Development of JMA's New Turbulence Index

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Previous Method in JMA

Cause of Turbulence
- KH instability (CAT)
- Convective clouds
- Mountain waves
- Mid-level cloud bases
- Transverse bands
- Other

Forecasting Method
- mainly VWS
- Empirical method
- Empirical method
- Empirical method

Problems
- Although VWS has the same or better accuracy compared to other indices, the accuracy is not enough.
- VWS is not adequate to forecast turbulences unrelated to KH instability.
- We had not used quantitative indices for non-CAT turbulences.
Ideas for Improvement

Cause of Turbulence

- KH instability (CAT)
- Convective clouds
- Mountain waves
- Mid-level cloud bases
- Transverse bands
- Other

Forecasting Method

- Mainly VWS
- Develop an index

Forecasting Method

- Skew wind shear
- Convective cloud index
- Lee wave index
- Vertically propagating mountain wave index
- Mid-level cloud-base index
- Transverse band index

Combine newly-developed indices and existing indices by using logistic regression method

→ JMA's new turbulence index (TBIndex)

Expected Effect

- To be able to predict various kinds of turbulences
- To improve forecast accuracy
Making procedure

**Step 1. Select Independent Indices**

Become easy to understand which indices contribute to TBindex

- 6 newly-developed indices
  - Skew wind shear
  - Convective cloud index
  - Lee wave index
  - Vertically propagating mountain wave index
  - Mid-level cloud-base index
  - Transverse band index

- 9 existing indices
  - Richardson number
  - Temperature gradient
  - Miyakoshi’s Index (TPI, TSI)
  - VWS
  - HWS
  - Ellrod's Index (TI1, TI2)
  - Dutton's empirical index

Indices whose correlation coefficient is 0.6 or less are selected

10 indices are selected for explanatory variables
Step 2. Logistic Regression Method

- Logistic regression is a kind of multiple linear regression
  - Objective variable: Log-odds ratio $\ln(p/1-p)$
    - Probability of occurrence $p$ can be calculated from the log-odds ratio
  - Training data set: Two years from 2008 to 2009
  - Observation data: PIREPs
    - We have about 1.8 million reports include 16 thousand (0.89%) MOG turbulence reports in this period

- The regression equations are stratified by altitude
  - Cause of turbulence is different in altitudes
Step 3. Adjustment of the Index

It is unfavorable to regard the probability value as a "probability of turbulence"

1. The probability is **NOT** a probability of turbulence in the real sense
   - Observation data (PIREPs) tend not to be reported in no-turbulent conditions

2. The optimal threshold is generally different by altitude
   - Operators have to change a threshold by altitude when they attempt to make optimal forecast

In stead of using the probability value as a "probability of turbulence", adjust the value to **be able to forecast optimally regardless of altitude by a single threshold**
By taking this conversion for every altitude, the optimal thresholds are expected to become 3.0 regardless of altitude.
**Verification** Jan. – Dec. 2010 (independent on the training data)

![Graph showing PODy and 1-PODn for TBindex and VWS](image)

<table>
<thead>
<tr>
<th>Speed (kt/1000ft)</th>
<th>PODy</th>
<th>1-PODn</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>3.0</td>
<td>0.75</td>
</tr>
<tr>
<td>10</td>
<td>2.6</td>
<td>0.42</td>
</tr>
<tr>
<td>12</td>
<td>3.4</td>
<td>0.36</td>
</tr>
</tbody>
</table>

※ Error bars: 95% confidence interval

- **PODy**: Probability of Detection "YES" events
- **PODn**: Probability of Detection "NO" events

Forecast with low 1-PODn and high PODy is good

TBindex improves forecast accuracy significantly compared to VWS
Verification Jan. – Dec. 2010 (independent on the training data)

The peak value is larger than that of VWS.

Heidke Skill Score according to altitudes.

HSS reaches the maximum at about TBindex=3.0 in every altitudes → 3.0 become the optimal threshold regardless of altitude as expected.
Case Study 1

In and Top of Cloud

Turbulences occurred in and top of convective clouds. A severe turbulence reported around the cloud top (FL270-250).

9-hour forecast at FL270
Initial time: 03 UTC 31st Oct 2010

↑ IR imagery at 12 UTC 31st Oct 2010 and MOG turbulences observed between 11 and 13 UTC

← VWS is small (3 ~ 6 kt/1000ft) in the area of severe turbulence, but TBindex is large because of large skew wind shear and large convective cloud index
Case Study 2
Lee Wave

↓ 6-hour forecast at FL070
Initial time: 21 UTC 5th Feb 2010

![Map with TBindex, Lee wave index, and VWS](image)

A number of moderate turbulences reported in the lee of mountain ranges below FL140

↑ IR imagery at 03 UTC 6th Feb 2010 and MOG turbulences observed between 02 and 04 UTC

← VWS is small (3 ~ 6 kt/1000ft) in the area of turbulence, but TBindex is large because of large lee wave index.
Case Study 3
Clear Air Turbulence

↓ 6-hour forecast at FL290
Initial time: 00 UTC 8th Dec 2010

A number of moderate turbulences reported between FL240 and FL340 around a trough with a convective outflow boundary

↑ IR imagery at 06 UTC 8th Dec 2010 and turbulences observed between 05 and 07 UTC

← VWS is small (3 ~ 6 kt/1000ft) in the area of turbulence, but TBindex is large because of large skew wind shear
Summary

JMA developed a new turbulence index (TBIndex)

- Existing indices and newly-developed indices are combined by logistic regression method
- By using only independent indices for explanatory variables, operators can easily understand which indices contribute to TBIndex
- TBIndex can predict various kinds of turbulence in a comprehensive manner by a single threshold (TBIndex = 3.0)
- TBIndex improves forecast accuracy significantly compared to VWS