Subseasonal to Seasonal Prediction of Tropical Cyclone Formation in the Northern Hemisphere: Using Statistical-Dynamical Methods to Leverage the Strengths and Mitigate the Weaknesses of CFS Version 2

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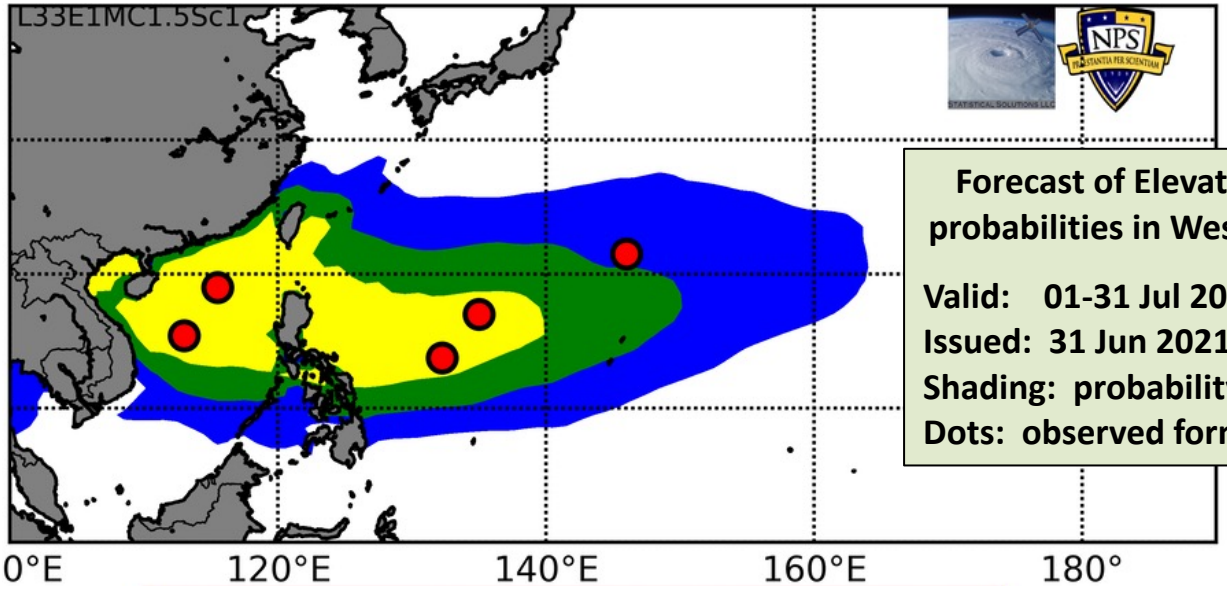

Forecast of Elevated TC Formation probabilities in Western North Pacific

Valid: 01-31 Jul 2021
Issued: 31 Jun 2021
Shading: probability categories
Dots: observed formations

Forecasts available at:

http://www.statisticalsolutionsllc.com/tropical-cyclonehurricane-formation-forecasts-2021.html

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S2S Statistical-Dynamical Forecasting of TCs

Motivations and Approach

1. Produce skilled TC formation forecasts at leads not possible with dynamical models
2. *System's statistical model is trained on archived LSEF forecasts from CFSv2.*
3. Forecast system forced with dynamical forecasts of large-scale environmental factors (LSEFs) that are easier to forecast than tropical cyclogenesis
4. The forced statistical model produces easily understood probabilistic forecasts of elevated TC formation potential.
5. Forecasts have spatial and temporal resolution.
6. **S2S formation forecasting is the essential first step for S2S forecasting of TC tracks and intensities**
7. Forecasts help fill the week 4 to month 2 gaps between CPC's GTBH forecasts and seasonal forecasts.

NPS Forecasting System: Overview

Build **statistical model based on relationships between TC formations and LSEFs (JTWC / HurDat II best tracks and CFSv2)**

Statistical model relates the LSEFs to TC formation probability

Force **statistical model with dynamical, ensemble-based, CFSv2 LSEF forecasts**

Produce **statistical-dynamical model output: ensemble-based forecasts of TC formation probabilities: 1-day lead forecasts to 2.5 month lead monthly outlooks**

1. LSEFs = large scale environmental factors:
   a. Western North Pacific (WNP): SST, $shear_{200\text{-}850}$, $\mathcal{Z}_{850}$, tropical cyclone heat potential
   b. North Atlantic (NA): SST, $shear_{200\text{-}850}$, velocity potential $_{200}$
2. Inputs: 6 hourly, 1/ 0.5° resolution
3. Outputs: daily, 1° resolution
4. Statistical model built by use of logistic regression
5. Each LSEF influences TC formation at over a 99% confidence level
6. S2S forecasts: 0.5, 1.5, and 2.5 month leads, 1-month valid period, ~120 ensemble members
7. For both the WNP and the NA:
   a. Forecasting is automated
   b. Does not require a forecaster-in-the-loop
   c. Objective, not subjective
   d. *Quantified* formation probability

