New observational strategies for operational global and hurricane model improvements using airborne Tropical Cyclone and Winter Storm surveillance flights

Vijay Tallapragada
Chief, Modeling and Data Assimilation Branch
NOAA/NWS/NCEP/EMC

Workshop on Observational Campaigns for Better Weather Forecasts
ECMWF, Reading, UK, June 10-13, 2019

Outline

- Upgrades to Operational GFS – a major advancement in global modeling at NCEP

- Targeted observations for operational model forecast improvements:
  - Tropical Cyclones: GFS and HWRF
  - Winter Storms: GFS

- New observing strategies for airborne reconnaissance & surveillance

Change History of GFS Configurations

Mon/Year	Lev	Truncations	Z-cor/dyncore	Major components upgrade
Aug 1980	12	R30 (375km)	Sigma Eulerian	first global spectral model, rhomboidal
Oct 1983	12	R40 (300km)	Sigma Eulerian	
Apr 1985	18	R40 (300km)	Sigma Eulerian	GFDL Physics
Aug 1987	18	T80 (150km)	Sigma Eulerian	First triangular truncation; diurnal cycle
Mar 1991	18	T126 (105km)	Sigma Eulerian	
Aug 1993	28	T126 (105km)	Sigma Eulerian	Arakawa-Schubert convection
Jun 1998	42	T170 (80km)	Sigma Eulerian	Prognostic ozone; SW from GFDL to NASA
Oct 1998	28	T170 (80km)	Sigma Eulerian	the restoration
Jan 2000	42	T170 (80km)	Sigma Eulerian	first on IBM
Oct 2002	64	T254 (55km)	Sigma Eulerian	RRTM LW;
May 2005	64	T382 (35km)	Sigma Eulerian	2L OSU to 4L NOAH LSM; high-res to 180hr
May 2007	64	T382 (35km)	Hybrid Eulerian	SSI to GSI
Jul 2010	64	T574 (23km)	Hybrid Eulerian	RRTM SW; New shallow cnvtion; TVD tracer
Jan 2015	64	T1534 (13km)	Hybrid Semi-Lag	SLG; Hybrid EDMF; McICA etc
May2016	64	T1534 (13km)	Hybrid Semi-Lag	4-D Hybrid En-Var DA
Jun2017	64	T1534 (13km)	Hybrid Semi-Lag	NEMS GSM, advanced physics
Jun 2019	64	C768 (13km)	Vertically Lagrangian Non-Hydrostatic Finite Volume	NGGPS FV3 dynamic core, GFDL MP

GSM has been in service for NWS operations for more than 38 years !

NGGPS FV3GFS-v1 (GFS v15) Transition to Operations

FV3GFS is being configured to replace spectral model based GFS (NEMS GSM) in operations on June 12, 2019

Configuration of GDAS/GFS V15:

- FV3GFS C768 (~13km deterministic)
- GFS Physics + GFDL Microphysics
- FV3GDAS C384 (~25km, 80 member ensemble)
- 64 layer, top at 0.2 hPa
- Uniform resolution for all 16 days of forecast

Evaluation Strategy:

- Retrospective experiments from May 2015 – May 2018
- Real-time parallel experiments from May 2018 – implementation date
- Independent EMC MEG Evaluation and Stakeholder Evaluation

Major Science Changes:
GFDL FV3 Dynamic core and Microphysics

GSM

Spectral
Gaussian
Hydrostatic
64-bit precision

Finite-volume
Cubed-Sphere
non-hydrostatic
32-bit precision

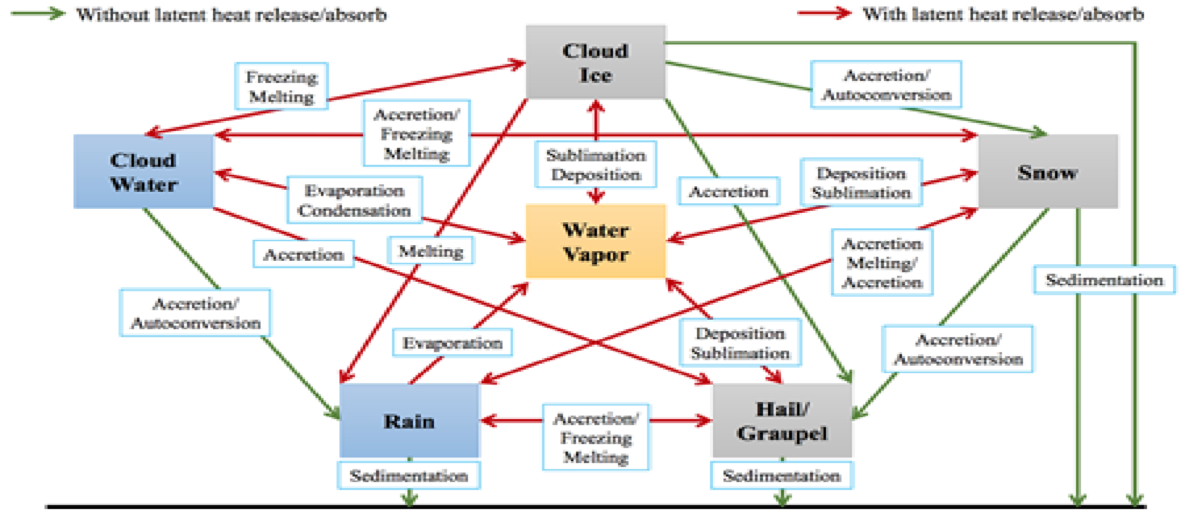
Physics runs at 64-bit precision

Zhao-Carr MP

Prognostic could species: one total cloud water

GFDL MP

Prognostics cloud species : five
Liquid, ice, snow, graupel, rain;
more sophisticated cloud processes



