Observation Impact on Tropical Cyclone Forecasts: An Adjoint Approach

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1. What is adjoint-derived observation impact?

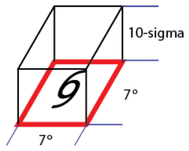
Just as the data assimilation system computes an analysis state from a background state and an **observation vector**, and the forecast system computes a forecast state from the analysis state, the adjoint of these systems can be used to progress backward, defining the sensitivity of some function of the forecast state (R) to the **individual observations**.

$$\left(\mathbf{x}_b, \mathbf{y}\right) \xrightarrow{DA\ System} \mathbf{x}_a \xrightarrow{Fcst\ System} \mathbf{x}_f$$

Operational (forward) analysis/forecast system

$$\left(\frac{\partial R}{\partial \mathbf{x}_b}, \frac{\partial R}{\partial \mathbf{y}}\right) \xleftarrow{DA\ Adj} \frac{\partial R}{\partial \mathbf{x}_a} \xleftarrow{Fcst\ Adj} \frac{\partial R}{\partial \mathbf{x}_f}$$

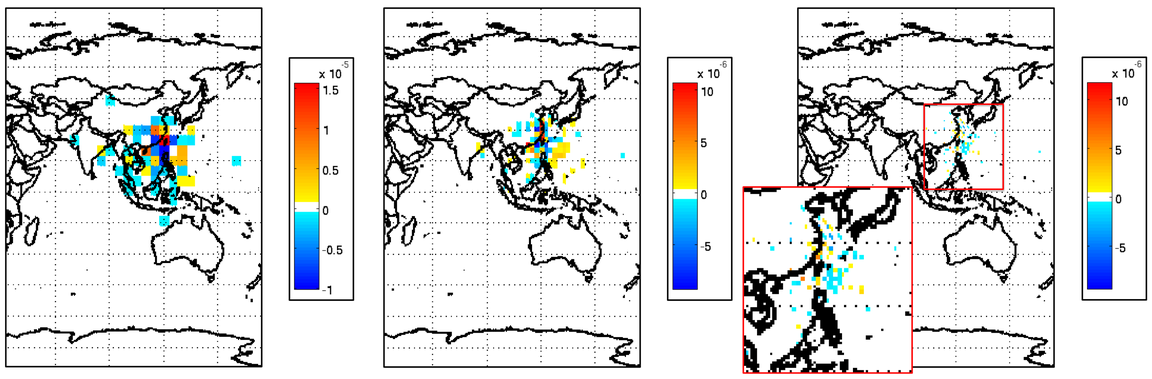
Adjoint of analysis/forecast system



R = vorticity surrounding forecast position of tropical cyclone

$$\frac{\partial R}{\partial \mathbf{y}} =$$ **contribution of any observation in y to forecast TC intensity**.