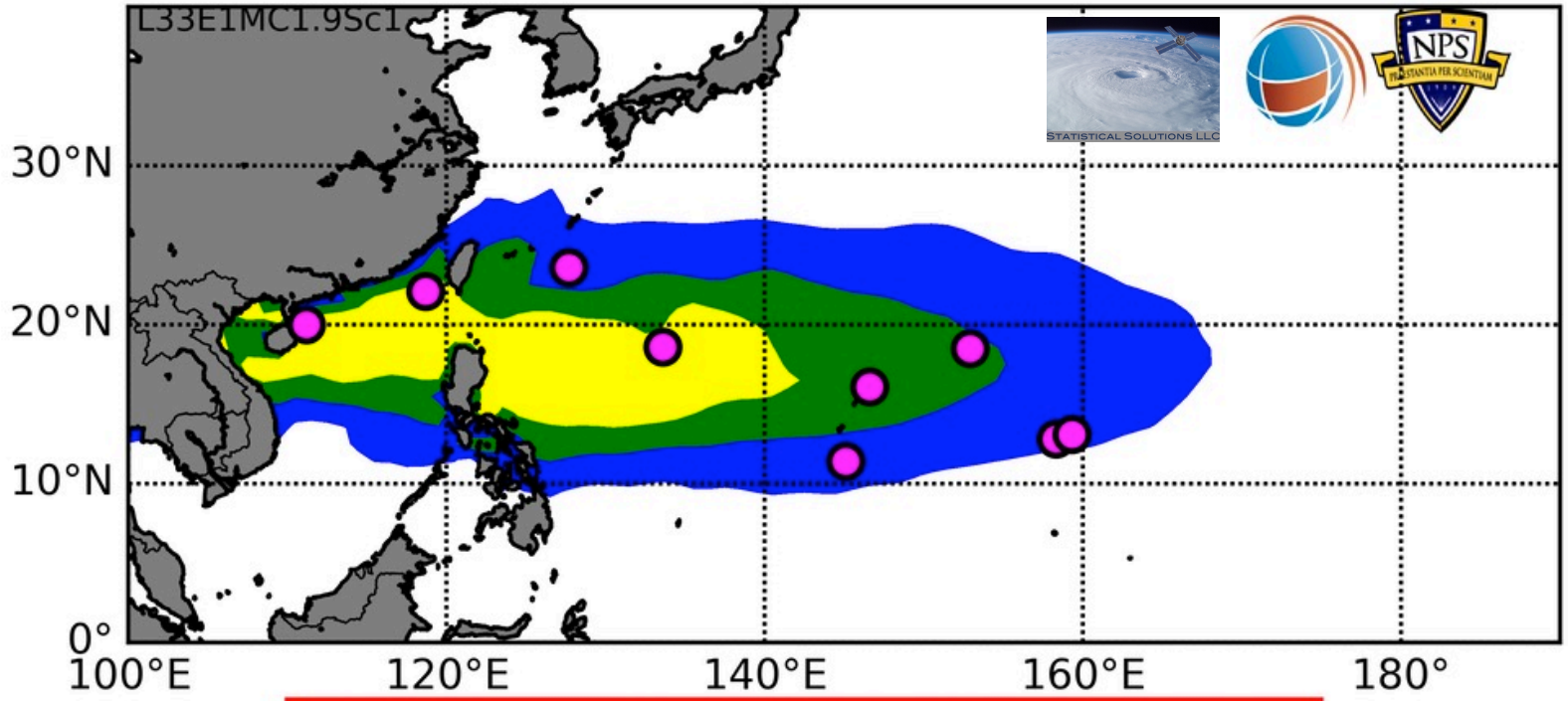
NPS Forecasting System: Statistical Model

1. Inspired by work of Dr. Bill Gray: there are large scale environmental factors that are necessary but not sufficient for TC genesis
    a. Dr. Gray's LSEFs are all significant ($p < 0.05$)
    b. Not all are well predicted
    c. Multicollinear relationship exists between many
2. Pool of potential LSEFs expanded to include those that are **better predicted** and **more distinct** than Gray's
3. Training data: archived CFSv2 forecasts
    a. Statistical model forced with the data from the same source it was built on.
    b. This training substantially improves skill and reduces biases compared to training based on reanalysis data.
4. Skilled at all leads.

