Retrieving Surface Wind Directions from Neural-Net Wind Speed Retrievals in Tropical Cyclones

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Based on SAR Tropical Cyclone (TC) Wind Retrievals
(See Horstmann, 17:45)

• SAR: 1 km wind vector retrievals in TCs
  (Horstmann, Wackerman)
  – Wind directions from imprint of TC boundary layer
    (TCBL) roll vortices
  – Wind speeds from model functions (CMOD5N (co-
    pol), Cross-pol, X-band
  – ~ 5-6 m/s RMS at hurricane force (up to low Cat-3)
  – Directions ~ 20°RMS rel. drop sondes, QuikSCAT
    (no-rain flag)
  – Wind retrieval quality flags
Calculate Sea-Level Pressure (SLP) Patterns from SAR imagery

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2. Standard $U_{10}$ processing
   - Mask low confidence winds
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4. Least-squares fit of pressure surface to $\nabla P$ vectors
   - Constraint: $\nabla \cdot V_{Geostrophic} = 0$
   - Scene-wide dynamical consistency
   - Normalize to observations (optional)
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5. Use SLP pattern to force TCBL model and derive “SLP-filtered” surface wind vector field
   – Fill-in masked regions
TCBL: Nonlinear *Mean Flow* Dynamics are Important

- “Standard” PBL Scaling: $U \cdot \nabla U \ll \overline{u' \cdot \nabla u'}$
- Typhoon TCBL scaling: $U \cdot \nabla U \sim \overline{u' \cdot \nabla u'}$
- Fully nonlinear TCBL model (Foster, 2009) currently too costly

\[ U_{total} = U + u' \]

(rotated into surface wind coordinates)

- Approximate nonlinear mean flow dynamics using gradient wind model
- Storm-relative correction

\[ \frac{1}{\rho} \frac{dP}{dn} = f V_g \left( 1 + \frac{V_g}{f R} \right) \]

\[ R = \alpha r; \quad \alpha \sim 0.65 \]
Two-Layer TCBL Model:

- Analytic match of inner and outer layers
- Inner (surface) layer
  - COARE/CBLAST-like surface layer
    - $C_{D_{max}} = 2.7 \times 10^{-3}$ for $U_{10} > \sim 30 \text{ m s}^{-1}$
    - $C_{H} \sim \text{const}$, when stratification is included
- Outer layer
  - Nonlinear mean flow dynamics
  - TCBL depth increases with radius
- Assume TC interior close to gradient-wind, $V_g$, balance
  - $U_{10} = U_{10}(V_g)$ “direct model”
  - $V_g = V_g(U_{10})$ “inverse model”
TCBL: Mean boundary layer depth increases with radius

- Swirling flow:
  - Positive Rayleigh discriminant defines gradient wind-dependent time scale
- \( I < f \), inner core; \( I \to f \) as \( r \to \infty \)
- \( \delta = \sqrt{2K_m/I} \)

\[
l^2 = \left( f + \frac{2V_g}{r} \right) \left( f + \frac{V_g}{r} + \frac{\partial V_g}{\partial r} \right)
\]


Cat-1 Typhoon Malakas

- Malakas 22 Sep, 2010, 20:30 UTC
- AF C-130J arrived 15 minutes after SAR overpass
- SFMR & 28 Drop Sondes
Malakas 22 Sep: Drop Sonde Surface Pressure

- RMSE = 1.7 mb
- $N = 28$

$\frac{N(N-1)}{2} = 378 \text{ pairs of sondes}$

- SLP pair-wise differences (PWD) give sense of SLP pressure shape retrieval

- SLP RMS < 2 mb
- SLP Pair-Wise Difference (PWD) RMS < 2.5 mb
Five SAR Scenes Compared to Drop Sonde Surface Pressure

<table>
<thead>
<tr>
<th></th>
<th>SLP Bias (mb)</th>
<th>SLP RMS (mb)</th>
<th>PWD Bias (mb)</th>
<th>PWD RMS (mb)</th>
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<tbody>
<tr>
<td>SAR</td>
<td>0.1</td>
<td>2.8</td>
<td>0.6</td>
<td>2.9</td>
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</tbody>
</table>

- Overall ~3 mb RMS compared to drop sondes

Lili      30 Sep, 2002
Katrina   27 Aug, 2005
Helene    20 Sep, 2006
Ike       13 Sep, 2008
Malakas   22 Sep, 2010
Malakas 22 Sep, 2010: Drop Sonde Surface Wind

<table>
<thead>
<tr>
<th></th>
<th>Speed RMS Good, N = 22 (m/s)</th>
<th>Speed RMS All, N = 28 (m/s)</th>
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</thead>
<tbody>
<tr>
<td>RAW</td>
<td>3.3</td>
<td>5.6</td>
</tr>
<tr>
<td>SLP-Filter</td>
<td>3.2</td>
<td>3.9</td>
</tr>
</tbody>
</table>