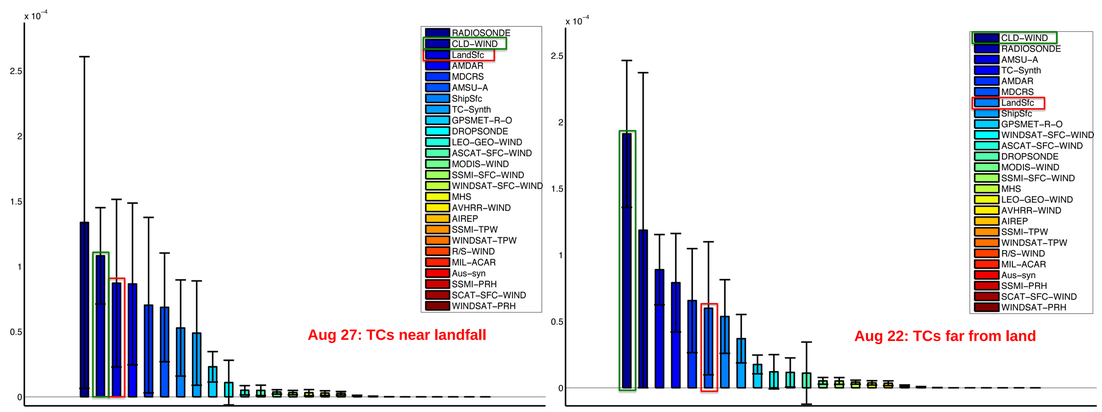
2. Observation impact by location



5x5 Degree Boxes | **2.5x2.5 Degree Boxes** | **1x1 Degree Boxes**

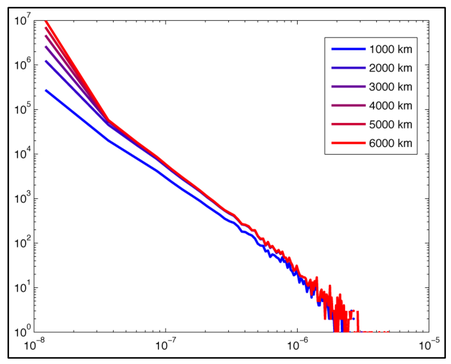
As impact is summed in smaller and smaller regions, the impact of all observations **recedes into a 'dust'**, with ever more poorly defined regions of positive and negative impact.

3. Observation impact by context

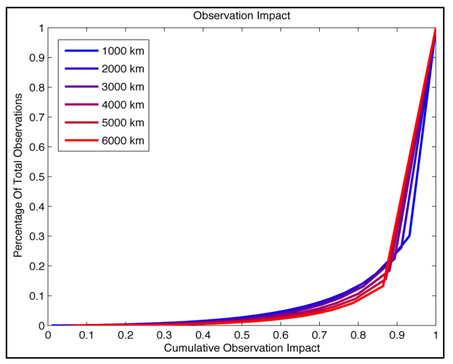


Rank of observation platforms depends heavily on context: Impact of land-based observations gains significant priority when TCs are **near landfall**. When TCs are remote from land, the impact of land-based observations is smaller, while **cloud-winds** (atmospheric motion vectors) become dominant.

4. Importance of high-impact observations

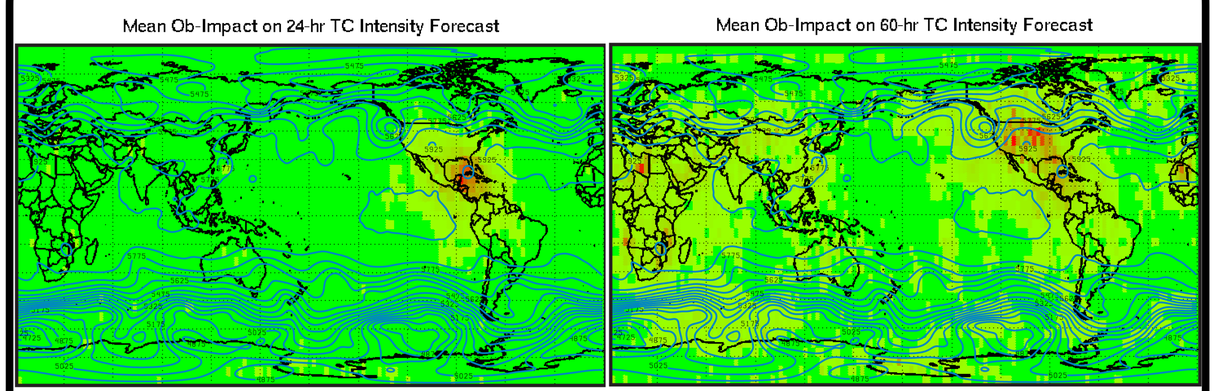


Impact of observations near the TC display a **power-law distribution**: the total impact is commanded by a very small subset of very high-impact observations



In general, roughly **half** of the total observation impact on TC intensity is achieved by **7%** of the total observations.

5. Observation impact by forecast length



While observation impact on the short-range forecast extends **radially out from the TC center**, observation impact on the mid-range forecast **migrates upstream**, preferentially toward regions of high-density observations over land.