There is a calculated risk in attempting to build a regression model based on a relatively small training data set (WNP: 2011-2019 / NA: 2011-2020)

TC Formation Forecast Features

Example Forecast of Elevated TC Formation Potential
Valid: 01-31 Aug 2018, Issued: 31 Jul 2018



TC formations occurred during this valid period at pink dot locations.

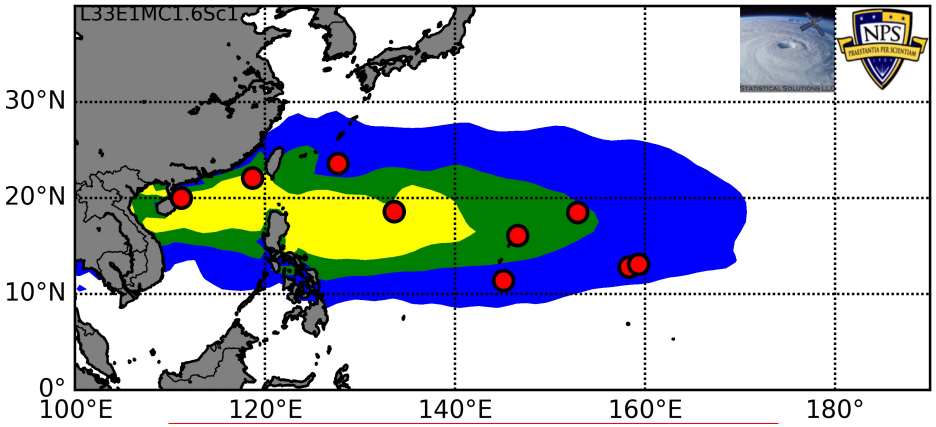
Blue: 90%, Green, 70%, Yellow 50% of formations for Aug 2011-2019

TC Formation Forecast Features

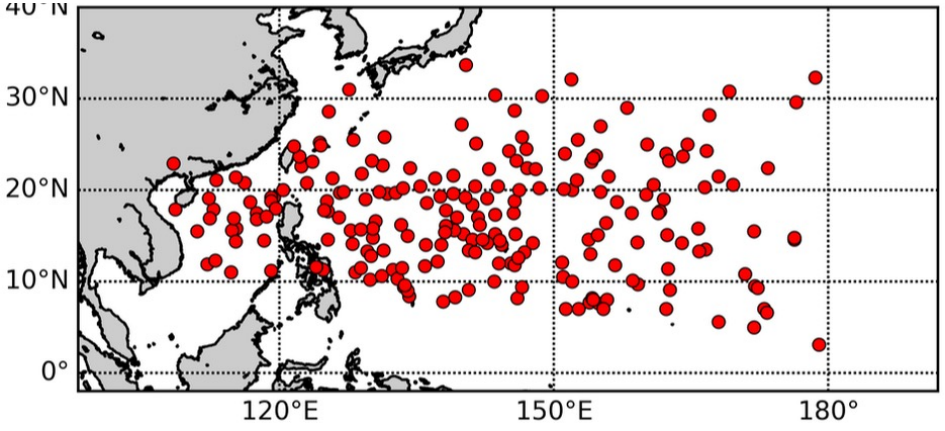
1. Three probability categories or *tiers* show:
    a. A small area where 50% of TCs will form
    b. A large area in which 90% of TCs will form
    c. An in-between area that is about half the size of the 90% area in which 70% of the TCs will form
2. Tiers are not a measure of confidence. They are heuristically determined probability levels to capture 90, 70, and 50% of TC formations on a monthly basis
4. Multi-objective optimization: Maximize hits while minimizing the size of the contoured area.
5. Skill as good at the start and end of the season as in the middle.