RAW winds in masked regions
Malakas 22 Sep, 2010 20:30: SFMR

<table>
<thead>
<tr>
<th>Condition</th>
<th>N</th>
<th>RMS (m/s)</th>
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</thead>
<tbody>
<tr>
<td>Good Only</td>
<td>5,454</td>
<td>3.4</td>
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<tr>
<td>RAW</td>
<td></td>
<td>3.4</td>
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<tr>
<td>SLP-Filter</td>
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<td>3.4</td>
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<tr>
<td>Masked Only</td>
<td>4,427</td>
<td>6.1</td>
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<tr>
<td>RAW</td>
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<tr>
<td>SLP-Filter</td>
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<td>4.9</td>
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<tr>
<td>All Data</td>
<td>9,881</td>
<td>7.8</td>
</tr>
<tr>
<td>RAW</td>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td>SLP-Filter</td>
<td></td>
<td>4.2</td>
</tr>
</tbody>
</table>

- SLP-filtered and RAW winds are equal quality in good region
- SLP-filtered winds are better quality than RAW winds in masked region
- SLP-filtered winds have overall lower RMS

Black: SFMR wind speed
Blue: RAW input wind (unmasked)
Red: SLP-filtered
Cyan: SFMR Rain Rate

Not plotted
Five SAR Scenes Compared to SFMR

- **SLP-filtered wind RMS is the same in good and masked regions**
- **RAW winds in masked region are lower quality than RAW winds in good region**
- **SLP-filtered winds has lower RMS overall**

### Good Only
- **RAW**: 5.7 m/s
- **SLP-Filter**: 5.5 m/s

### Masked Only
- **RAW**: 8.6 m/s
- **SLP-Filter**: 5.4 m/s

### All Data
- **RAW**: 7.4 m/s
- **SLP-Filter**: 5.4 m/s

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**Dates:**
- **Lili**: 30 Sep, 2002
- **Katrina**: 27 Aug, 2005
- **Helene**: 20 Sep, 2006
- **Ike**: 13 Sep, 2008
- **Malakas**: 22 Sep, 2010
QuikSCAT Neural Net GMF
(See Stiles, 17:00)

• Special Speed-only GMF for TCs
  – 10 years of data at JPL:
    http://tropicalcyclone.jpl.nasa.gov/hurricane/gemain.jsp
  – NN trained to 2005 H*WIND
  – 12.5 km pixels

• Scatterometer wind directions are **bad** in TC inner core
  – Fix with ZU-SLP retrieval iteration
Hurricane Bill
20 Aug 2009, 09:45
QuikSCAT NN

Note: “squared-off” vortex shape & misplaced storm center
Deformation Flow from QuikSCAT
ZU-SLP directions
Investigation of Circulation Center

• Use initial guess at center (HRD, Best Track, etc.)
• Find metric based on circulation near RMW (radius maximum wind)
• Circulation center varies greatly over depth of TCs
  – Best track/HRD near flight level or “steering” level
  – Scatterometer data needs surface circulation center
Use flow partition analysis & SLP data to refine estimates of surface-level circulation center

- Best fit to SLP obs
- Find flow partition metrics e.g.:
  - Maximize circulation near RMW
  - Location of deformation cull
  - Comparison with numerical simulations (e.g. UMCM 3-way coupled model)
UMCM AWO (Ike, approaching landfall)

(First-look results of UMCM modeling system TCBL response to wave model)

(Not rotated in rad/tan contributions)

UMCM AWO (Ike, approaching landfall)
Note smaller Convergent radial flow Magnitudes Compared to SR Urad
Future Research

• Upgrade TCBL model in SLP retrieval
  – Improve nonlinear dynamics ala Foster (2009)

• Use SLP to improve wind directions for scatterometers in TC conditions
  – Iterate SLP/partition analysis

• Combine with upper-level winds to study in→up→out TC-scale secondary circulation
  – Flow partitions at two levels

• Investigate TC TCBL roll vortices (SAR)
  – TCBL parameterization
  – Improve SAR wind directions
Summary

- Developed new methodology to calculate Sea-Level Pressure patterns from SAR images of Tropical Cyclones
  - 1 km pixels
  - <3 mb RMS compared to drop sondes
- Scene-wide SLP-filtered surface winds
  - Similar quality to RAW SAR winds in unmasked regions
  - Fills gaps where SAR winds are less certain (masked)
  - SAR wind speed comparable to SFMR RMS
    - SAR has more coverage
    - Cat2 + model functions not well established or tested
  - Dynamically consistent SLP and SLP-filtered $U_{10}$
- Apply to Scatterometer NN data sets
  - Coarser resolution
  - Longer and larger data set (QuikSCAT)
  - OSCAT & ASCAT scatterometers currently operational
  - RapidSCAT & HSCAT coming
Malakas 22 Sep, 2010

RAW SAR wind vectors
Mask less certain winds

SLP-filtered wind vectors
SLP contours (4mb interval)

Masked regions tend to be high wind regions at low incidence

Superposed (adjusted for storm translation):
SFMR wind speeds
Drop sonde $U_{10}$ and directions

(direcions every 40 km)
C-130J Surface Pressure

Black: C130 Sea-level Pressure from Flight Level Data
Red: SAR sea-level pressure
TCBL Model Development Needed for SLP Retrieval

• Approximated nonlinear mean flow dynamics
  – Storm-relative nonlinear dynamics corrections
  – Modified gradient wind correction
• Dynamical increase of TCBL depth with radius
  – Based on rotational “stiffness” of swirling flow
• High winds limit on $C_D^{\text{max}} = 2.5 \times 10^{-3}$