A Novel Approach to Modeling Tropical Cyclone Structure Change

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Doesn't this logo look like Simon's cat?

Introduction

- **Hurricane track forecasts are good.** 🙂
- **Hurricane intensity forecasts are less good.** ☹
- **Numerical models try to do both of these at the same time.**
- **If we linearize dynamics, are the higher-order terms small enough that we can get away with treating these problems separately?**

- **Introducing: *Tangent Linear Inverse Modeling (T-LIM)***

Philosophy: Let the data tell you about the dynamics.

For the observational part of the study we use the NESDIS MTCSWA [Multi-Platform Tropical Cyclone (TC) Surface Wind Analyses] (Knaff and DeMaria 2006).

Let x denote the state vector of a particular TC. For the MTCSWA, we use the 200x36 wind speed field in cylindrical coordinates so x is a 7200 long vector. A general equation for x is

$$\boxed{\frac{dx}{dt} = n(x,t) + F(t)}$$

$n(x,t)$: internal dynamics of the system

$F(t)$: the deterministic, external forcing, e.g., SST and upper-tropospheric 'exhaust' temperature

Average over an ensemble of TCs having similar properties (e.g., storm longevity) and driven by similar forcing (average denoted by <•>):

$$\frac{d < x(t) >}{dt} = < n(x,t) > + F(t)$$

We'll look a lot at mean dynamical properties in this poster. Notice the means are time-dependent.

The next step is to look at internal variability. Let

$$y(t) = x(t) - <x(t)>.$$

Then

$$\frac{dy}{dt} = n(x,t) - < n(x,t) > \equiv \Delta n(y,t).$$

Let's say $t = 0$ when a TC is first taken seriously (genesis). Linearize Δn about $y(t)=0$, but *keep* the higher order terms:

$$\frac{dy}{dt} \approx \left(\frac{\partial \Delta n}{\partial y}\right)_{y=0} y + H.O.T. \equiv L(t)y + \xi.$$

We assume (and verify later) that the *predictable* dynamics are described by the linearized term and that *H.O.T.* is rapidly varying. For short times Δt,

$y(t_o + \Delta t) \approx \exp(L\Delta t)\, y(t_o)$ + random terms uncorrelated with $y(t_o)$.

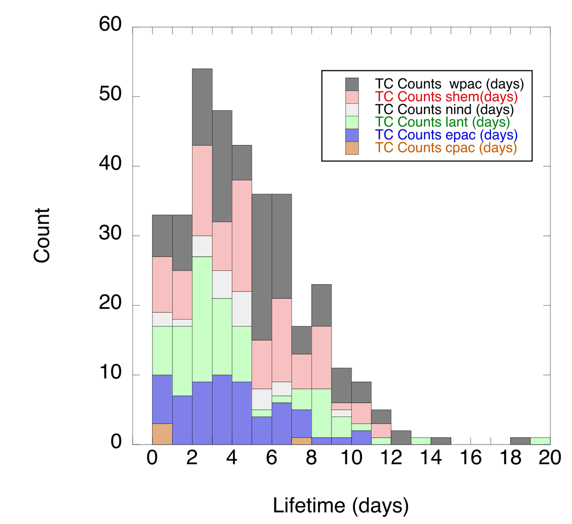
Finally, $\mathbf{G}(t_o, \Delta t) \cong \exp(L\Delta t) \approx <y(t_o + \Delta t)\, y^{\mathrm{T}}(t_o)><y(t_o)\, y^{\mathrm{T}}(t_o)>^{-1}$.

$$y(t_o + \Delta t) \approx \mathbf{G}(t_o, \Delta t)\, y(t_o)$$

$\mathbf{G}(t_o, \Delta t)$ ***is a data-based dynamical model***

Data Stratification

Storms during 2010-2013 in the MTCSWA data set are stratified by longevity.