TC Formation Forecasts vs. Climatology

Forecast for Aug 2018, 0.5-Month Lead



All TC Formations, Aug 1979-2017

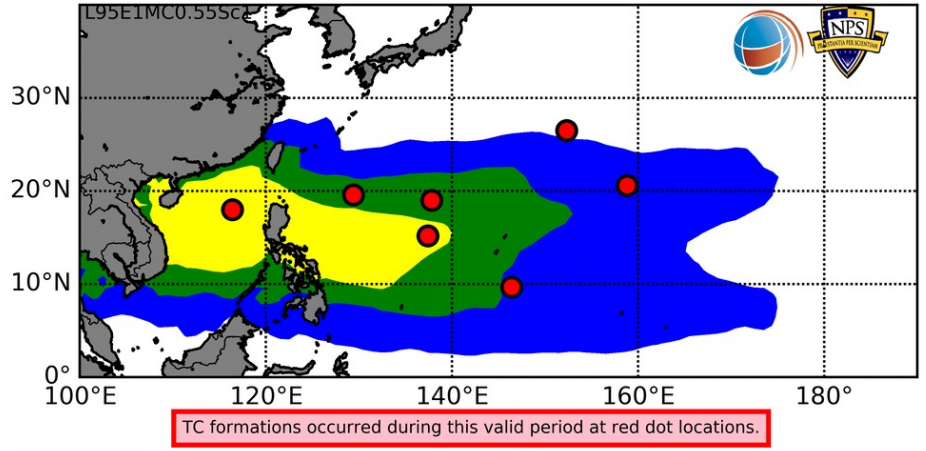


1. **Forecasted areas are much smaller than climatologically possible formation areas.**
2. **This is especially true for the 50% and 70% areas.**

Lead time: Time from issue date to middle of valid period.
Ex: Issued on 31 Jul and valid for 01-31 Aug indicates a 0.5-month lead.

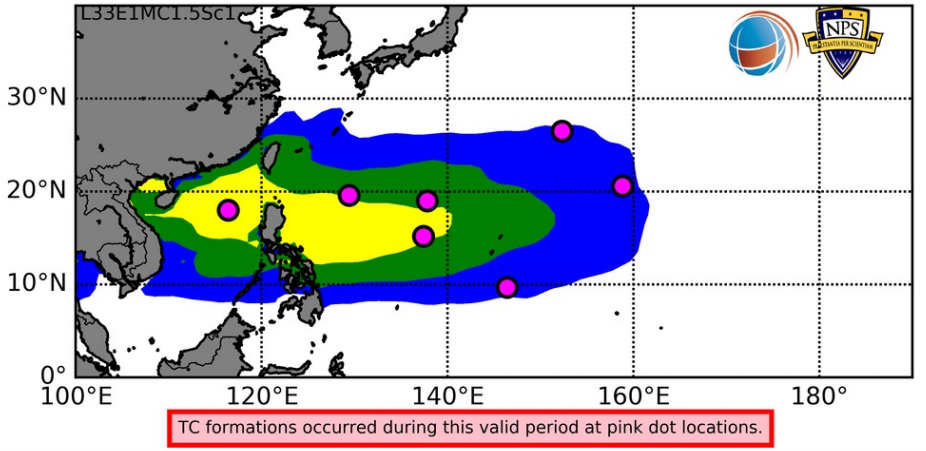
TC Formation Forecasts: Variations by Lead Time

