Insights into the Tropical Cyclogenesis of Hurricane Sandy (2012)

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Overview/Motivation

Hurricane Sandy was one of the most damaging storms in US history. In this work, we examine Sandy's tropical cyclogenesis sequence and attempt to answer the following questions:

1)What were the dynamic and thermodynamic mechanisms that led to the formation of Hurricane Sandy?
2)Did the tropical cyclogenesis sequence follow the 'marsupial paradigm' as proposed in Dunkerton et al. (2009) and demonstrated during PREDICT (Montgomery et al., 2012)?
3)What affect did external synoptic-scale features such as the SACZ, Hurricane Tony or a Caribbean Gyre have on Sandy's tropical cyclogenesis?
4)Are numerical forecast models able to accurately predict tropical cyclogenesis in this case?

Synoptic Overview

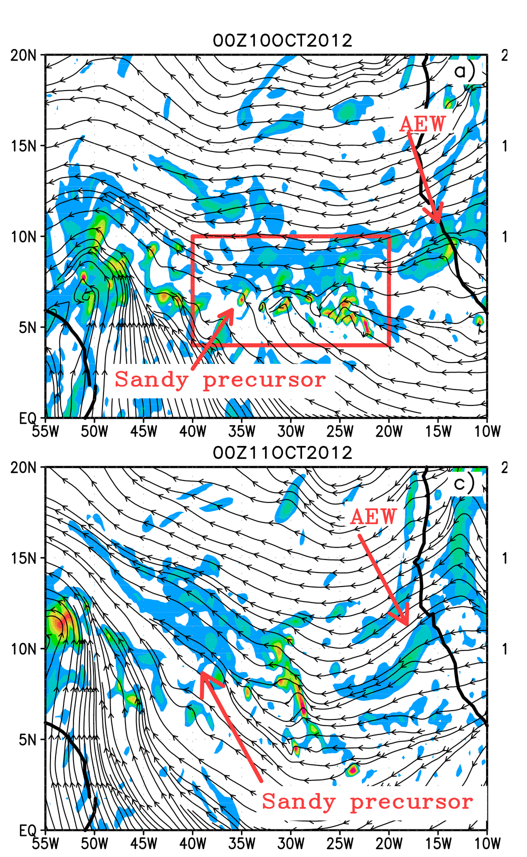


Fig. 1. Two-panel plot of 700 hPa ECMWF streamlines (earth-relative) and relative vorticity (shaded). The red box in the first panel indicates the region of the ITCZ breakdown and the red arrows highlight important synoptic-scale features.