The Issues and Proposed Changes

- FV3GFS real-time evaluation has revealed two issues:
  - Unrealistically large accumulation of snow under certain conditions
  - Exacerbated cold bias in the lower atmosphere

- We determined at least one cause of excessive snow and two causes of some of the exaggerated cold bias in the lower atmosphere.
- **Fractional Snow Flag:**
  - Redefine snow flag in the LSM (srflag) as a fractional number between frozen precipitation and total precipitation.
- **Zenith angle bug fix**:
  - A bug in the computation of solar zenith angle caused a slight shift of the solar radiation diurnal cycle and adds more solar energy to the system. This bug has been fixed.
- **Enhanced cloud-radiation interactions:**
  - Instead of partitioning total cloud condensate from GFDL MP into water and ice clouds based on temperature profiles, individual hydrometeors are directly fed into radiation.

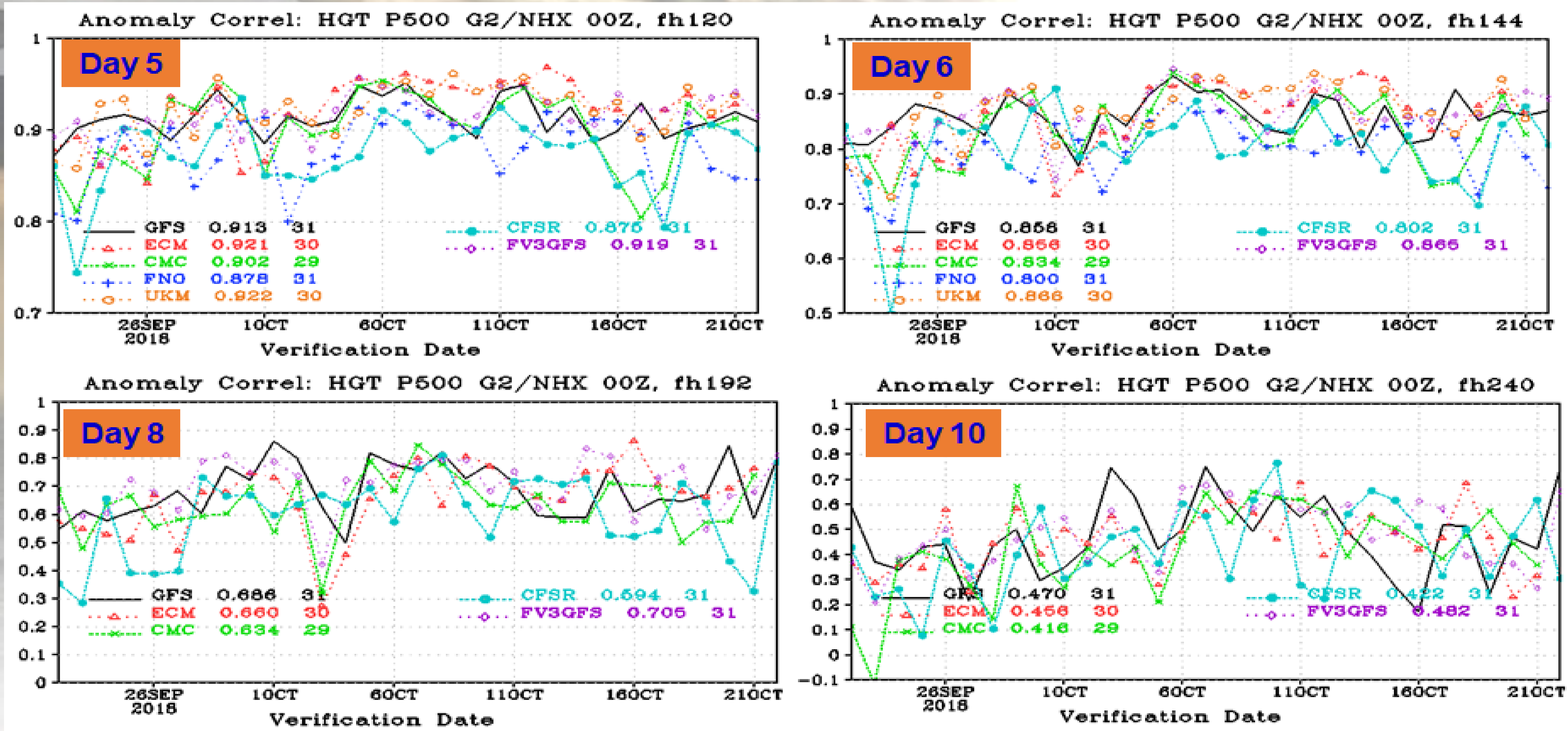
NCEP has recommended implementing FV3GFS with these changes