Forecast for Jul 2018, 2.5 Month Lead



Blue: 90%, Green, 70%, Yellow 50% of formations for Jul 2011-2019

Forecast for Jul 2018, 0.5 Month Lead



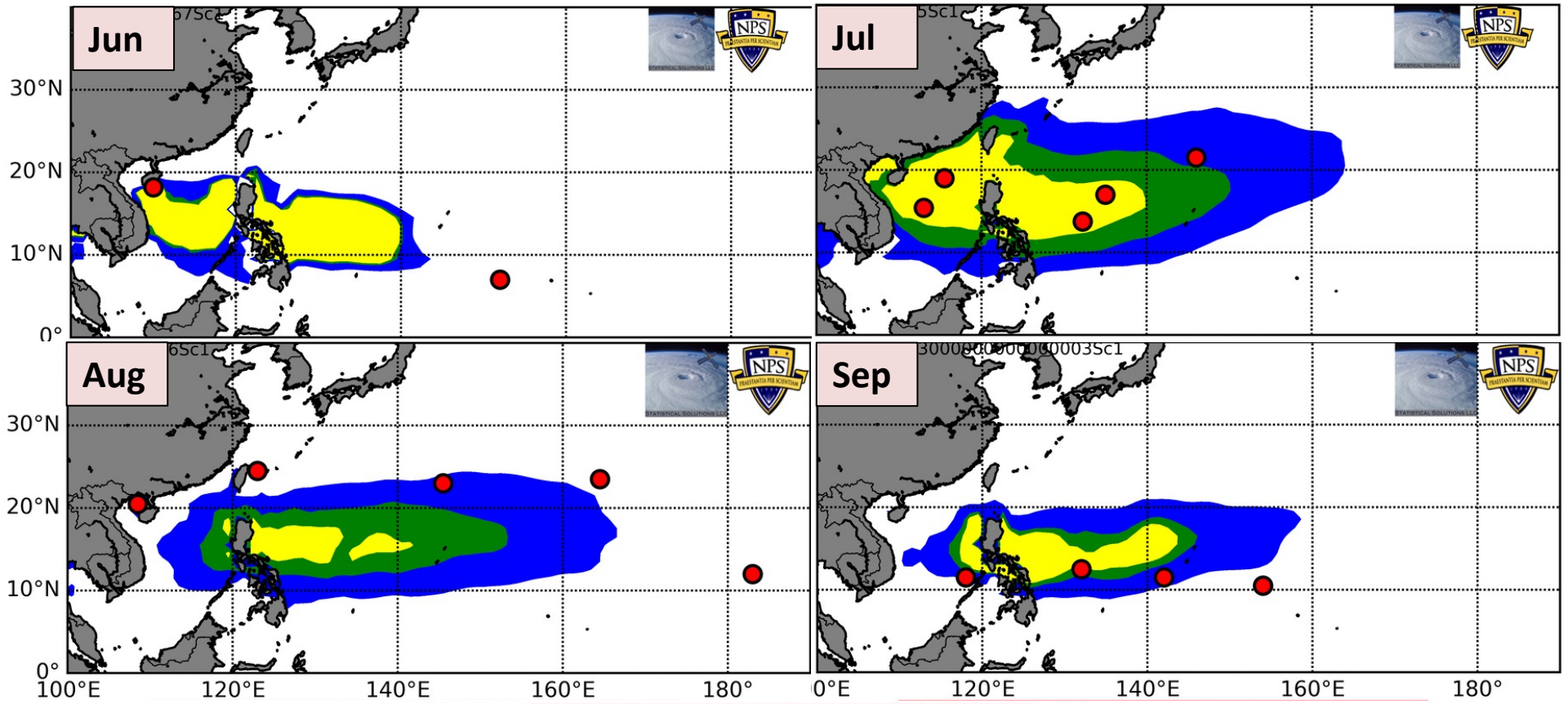
Blue: 90%, Green, 70%, Yellow 50% of formations for Jul 2011-2019

1. **Forecasts tend to be relatively consistent across lead times.**
2. **As lead time decreases:**
   a. **Skill increases (number of hits is constant, but the contoured area shrinks)**
   b. **Forecasts tend to become more focused, with 90% region often slightly shifting and/or contracting**

Lead time: Time from issue date to middle of valid period.
Ex: Issued on 30 Apr and valid for 01-31 Jul indicates a 2.5-month lead.

TC Formation Forecasts for a Season

0.5 Month Lead Forecasts and Actual Formations, Jun-Sep 2021



TC formations occurred during this valid period at red dot locations.

Blue: 90%, Green, 70%, Yellow 50% of formations for Aug 2011-2019

Forecasts vary in physically plausible ways by month and by year.

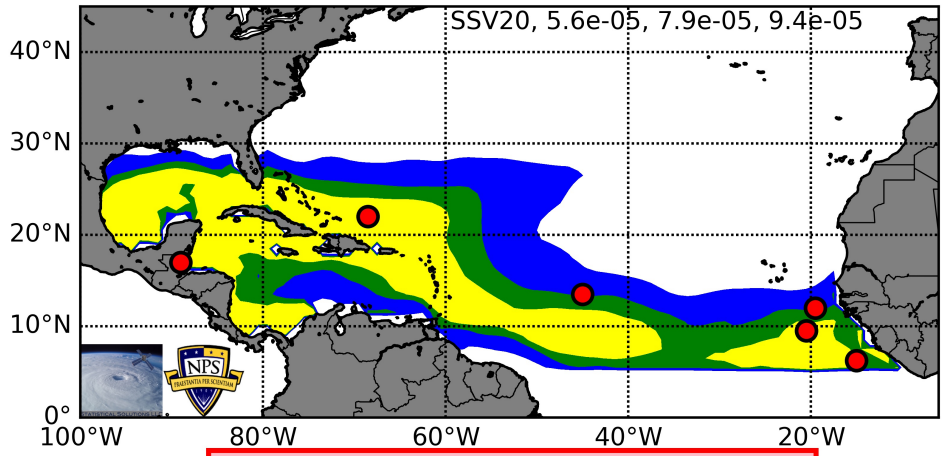
Lead time: Time from issue date to middle of valid period.
Ex: Issued on 31 Jul and valid for 01-31 Aug indicates a 0.5-month lead.