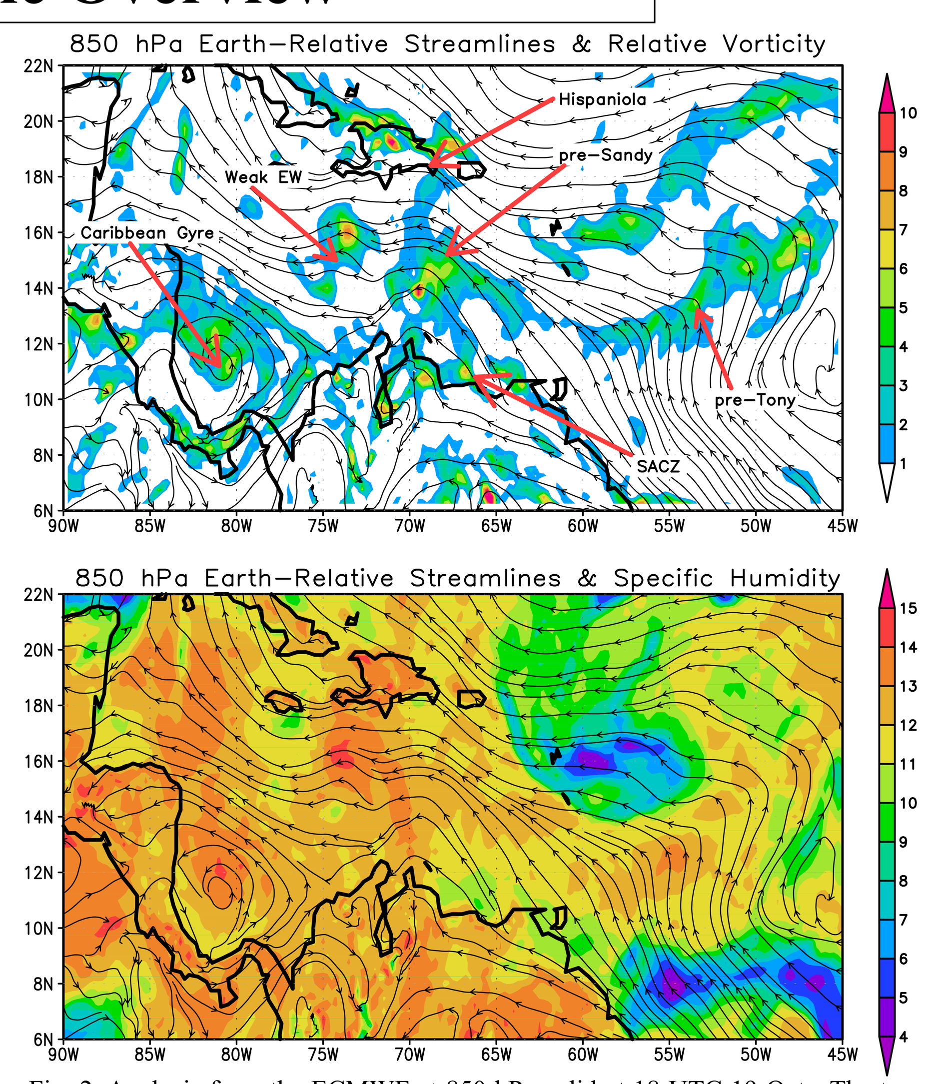
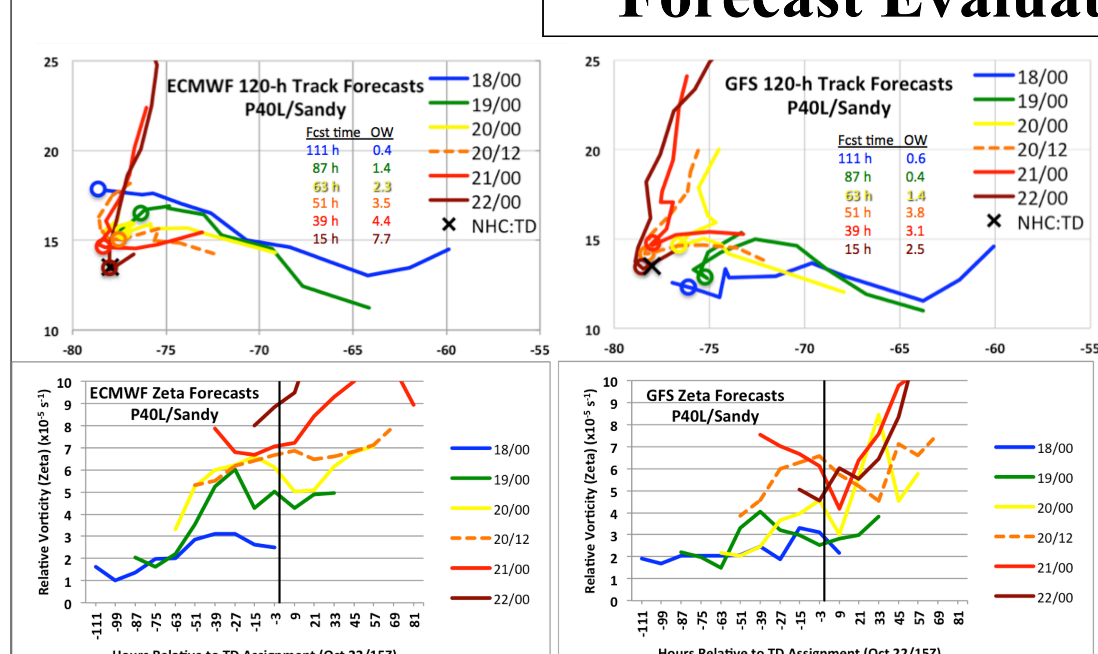


Fig. 2. Analysis from the ECMWF at 850 hPa valid at 18 UTC 19 Oct. The top panel (a) is relative vorticity and the bottom (b) is specific humidity.

