Adjoint-Based Analysis of Observation Impact on Tropical Cyclone Intensity Forecasts

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Objective

- In what ways are the TC intensity forecast sensitive to initial conditions?
- How do assimilated observations impact the TC intensity forecast?
- What differences exist between sensitivity/ob-impact of 24 and 48 hr forecasts?
Nonlinear NWP model evolves analysis state ($X_0$) to forecast state ($X_f$).

TC intensity forecast can be defined as a function of the final state – $R$. 
Adjoint Models

**Nonlinear NWP model** evolves analysis state \((X_0)\) to forecast state \((X_f)\).

**TC intensity forecast** can be defined as a function of the final state – \(R\).

Adjoint model evolves backward along nonlinear NWP trajectory, computing the gradient of some function of the forecast state \((R)\) to perturbations to the initial state – **sensitivity of forecast TC intensity to initial state**.
Sensitivity to Initial State

Hurricane Sandy – Storm-centered composites from model initialized 0600 UTC 24 Oct - 1800 UTC 28 Oct 2012

Sensitivity of 24-hr intensity forecast to wind perturbations near 500 hPa
Sensitivity to Initial State

Sensitivity of 48-hr intensity forecast to wind perturbations near 500 hPa

Higher sensitivity upstream, especially near trough and extending into jet
Sensitivity to Initial State

Sensitivity of 48-hr intensity forecast to wind perturbations near 500 hPa

Higher sensitivity *upstream*, especially *near trough* and *extending into jet*
Sensitivity of 48-hr forecast migrates toward larger radii at low levels (left) and up to mid/upper troposphere toward the upstream environment (right), compared to sensitivity at 24-hr
Observation Impact

- WINDSAT–TPW
- SSMI–TPW
- AVHRR–WIND
- AIREP
- LEO–GEO–WIND
- MODIS–WIND
- WSAT–SFC–WIND
- MHS
- SSMI–SFC–WIND
- ASCAT–SFC–WIND
- GPM–MET–R–O
- TC–Synth
- LandSfc
- AMDAR
- SSMIT
- AQUAS
- AMSU–A
- IASIS
- ShipSfc
- RAOBS
- CLD–WIND
- MDCRS

24-hr forecast impact

\[
\left\langle \frac{\partial R}{\partial x_{0}} \right\rangle_{inv}
\]
Highly improved impact from **MDCRS/AMDA**, **AMVs**, and **Radiosondes** at 48-hrs
Observation impact follows a power-law distribution: Significant contribution of total impact from a small minority of very high-impact obs.
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Relationship is observed for obs even within small radii of TC center
Contribution From Large Impact Obs

**Observation impact follows a power-law distribution:** Significant **contribution** of total impact from a **small minority** of very high-impact obs

Relationship is observed for obs **even within small radii** of TC center
In general, **half** of the total observation impact on TC intensity is contributed by **3-5%** of the total observations! The remaining ~95% of observations contribute the other half.
**Sensitivity** of intensity forecast at mid-range can extend over a **broad region**

**Impact** on intensity forecast caused by a **small minority** of total observations

**Satellite** observations (AMVs, radiances, etc) seem particularly **well-suited** to this task.