Legend:

wpac = western Pacific
epac = eastern Pacific
cpac = central Pacific
shem = Southern Hemisphere
nind = Indian Ocean
lant = Atlantic Ocean

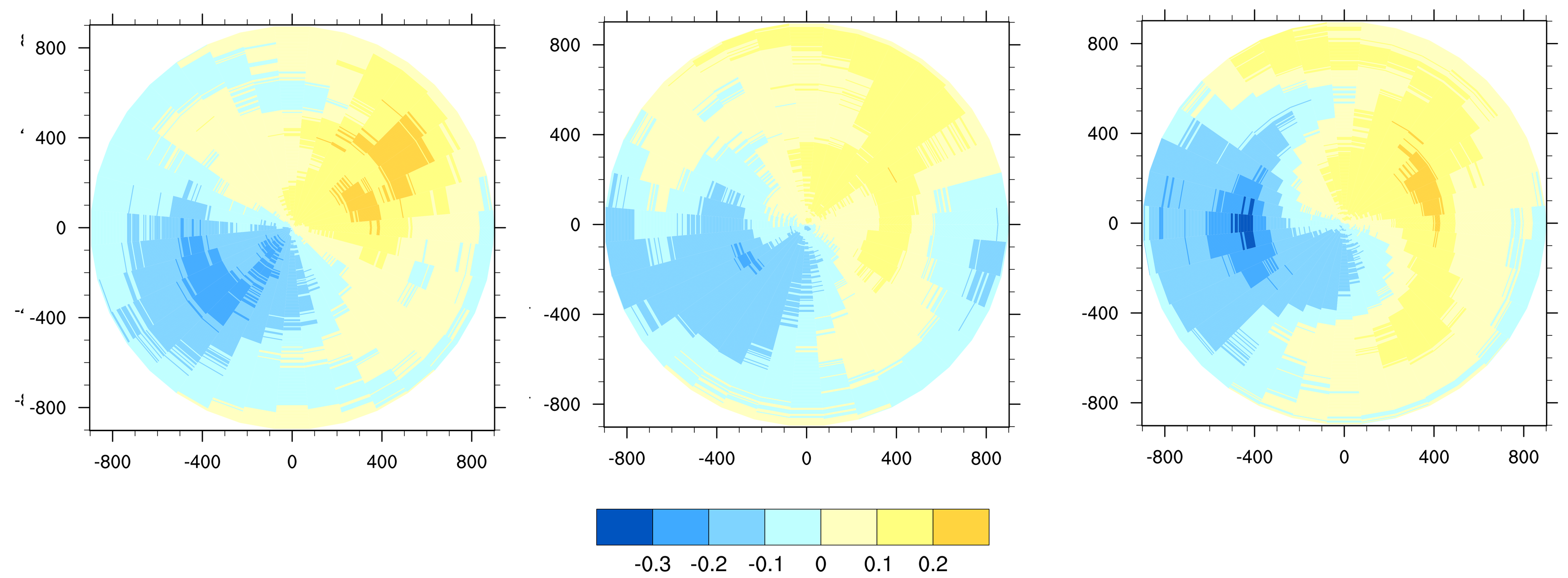
Three ensembles:
1) 2-day storms
2) 4-day storms
3) 6-day storms

Storms must be continuously classified at least as strong as a tropical depression for at least (2, 4, 6) days and for no more than (3, 5, 7) days to be included in ensemble (1, 2, 3). This gives us (47, 37, 30) ensemble members.

Deviation of wind speed from azimuthal mean: Growth Phase

Wind speeds normalized to (17.6, 19.6, 24.6) kt.