TC Formation Forecasts: Variations by Lead Time

1. The forecasts tend to be relatively consistent as lead time decreases (i.e., relatively small changes with lead time).
2. Consistency and skill of the 0.5, 1.5, and 2.5 month lead forecasts indicate that there may be skill at leads greater than 2.5 months.
3. The forecasts show promise for more quantification --- for example:
    a. *"Given the size and probabilities of the forecast, expect 4-6 TC formations in the valid period."*
    b. *"July is expected to be 20-40% more active than last July but still below average overall."*

NA TC Formation Forecasts vs. Climatology

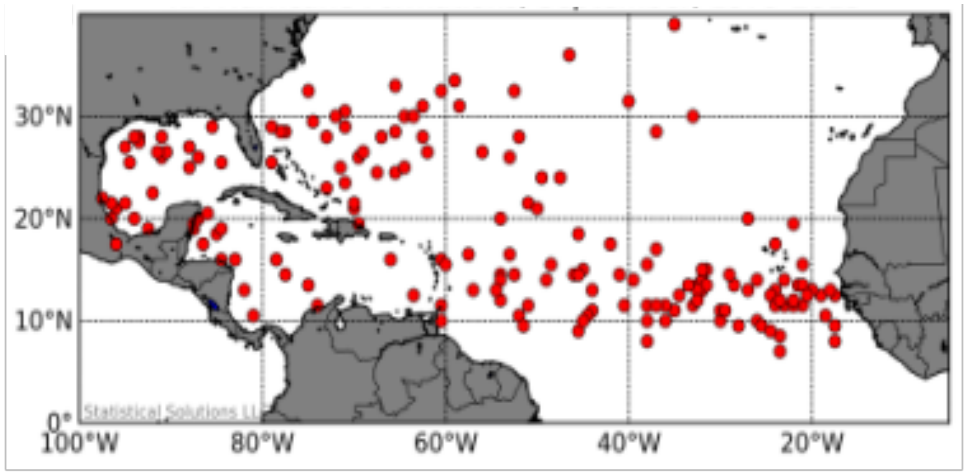
Forecast for Sep 2021, 1.5 Month Lead



TC formations occurred during this valid period at red dot locations.

Blue: 80%, Green, 60%, Yellow 40% of formations for Sep 2011-2020

All TC Formations, Sep 1979-2017



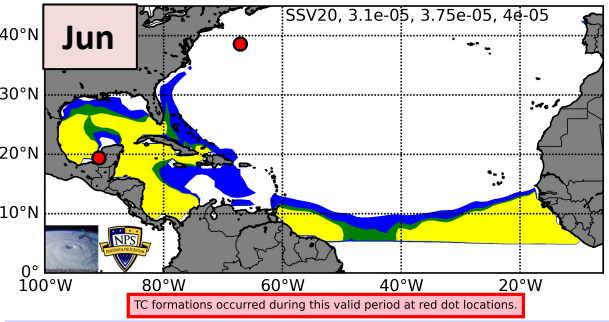
1. **Initial North Atlantic (NA) forecasts are encouraging but still in development.**
2. **Probability tiers are slightly different than for WNP.**
3. **Forecasted areas are much smaller than climatologically possible formation areas.**
4. **This is especially true for the 50% and 70% areas.**

Lead time: Time from issue date to middle of valid period.
Ex: Issued on 31 Jul and valid for 01-30 Sep indicates a 1.5-month lead.

TC Formation Forecasts for a Full Season

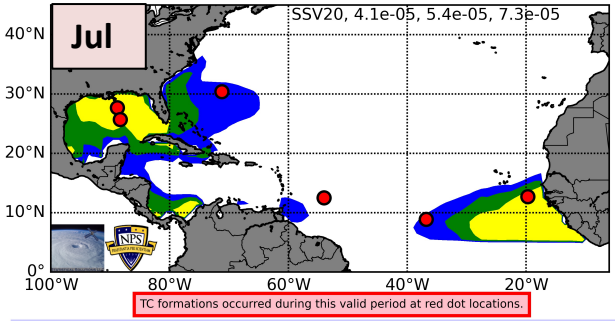
Representative Forecasts, Jun-Nov 2020, with Verifying Formations, 0.5-Month Lead

TC Formation Potential
Issued: 30May2020, valid: 01-30Jun2020
Hit: 03L, Miss: 04L



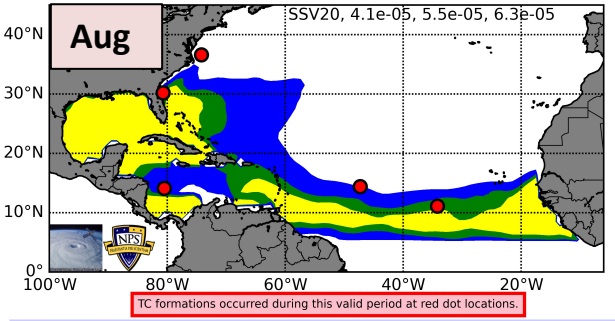
Blue: 80%, Green, 60%, Yellow 40% of formations for Jun 2011-2020