1) The precursor disturbance to Hurricane Sandy was a westward propagating disturbance that originated from an **ITCZ breakdown** on 10 Oct.
2) By 19 Oct, the **Caribbean basin is ripe with sources of low-level cyclonic** vorticity that is available for accretion into pre-Sandy wave.
3) There is **abundant moisture** in the Caribbean, another favorable environmental condition for tropical cyclogenesis.

Forecast Evaluation



1) The **GFS forecast positions indicates a smaller spread** in predicted genesis location over the 5-day period.
2) The **ECMWF position forecast improves substantially within 48 hours** of genesis.
3) The intensity forecasts are similar, however, the ECMWF indicates a stronger vortex throughout most of the period.

Fig. 3. Position (top) and intensity (bottom) forecasts for Hurricane Sandy from the ECMWF (left) and GFS (right) global forecast models. The circles on the position figures indicate the time of NHC TD declaration. For the intensity forecasts, the zero hour on the abscissa is the time NHC declared the storm a TD and is indicated by the gray vertical line.

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Applications of the Marsupial Paradigm & Vorticity Accretion

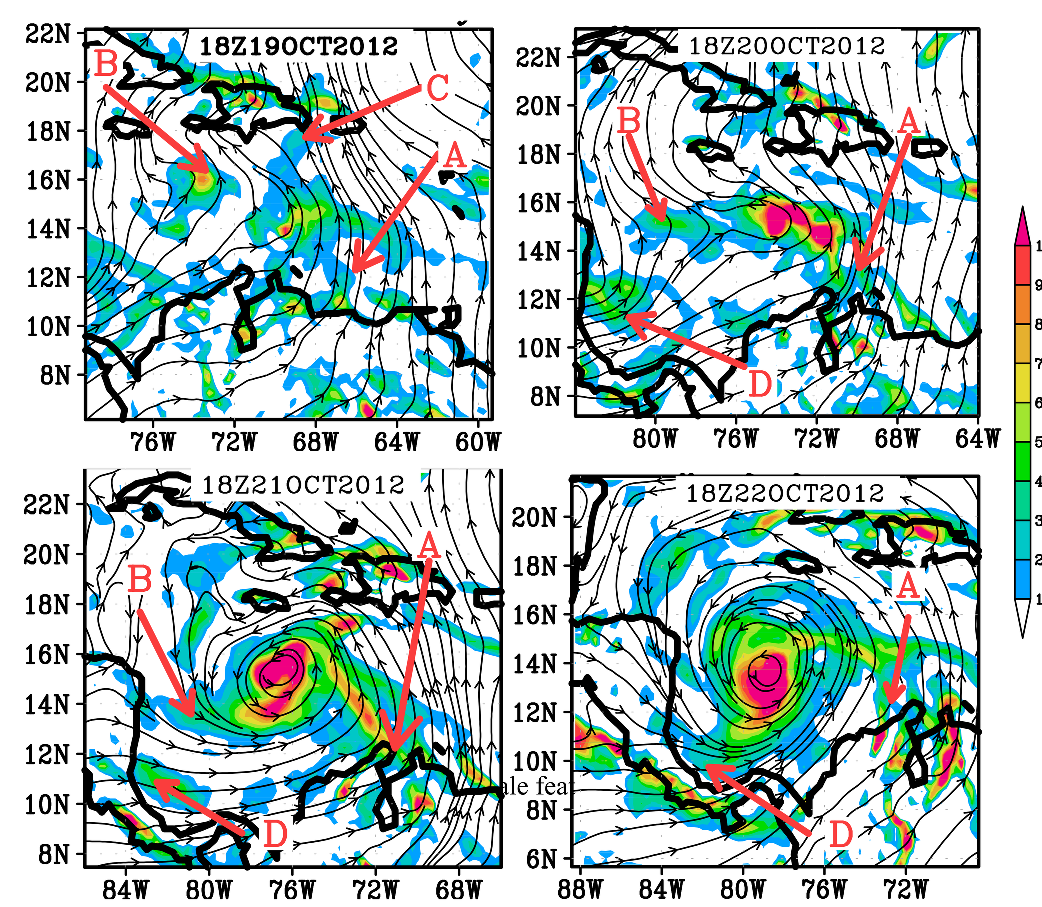


Fig. 4. Analysis from the ECMWF at 850 hPa ECMWF valid at 24 h intervals from 18 UTC 19-22 Oct. The shading is relative vorticity and the streamlines are in the co-moving frame.