✓ = Retained in the new configuration

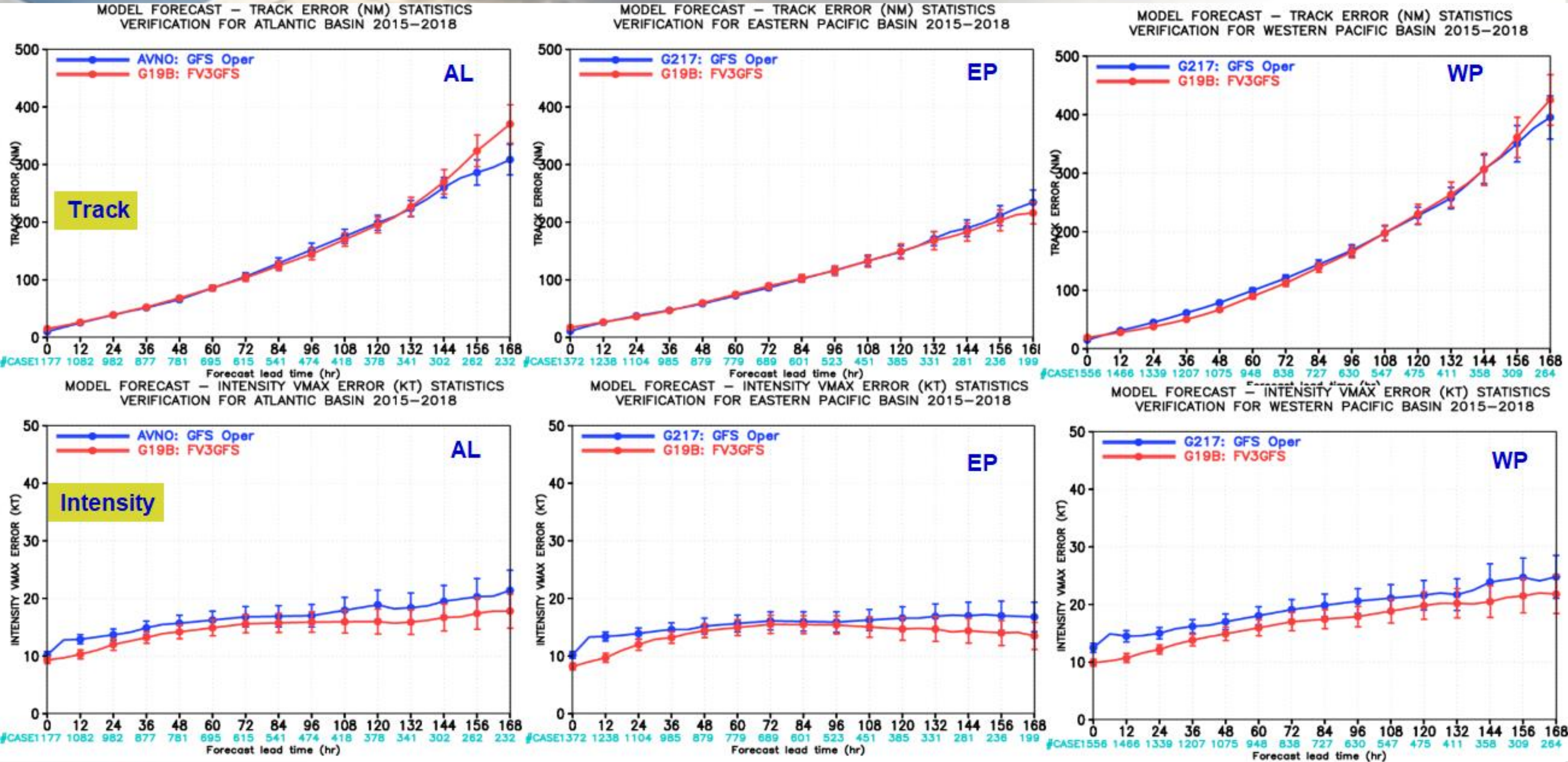
Improvements over operational GFS in retrospective runs

- ✓ (significantly) Improved 500-hpa anomaly correlation (NH and SH)
- ✓ Intense tropical cyclone deepening in GFS not observed in FV3GFS
- ✓ FV3GFS tropical cyclone track forecasts improved (within 5 days)
- ✓ Warm season diurnal cycle of precipitation improved
- ✓ Multiple tropical cyclone centers generated by GFS not seen in FV3GFS forecasts or analyses
- ✓ General improvement in HWRF and HMON runs
- ✓ New simulated composite reflectivity output is a nice addition
- ✓ Some indication that fv3gfs can generate modest surface cold pools from significant convection
- FV3GFS with advanced GFDL MP provides better initial and boundary conditions for driving stand alone FV3, and for running downstream models that use advanced MP.
- FV3 based GEFS V12 showed significant improvements when initialized with FV3GFS
- ✓ Improved ozone and water vapor physics and products
- Improved extratropical cyclone tracks
- ✓ Improved precipitation ETS score (hit/miss/false alarm)
- Overall reduced T2m biases over CONUS

NH 500-hPa HGT ACC (Days 5, 6, 8 and 10)



