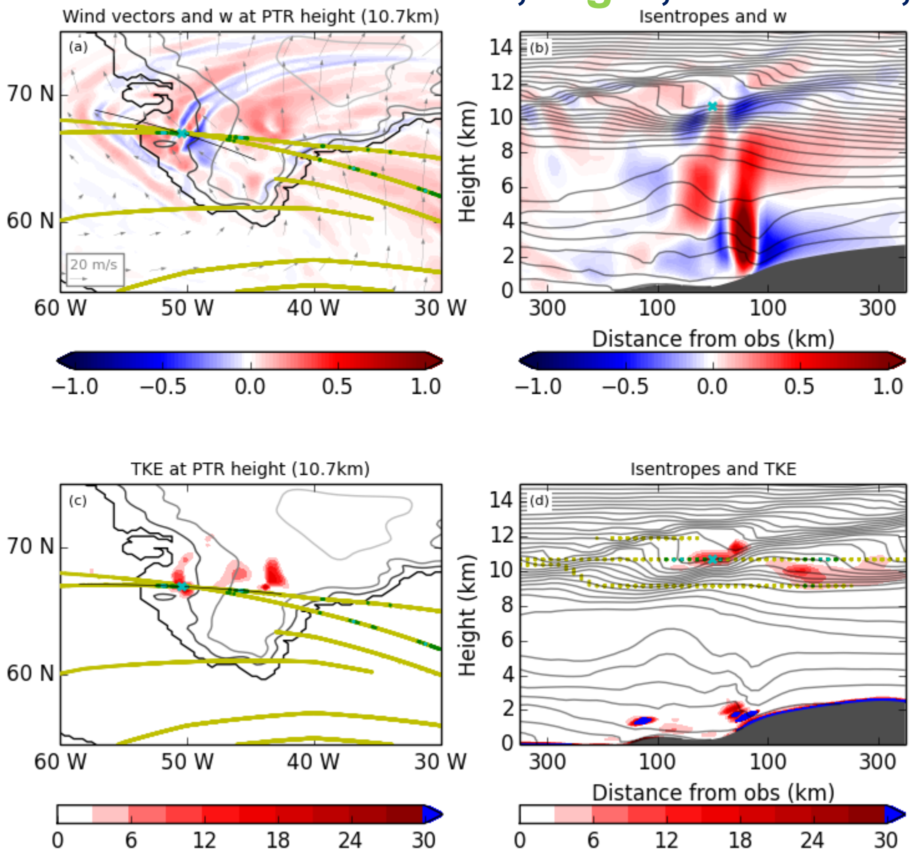


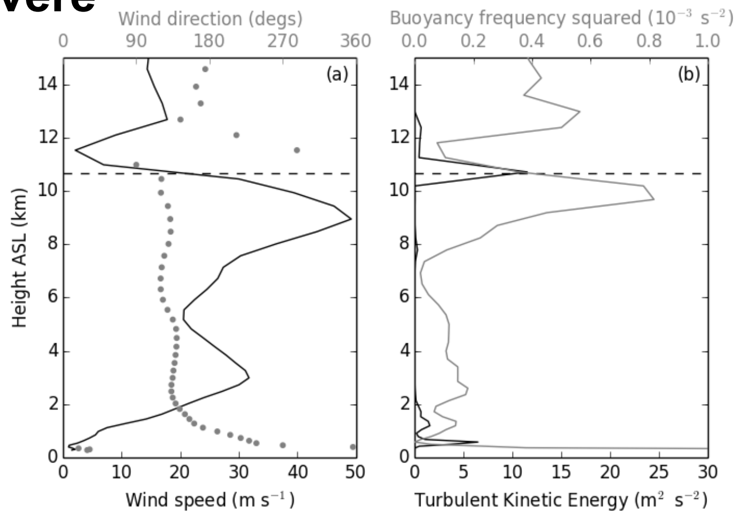


Case details see Sharman et al. 2012

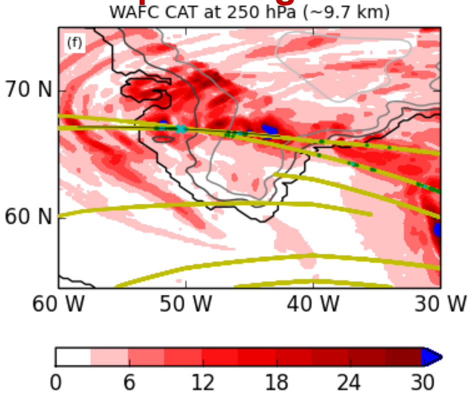
GADS Moderate Case

Tracks: No turbulence, Light, Moderate, Severe

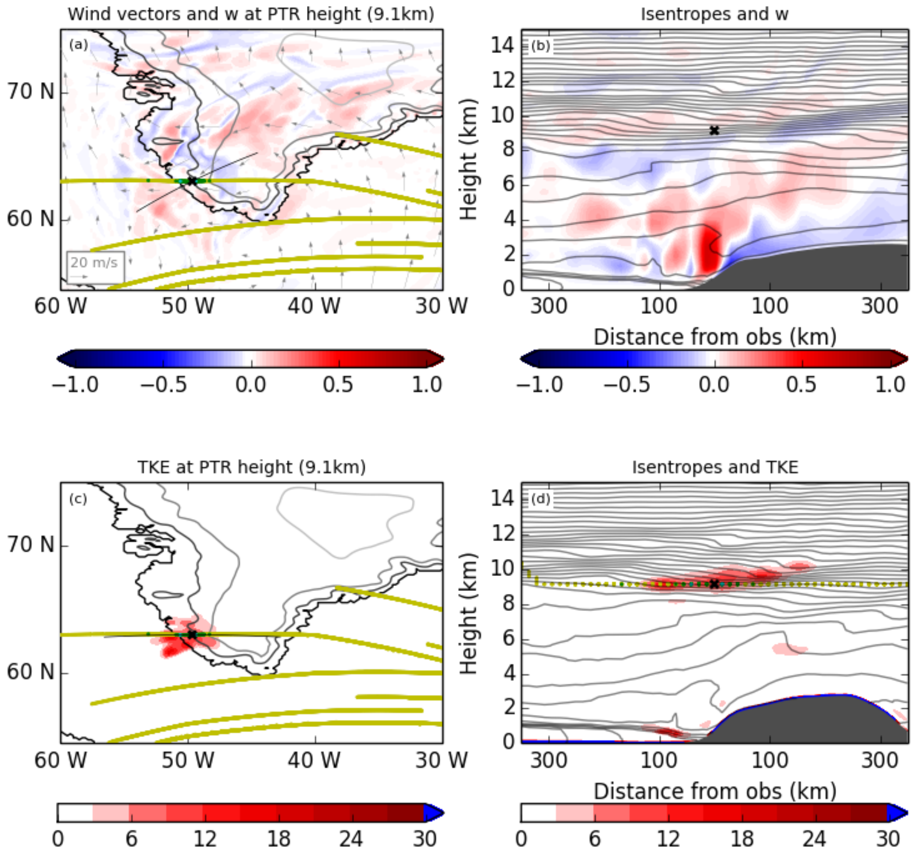




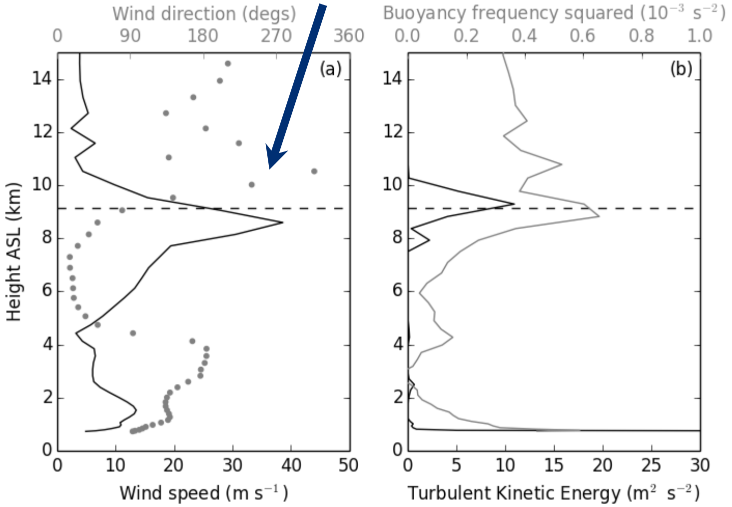
Peak turbulence report height



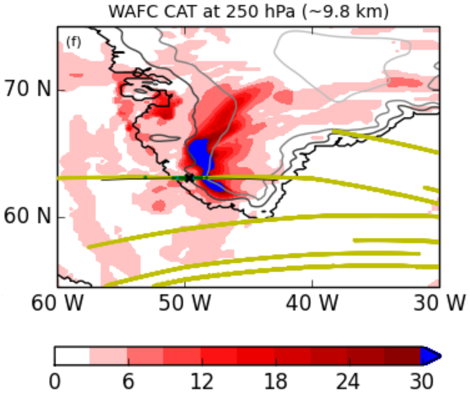
GADS Severe Case



Shear-induced critical level breaking -- flow direction northerly to southerly



PTR height



Long-term verification: **method**

GADS reports

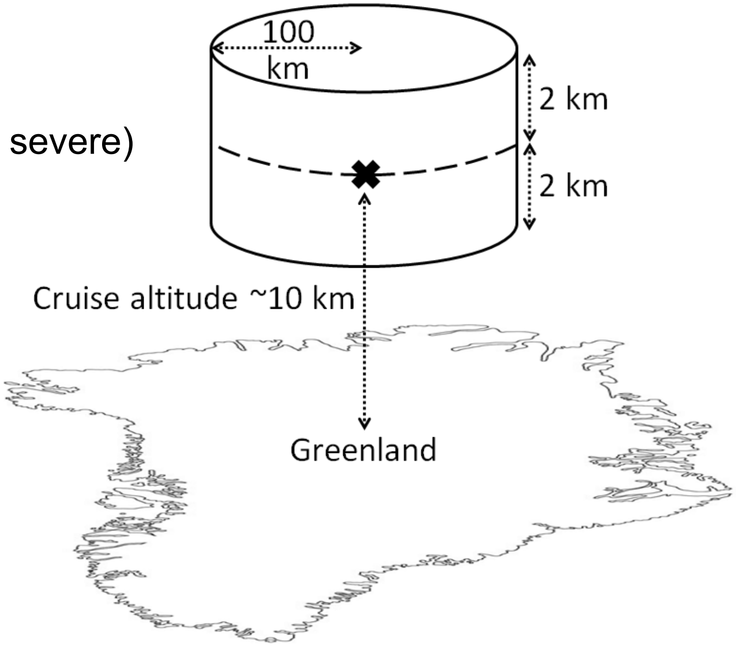
- over Greenland
- 17 month period (1st August 2014 to end December 2015).

Corresponding **model diagnostics:**