TC Formation Potential
Issued: 30Jun2020, valid: 01-31Jul2020
Hit: 05L, Hit: 06L, Hit: 07L, Hit: 08L
Miss: 09L, Hit: 10L



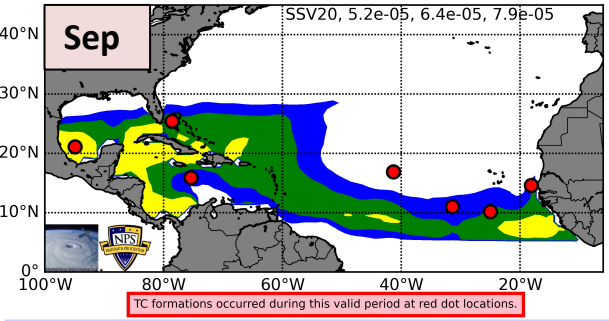
Blue: 80%, Green, 60%, Yellow 40% of formations for Jul 2011-2020

TC Formation Potential
Issued: 31Jul2020, valid: 01-31Aug2020
Hit: 11L, Miss: 12L, Hit: 13L, Hit: 14L
Hit: 15L



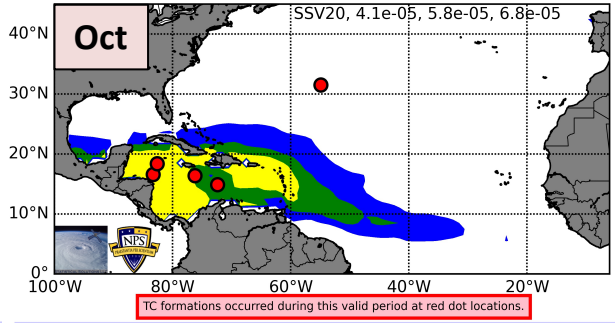
Blue: 80%, Green, 60%, Yellow 40% of formations for Aug 2011-2020

TC Formation Potential
Issued: 30Aug2020, valid: 01-30Sep2020
Hit: 16L, Hit: 18L, Miss: 17L, Hit: 19L
Hit: 20L, Hit: 22L, Hit: 23L



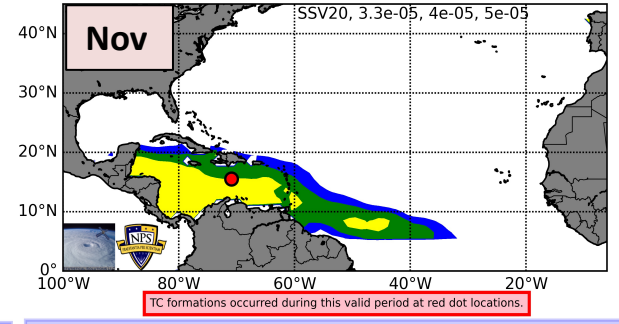
Blue: 80%, Green, 60%, Yellow 40% of formations for Sep 2011-2020

TC Formation Potential
Issued: 30Sep2020, valid: 01-31Oct2020
Hit: 25L, Hit: 26L, Miss: 27L, Hit: 28L
Hit: 29L