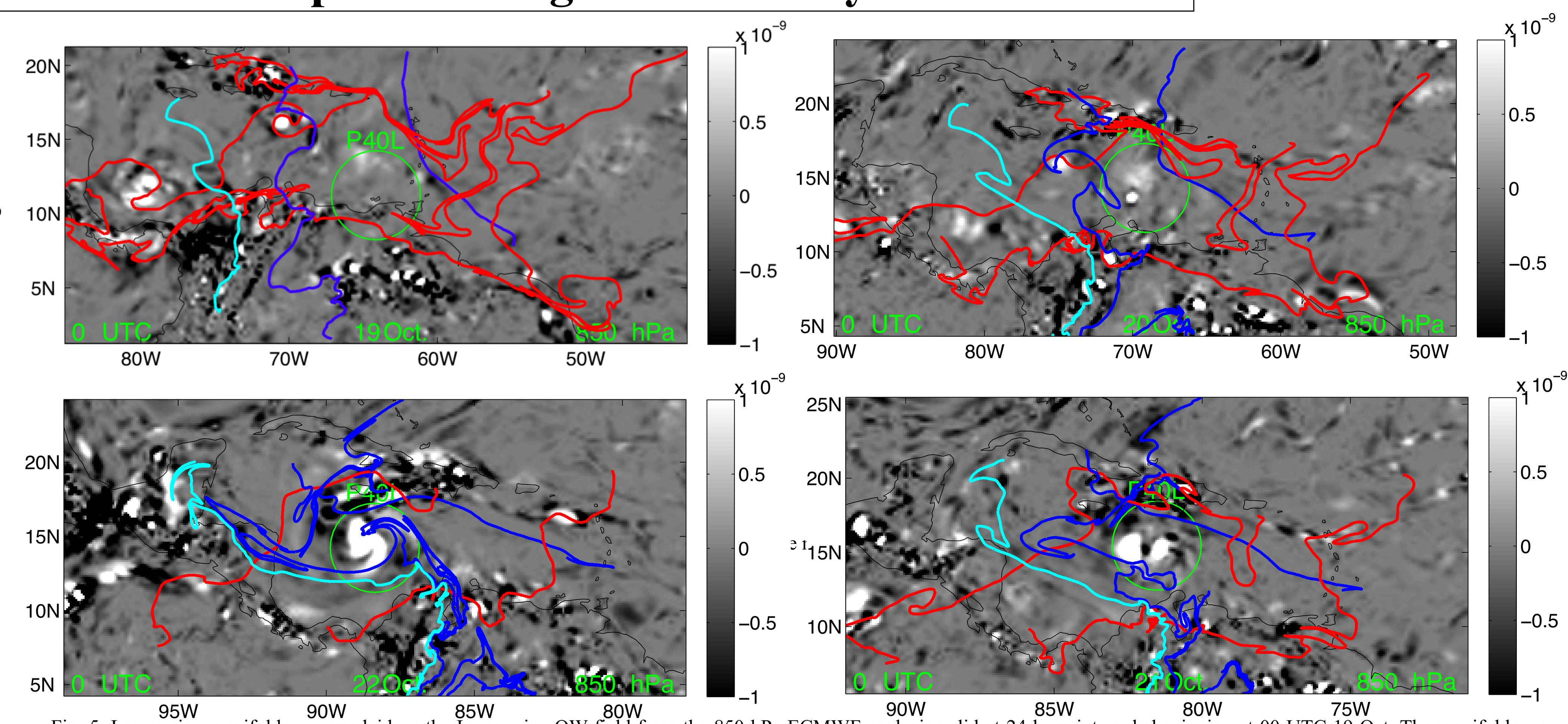


Fig. 5. Lagrangian manifolds are overlaid on the Lagrangian OW field from the 850 hPa ECMWF analysis valid at 24 hour intervals beginning at 00 UTC 19 Oct. The manifolds are computed in the time interval ranging from 18 Oct when the saddle points emerge and the unstable manifold is initialized, to 23 Oct when the western saddle point vanishes and the stable manifold is initialized.

1) In the co-moving frame of reference, there is a wave pouch and indications of a **opening to the south** of the sweet spot position. Cyclonic vorticity