- closest forecast time, and must be within one hour of each report
- averaged over area within 100 km (radius) and over depth +/- 2 km of each report

Evaluated for:

- **All turbulence** reports:
  482 reports (16 of which moderate to severe)
- **1 % of no-turbulence** reports:
  2124 reports



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Long-term verification: **results**

	No turbulence	Light turbulence	Moderate-severe turb.
Number of reports	2124	466	16
Mean TKE_{mean}	**0.04**	**0.52**	**0.91**

Hit rate = likelihood of detection = Hits / (Hits + Misses)
False alarm rate = FalseAlarms / (Hits + FalseAlarms)

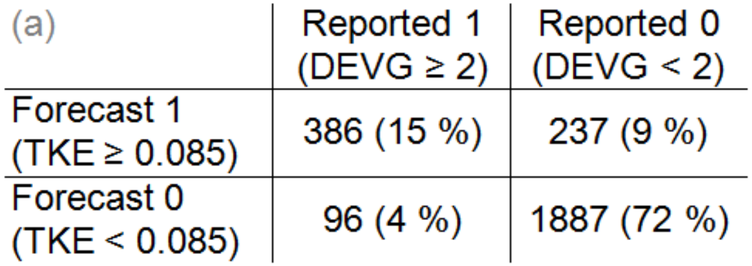
Aim to **maximise hit** rate and **minimise false alarm** rate

Forecast	**Turbulence Reported**	
	True	False
True	HIT	False Alarm
False	MISS	NULL

Long-term verification

Define [report = 1] where DEVG >= 2
Define [forecast = 1] TKE threshold so that **hit rate** >= 80 %

Using mean TKE (within cylinder):



(a)	Reported 1 (DEVG ≥ 2)	Reported 0 (DEVG < 2)
Forecast 1 (TKE ≥ 0.085)	386 (15 %)	237 (9 %)
Forecast 0 (TKE < 0.085)	96 (4 %)	1887 (72 %)

Hit rate = 80 %
False alarm rate = 38 %

Conclusions

- Modern global NWP models are capable of representing a sufficient proportion of the gravity-wave spectrum to allow mountain wave CAT to be **directly diagnosed** from model **resolved wave** motions
- TKE diagnostic has
  - demonstrated skill in predicting mountain CAT
  - superior skill compared with current operational product.