Hurricane Track and Intensity 20150601 ~ 20180919 Red: FV3GFS; Blue Oper. GFS



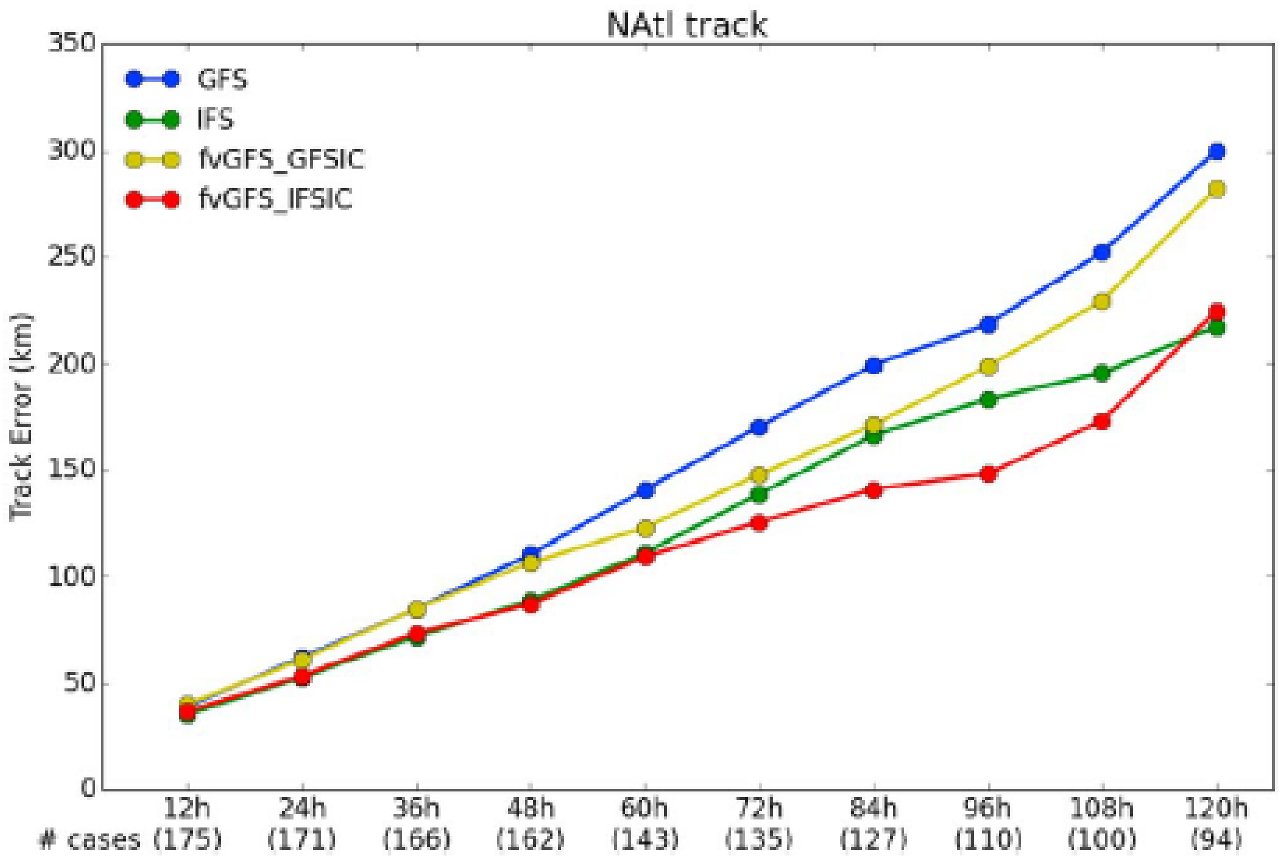