generated in the SACZ (A) is able to enter the center of the wave pouch through this opening.
2) Cyclonic vorticity from a weak wave west of the Sandy disturbance (B) and immediately south of Hispaniola (C) is accreted into the wave pouch.
3) Cyclonic vorticity from the Caribbean Gyre and the pre-Tony wave are outside of the Lagrangian boundaries that define the wave pouch, therefore, they have no impact on the accretion of vorticity that leads to the development of Hurricane Sandy

Vortex Spin-up

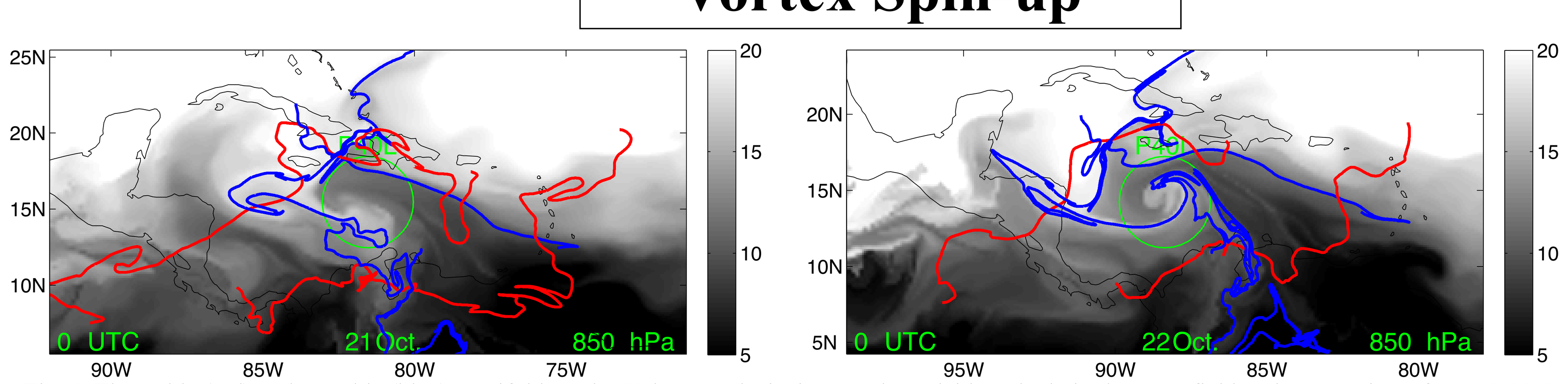
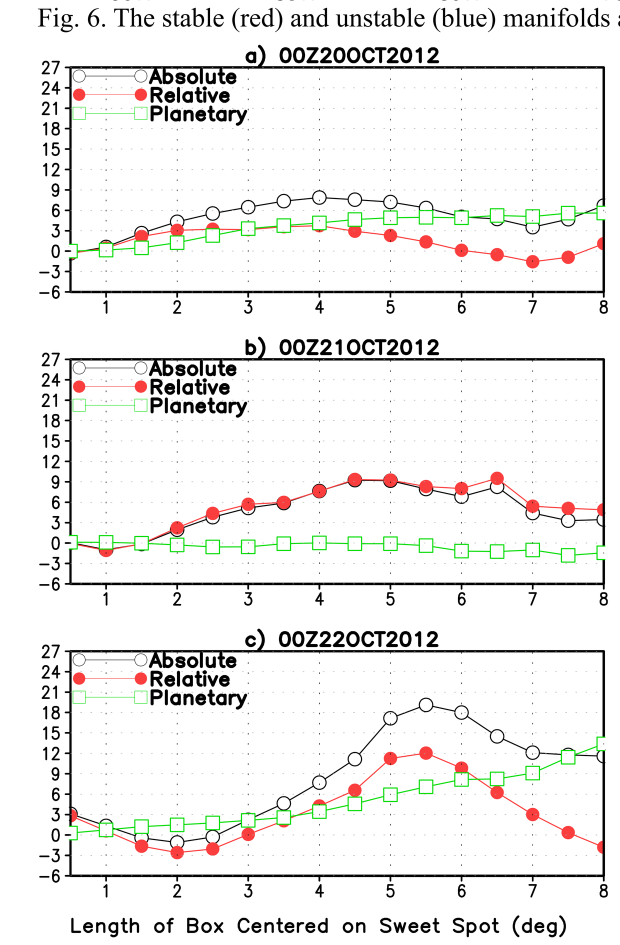