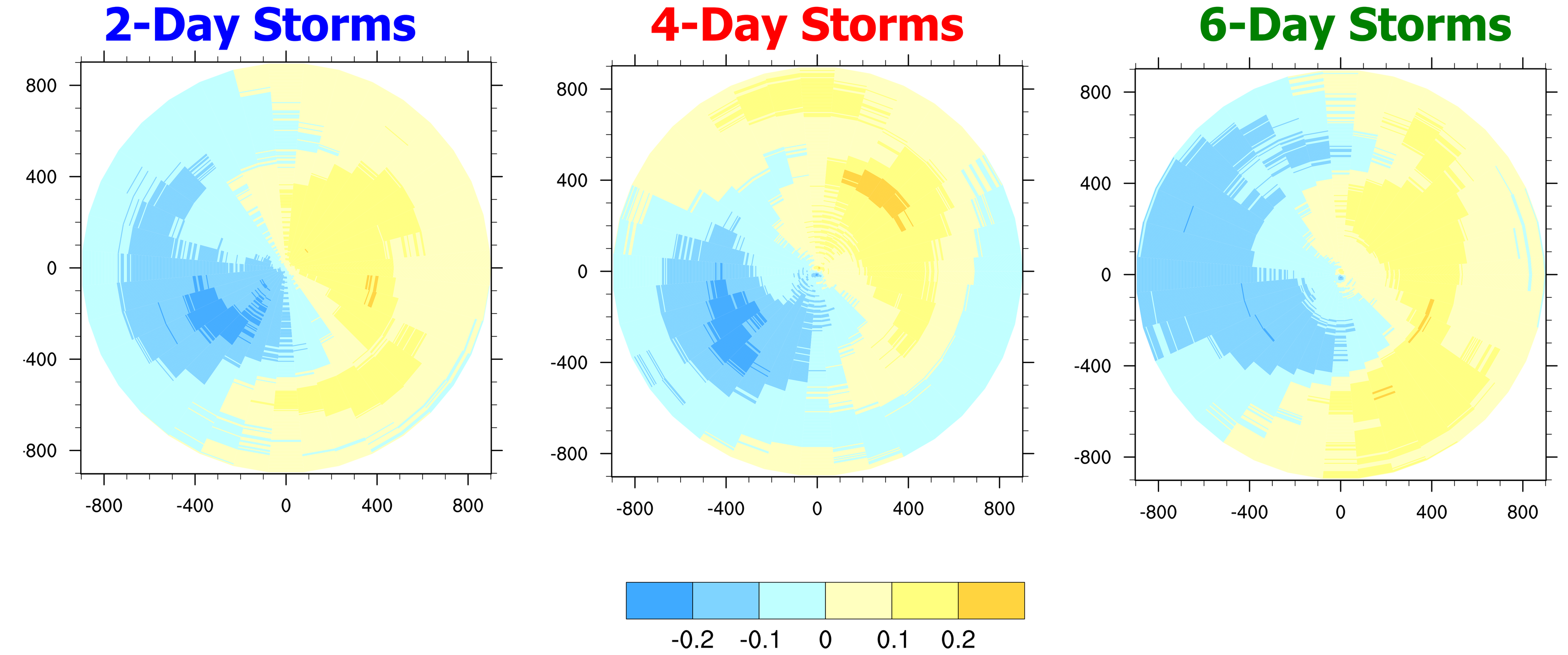
2-Day Storms **4-Day Storms** **6-Day Storms**