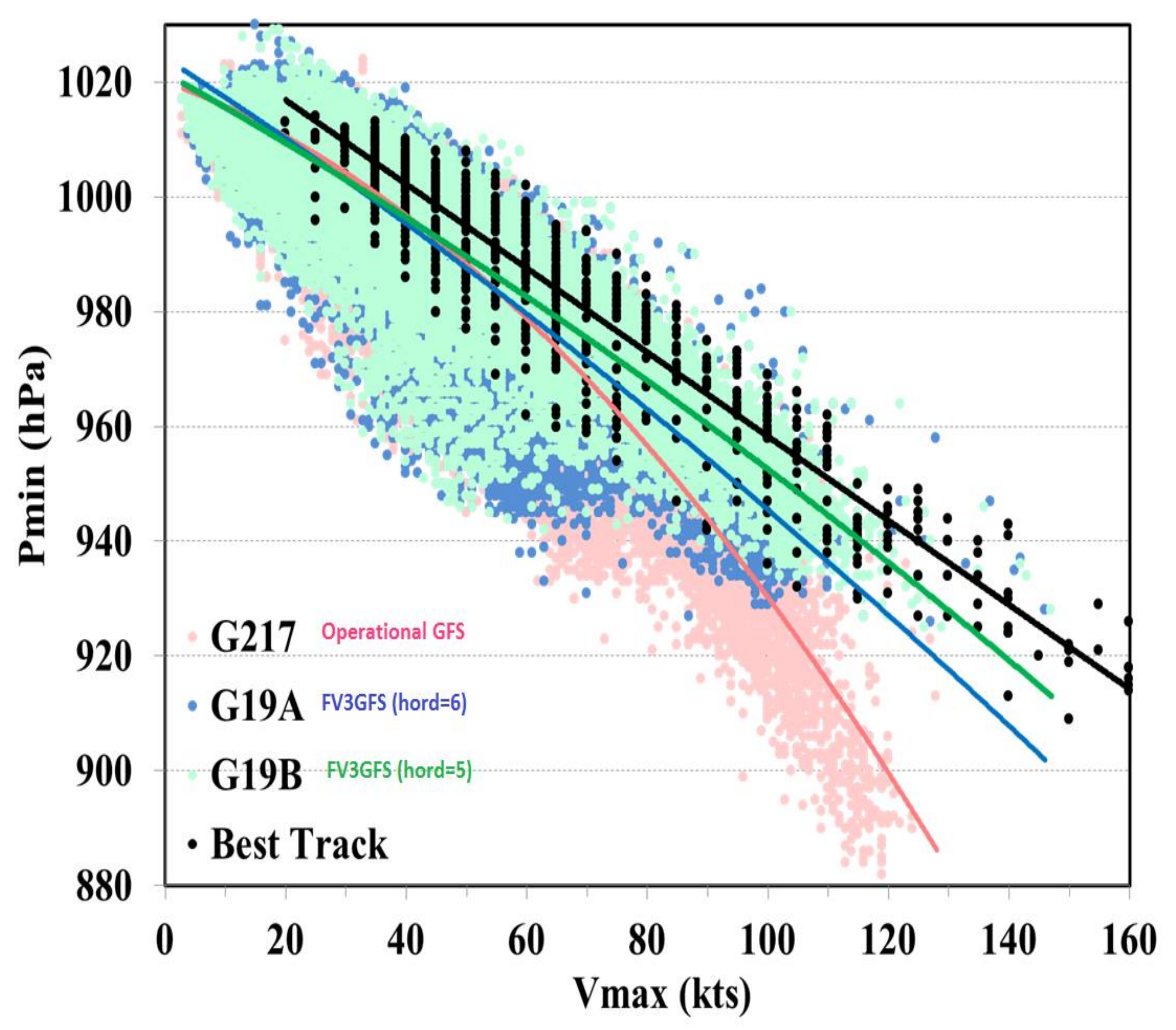
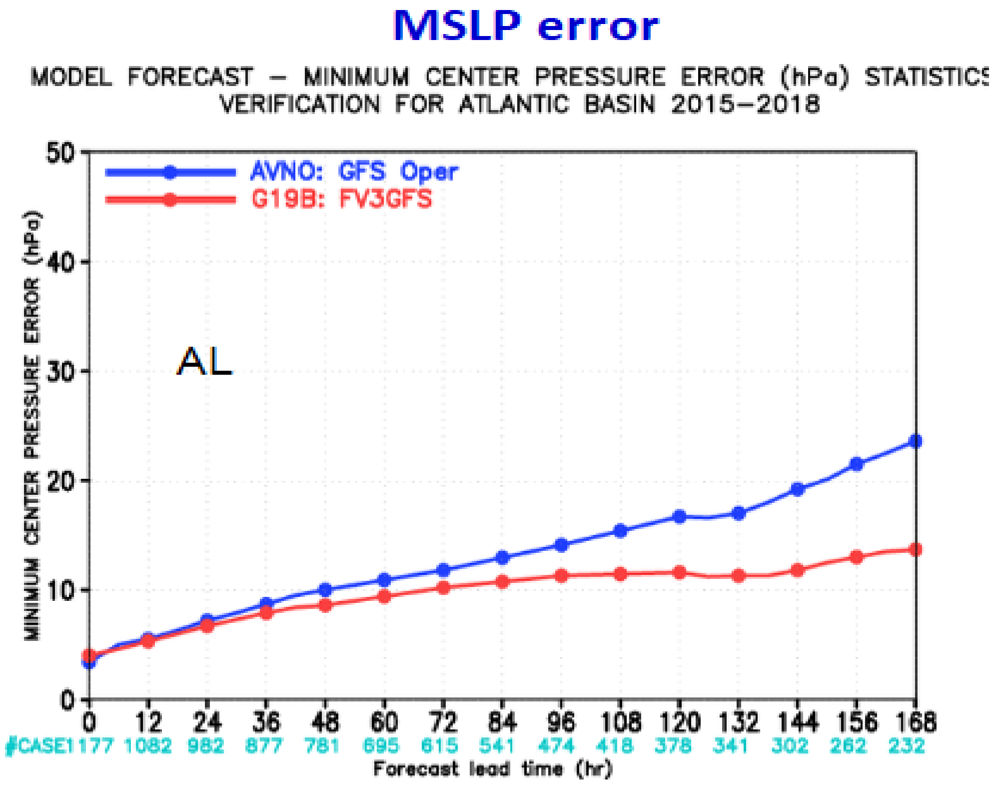