Blue: 80%, Green, 60%, Yellow 40% of formations for Oct 2011-2020

TC Formation Potential
Issued: 30Oct2020, valid: 01-30Nov2020
, Hit: 31L



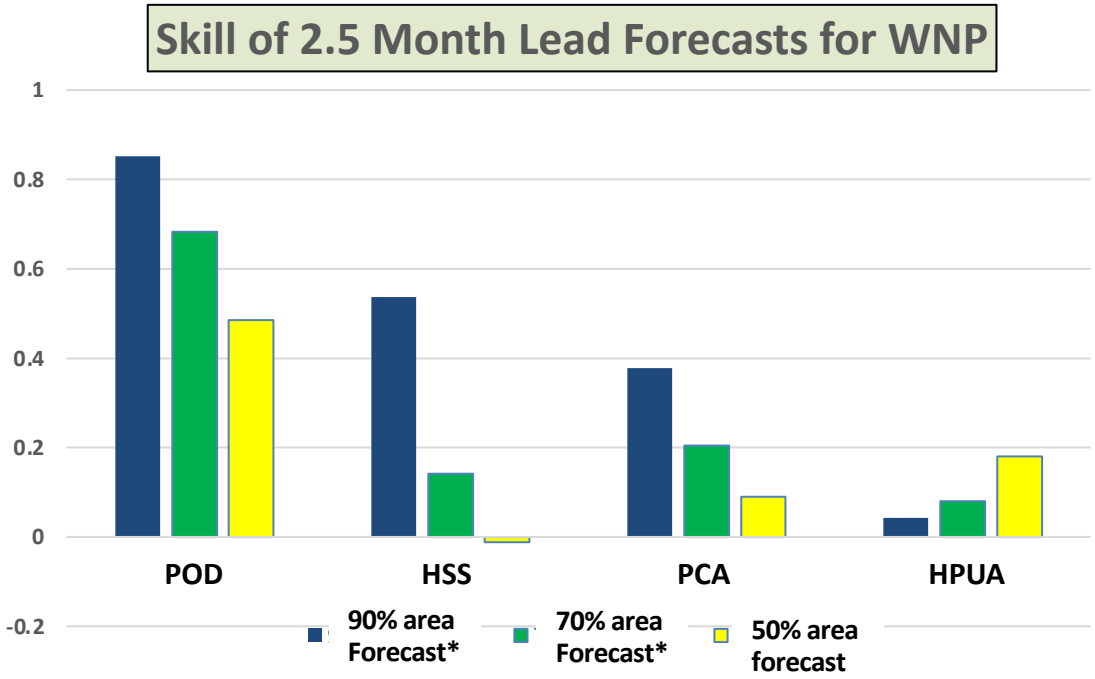
Blue: 80%, Green, 60%, Yellow 40% of formations for Nov 2011-2020

Key points: Forecast is clear a function of time of year; Each monthly outlook is demonstrably smaller than monthly climatology; anecdotal skill - above average PCA, above average year

Hindcasts and Skill Assessments

1. Multi-year hindcasting done at 0.5, 1.5, and 2.5 month leads using the archived CFSv2 forecasts of the LSEFs for:
    a. WNP for Jun-Nov 2011-2019
    b. NA for Jun-Nov 2011-2020
2. Skill was evaluated for each month and for the season.
3. In all cases, the forecasting systems were found to be skilled.
4. Examples: probability of detection (POD) and Heidke skill scores (HSS) show skill.
5. Developed and applied two new skill metrics:
    a. <u>Percent of contoured area (PCA)</u>:
        1. Measures the size of the "net" cast for a given POD.
        2. PCA is the forecast contoured area/total area.
        3. A lower PCA for a given POD is good.
        4. PCA serves the same purpose as false alarm ratio but is better suited than FAR for the types of forecasts we are producing.
    b. <u>Hits per unit area (HPUA)</u>:
        1. An indicator of reliability.
        2. For a reliable statistical model, as the likelihood of formation increases, the number of formations per unit area increases

Skill Assessments



WNP Verification:
- Hindcasted 2011-2019
- Cross-validated 2011-2019
- Re-verified with 2020 best tracks
- 2021 forecasts show skill

NA Verification:
- Hindcasted 2011-2020
- Cross-validated
- 2021 forecasts show skill

WNP Summary
- Skilled using conventional metrics POD, HSS, TS, ETS (TS and ETS not shown here)
- Skilled compared to climatology, even for the 90% of formations region
- Skilled when using our own metrics to better describe performance (PCA, HPUA)

NA Summary
- Comparable in performance to WNP system
- Less mature (smaller data set for statistical training, no 2021 best track data yet for verification of a fully independent season)

* Contours are reduced in Oct/Nov to 80 and 65% to reduce the impact of unusual storms on low activity months

Conclusions

1. Skilled experimental S2S forecasts of TC formations with relatively high temporal and spatial resolution can be produced using a statistical-dynamical forecasting system.
2. The skill of the system is achieved by using archived CFSv2 forecasts of the LSEFs for training the statistical model instead of CFSR or other reanalysis data.
3. The skill of the 2.5-month lead forecasts is similar to that of the 0.5-month and 1.5-month forecasts, indicating that:
    a. There may be skill in forecasting for leads greater than 2.5 months
    b. Additional quantification of activity is possible (e.g., identify on a monthly basis if activity may be above/below average, estimate number of formations, …)
4. Innovations in skill metrics were needed to more fully assess the forecasts.
5. **Skillful S2S forecasts of TC formation lay the foundation for skillful S2S forecasts of TC tracks and intensities.**
6. Forecasts are updated each Monday during TC season.
7. Forecasts, archived forecasts (2011-current), and verification data can be found on the Statistical Solutions LLC website at:

http://www.statisticalsolutionsllc.com/tropical-cyclonehurricane-formation-forecasts-2021.html

QUESTIONS?

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