Fig. 6. The stable (red) and unstable (blue) manifolds at the 00 hour analysis times and overlaid on the latitude tracer field at the same times from 19-22 Oct.



1) The latitude tracer field illustrates the **wave breaking** and indicates that much of the **air entering the center of the disturbance originated from south** of the center position.
2) We calculate the circulation tendency (Haynes and McIntyre, 1987) to assess the contributions of relative and planetary vorticity to spin-up:

$$\frac{d\Gamma_a}{dt} = -\oint_{\delta A} \eta \mathbf{u}\bullet\mathbf{n}\, ds - \oint_{\delta A} \omega \frac{\partial \mathbf{u}}{\partial p}\bullet\mathbf{t}\, ds + \oint_{\delta A} \mathbf{F}\bullet\mathbf{t}\, ds$$

3) There are areas and times where convergence of relative or planetary vorticity fluxes dominate the contributions to spin-up.
4) Areas where **relative vorticity fluxes dominate** are typically at distances **co-located with vorticity accretion.**

Fig. 7. Three-panel plot of 850 hPa absolute (black), relative (red), and planetary (green) advective vorticity flux convergence from the ECMWF analysis data. The flux is calculated as in through 0.5 degree length boxes centered on and moving with the sweet spot position. These data are temporally-averaged, from 18 UTC the previous day to 00 UTC of the indicated day.

References

Dunkerton, T. J., Montgomery, M. T., and Wang, Z., 2009: Tropical cyclogenesis in a tropical wave critical layer: easterly waves, *Atmos. Chem. Phys,* **9**, 5587-5646.

Haynes, P. H. and M. E. McIntyre, 1987: On the evolution of vorticity and potential vorticity in the presence of diabatic heating and frictional or other forces. *J. Atmos. Sci.*, **44**, 828-841.

Kimball, S. K and M. S. Mulekar, 2004: A 15-Year Climatology of North Atlantic Tropical Cyclones. Part I: Size Parameters. *J. Climate*, **17**, 3555–3575.