Figure 2. Mean TC track forecast errors (km) in the North Atlantic basin. Track errors as a function of forecast lead time for GFS (blue), IFS (green), fvGFS_GFSIC (yellow), and fvGFS_IFSIC (red). Numbers of homogeneous cases for each lead time are listed in the brackets at the bottom of each abscissa.

Improved Wind-Pressure Relationship and Intensity (MSLP) Errors





Much reduced MSLP Errors from FV3GFS

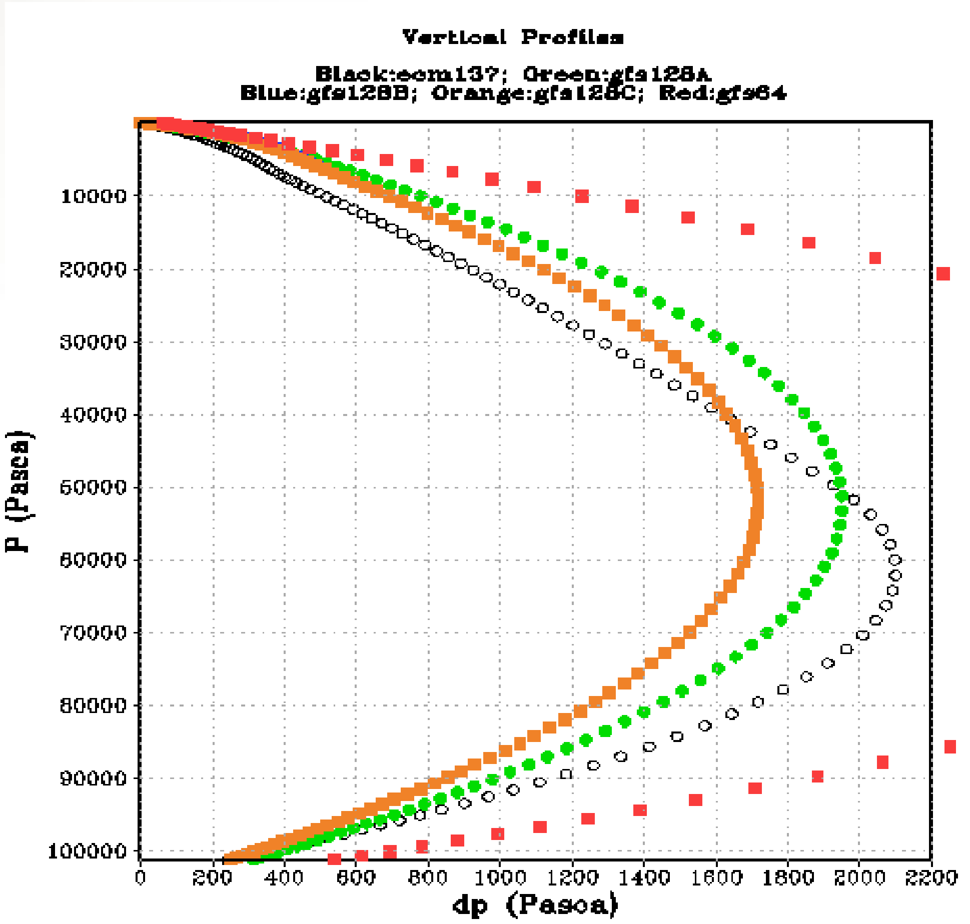
GFS V16 (Q2FY21): Major Upgrades to Deterministic Global Model

- **Model resolution:**
  - Increased vertical resolution from 64 to 127 vertical Levels and raise model top from 54 km to 80 km; Increased horizontal resolution from 13 km to 10 km (depending on operational resources)
- **Dynamics:** New advection algorithms from GFDL
- **Advanced physics chosen from Physics Test Plan:**
  - PBL/turbulence: K-EDMF => sa-TKE-EDMF
  - Land surface: Noah => Noah-MP
  - Gravity Wave Drag: => unified gravity-wave-drag
  - Radiation: updates to cloud-overlap assumptions,
  - Microphysics: Improvements to GFDL MP
- **Coupling to WaveWatchIII**
  - Two-way interactive coupling of atmospheric model with Global Wave Model (GWM)

- **Data Assimilation Upgrades:**
  - Local Ensemble Kalman Filter (LETKF), including early cycle updates in support of GEFS
  - 4-Dimensional Incremental Analysis Update (4DIAU)
  - Stochastic Kinetic Energy Backscatter (SEKB) based land surface perturbations
  - Stratospheric humidity increments
  - Improved Near Surface Sea Temperature (NSST) analysis
  - Land Data Assimilation
  - Shifting and Lagging Ensemble Members to expand ensemble size
  - Improved cloud analysis
  - Delz increments