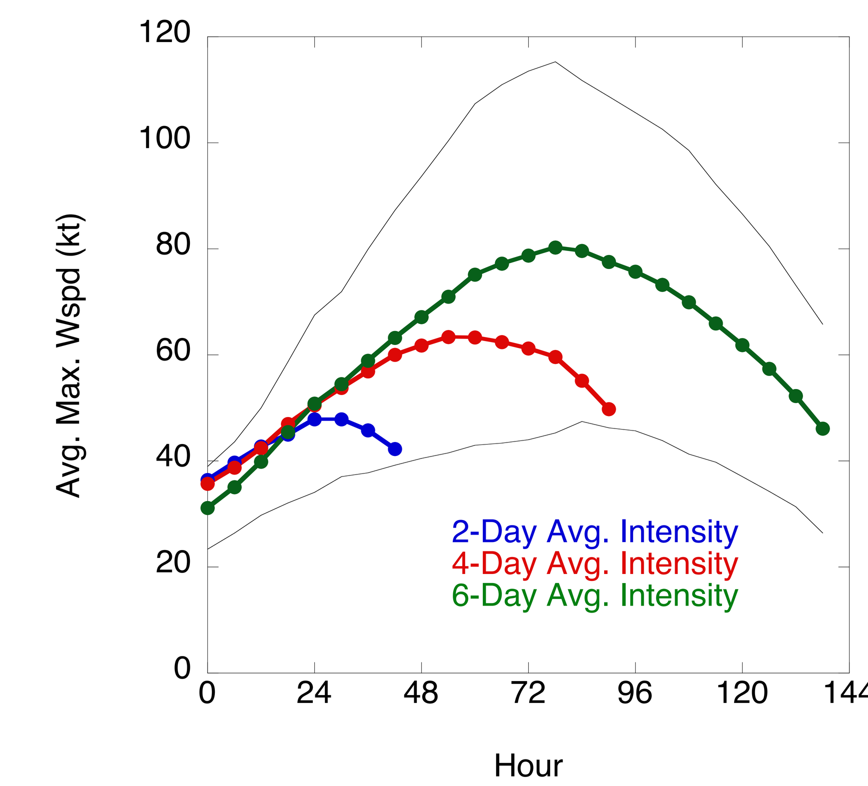


Deviation of wind speed from azimuthal mean: Peak Phase

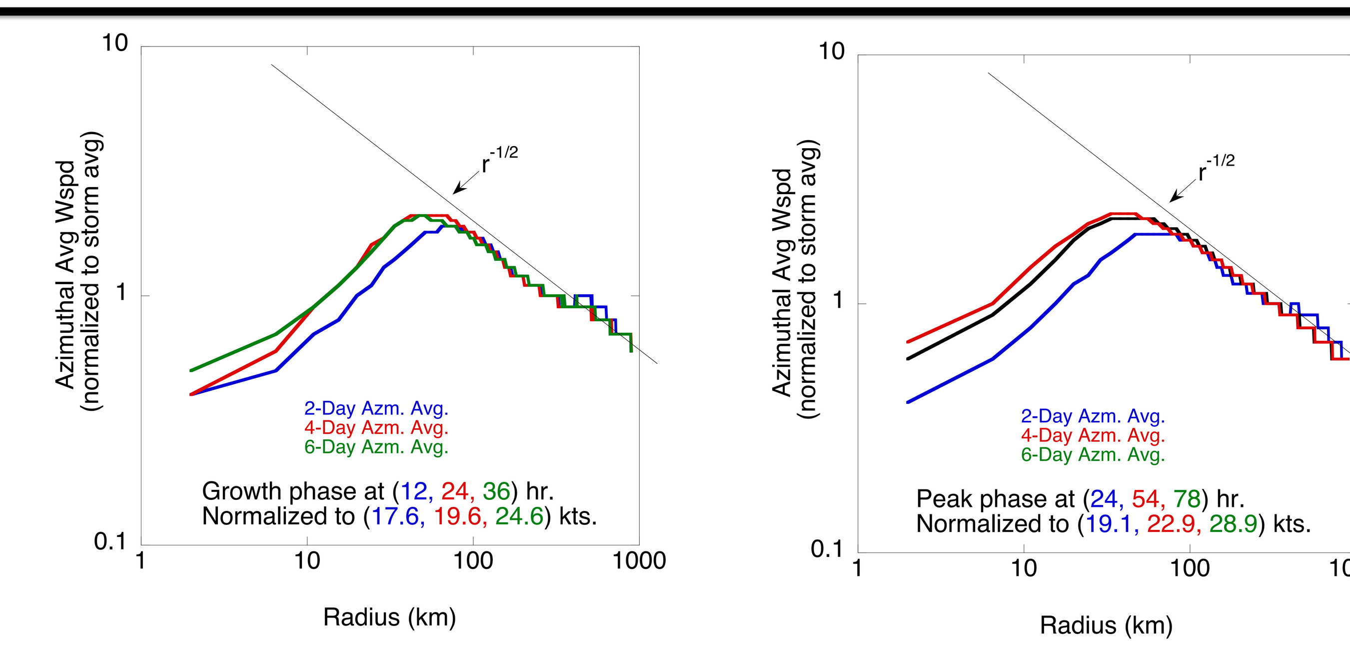
Wind speeds normalized to (19.1, 22.9, 28.9) kt.

2-Day Storms **4-Day Storms** **6-Day Storms**





Evolution of average storm intensity (Max wind speed). Also shown: the ***one*** standard deviation of 6 day storms' intensity (black lines).



Normalized azimuthally averaged wind speed profile for growth and peak phases.

Analysis of Internal Variability using T-LIM

Okay; we're getting there. We do have one robust result:

- The Green function $\mathbf{G}(t_o, \Delta t)$ is diagonally dominant, indicating that dynamics are in the linearized regime during a 6 hour period.

Conclusions and Future Work

- The MTCSWA data set is useful for analyzing tropical cyclone structure change.
- TC longevity determines mean intensity, but internal variations are large.
- Preliminary T-LIM results suggest that a joint wind speed – latent heat (i.e., precip) state vector would capture the dynamical description of TCs better than wind speed alone.