Montgomery, M. T., Davis, C., Dunkerton, T., Wang, Z., Velden, C., Torn, R., Majumdar, S. J., Zhang, F., Smith, R. K., Bosart, L., Bell, M. M., Haase, J. S., Heymsfield, A., Jensen, J., Campos, T. and Boothe, M. A., 2012: The Pre-Depression Investigation of Cloud-systems in the Tropics (PREDICT) Experiment, *Bull. Amer. Meteor. Soc.*, **93**, 153-172.

Conclusions & Future Work

1) The genesis of Hurricane Sandy appears to **follow the tropical cyclogenesis sequence outlined in Dunkerton et al. (2009)**.
2) An interesting aspect of this formation is the apparent opening in the wave pouch to the south that allows **accretion of vorticity from the SACZ**.
   a) Additional features that contribute to vorticity accretion are the weak wave to the west and vorticity generated south of Hispaniola.
   b) The **Caribbean Gyre and pre-Tony wave do not appear to contribute** to the cyclogenesis process through accretion.
3) Both the **GFS and ECMWF show indications of tropical cyclogenesis.** The limit of predictability in this case is about 48 hrs.

Future Work: The growth and intensification of Hurricane Sandy
1) Why did Sandy grow to such a large size?
2) Did accretion of vorticity continue and help grow the vortex?
3) Test a new model of tropical cyclone intensification.
4) Why don't all storms grow this large?

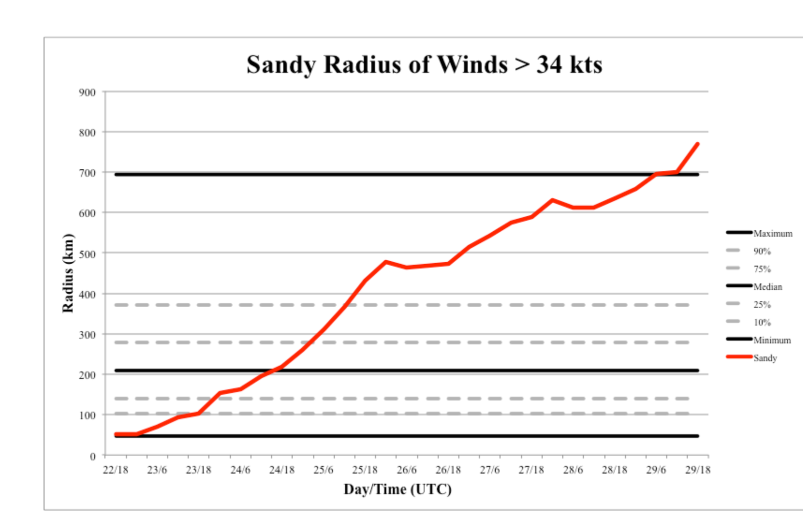


Fig. 8. Hurricane Sandy's size as compared to the climatology of Kimball and Mulekar (2004).

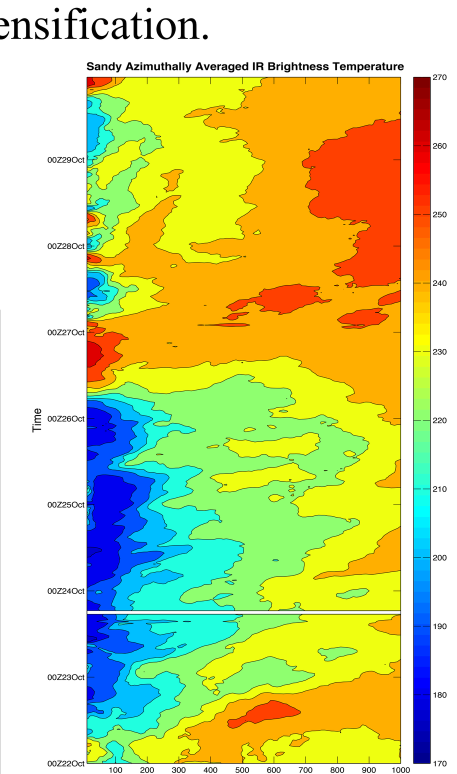


Fig. 9. Hovemoller diagram of azimuthally-averaged IR brightness temperatures from GOES-13.