DA Plans for GFSv16

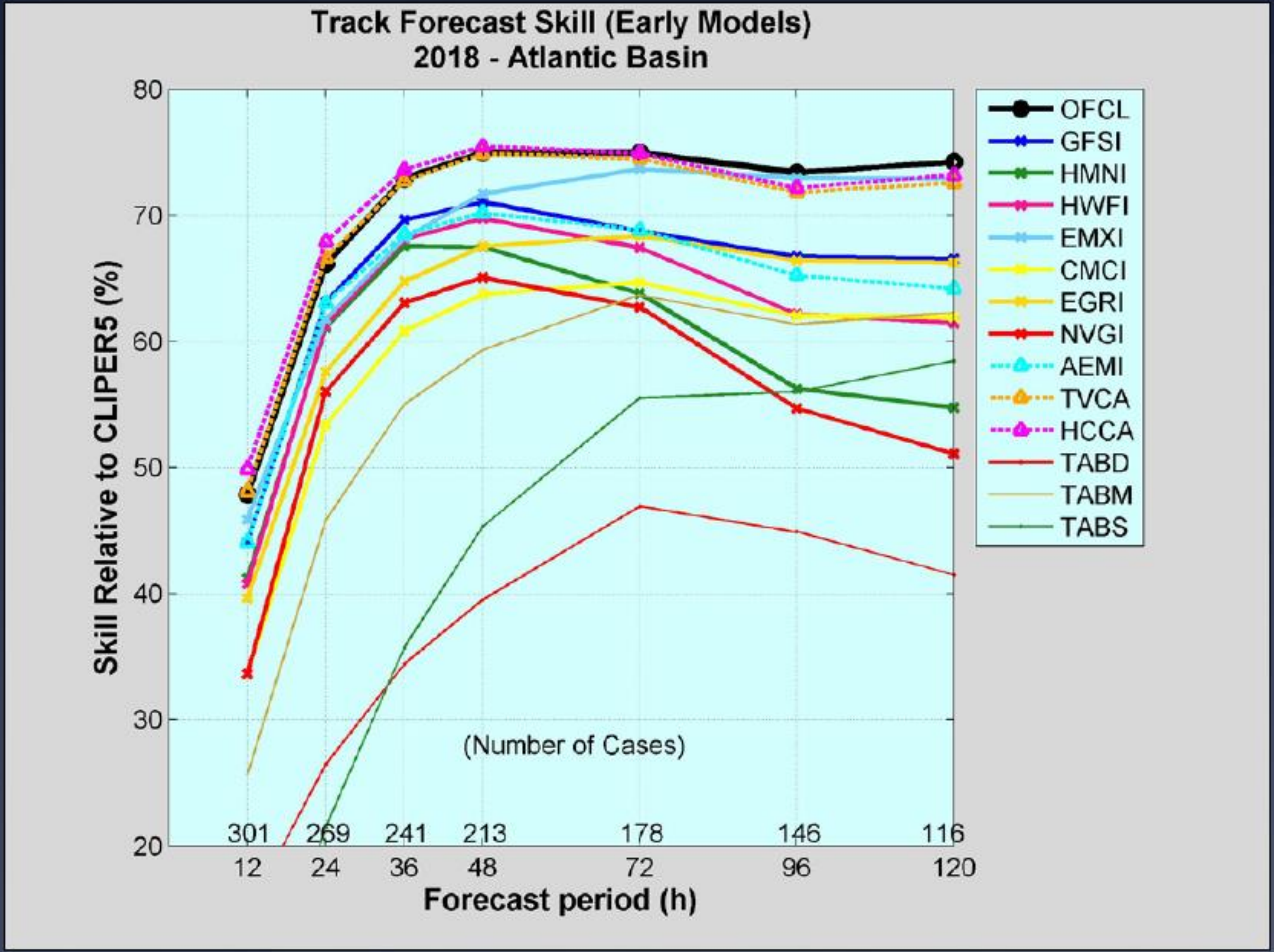
- Vertical Resolution: 127L with 80km top (Currently 64L with 50km top). Adaptation for "advanced physics" (suites currently being tested).
- Ensemble Perturbation Update: LETKF (replace EnSRF), Early Cycle (instead of late, GDAS cycle)
- 4D Incremental Analysis Update
- Inter-channel correlated ob error
- Hydrometeor control variables;
  pass increment to model
- SDL/SDW, Shifting-Lagging (?)
- Global "LDAS"
- Include dropsonde drift, and position assimilation for TCs



Targeted Observations for improving Tropical Cyclone Forecasts

2018 Track Guidance

State of the art on Atlantic TC Forecasts: 2018 Season



Official forecasts were very skillful and near or better than the best performing models (HCCA and TVCA).

EMXI best individual model at 48 h and beyond and near the skill of the consensus aids at those times.

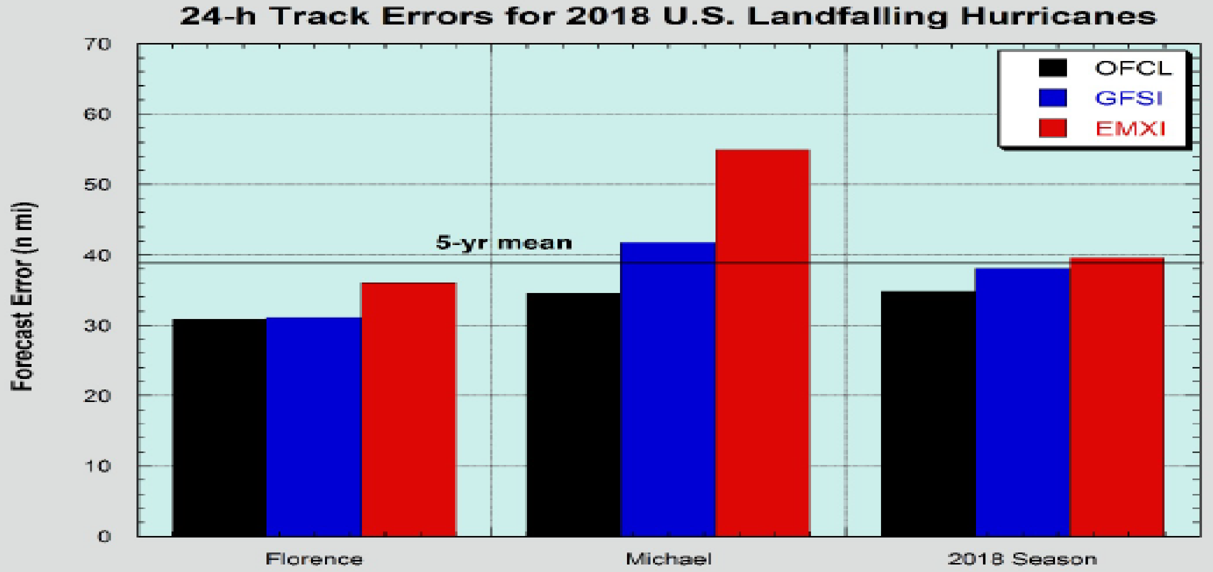
GFSI best individual model at 24 and 36 h, but not as good after that.

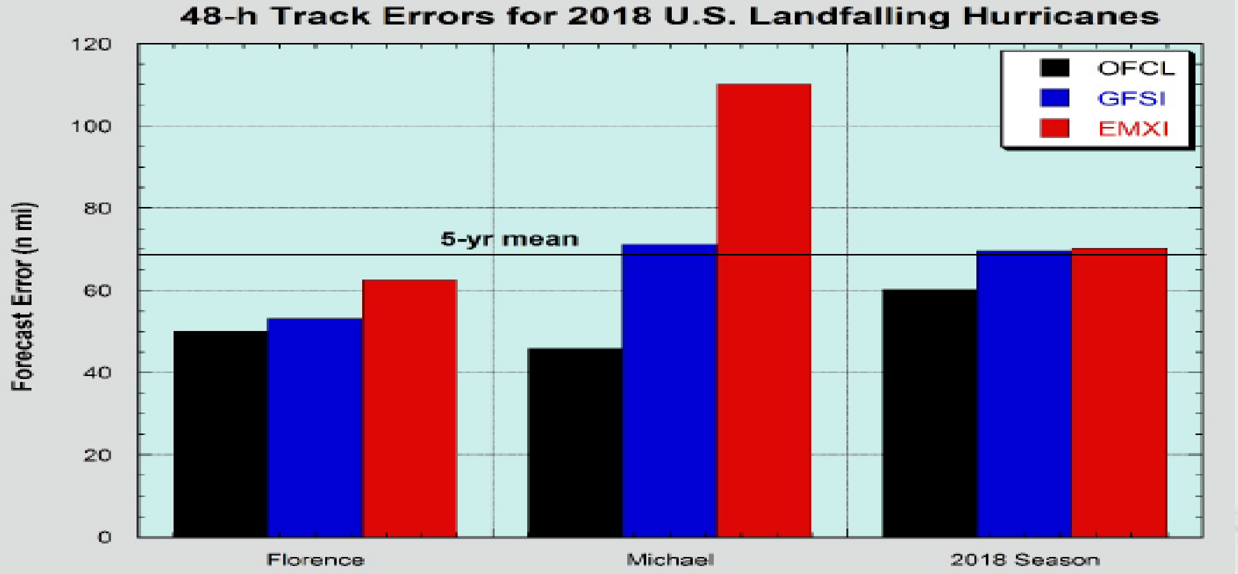
AEMI, EGRI, HWFI were fair performers.

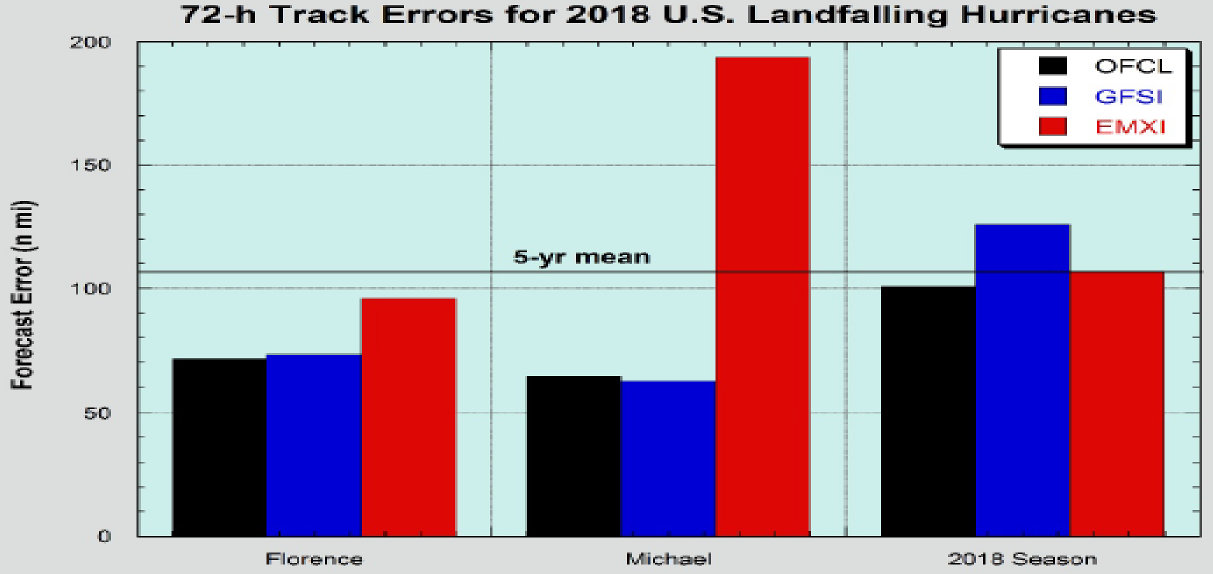
HMNI competitive early, but skill dropped off after 48 h.

NVGI and CMCI less competitive.

State of the art on Atlantic TC Forecasts: 2018 Season Landfalling Storms



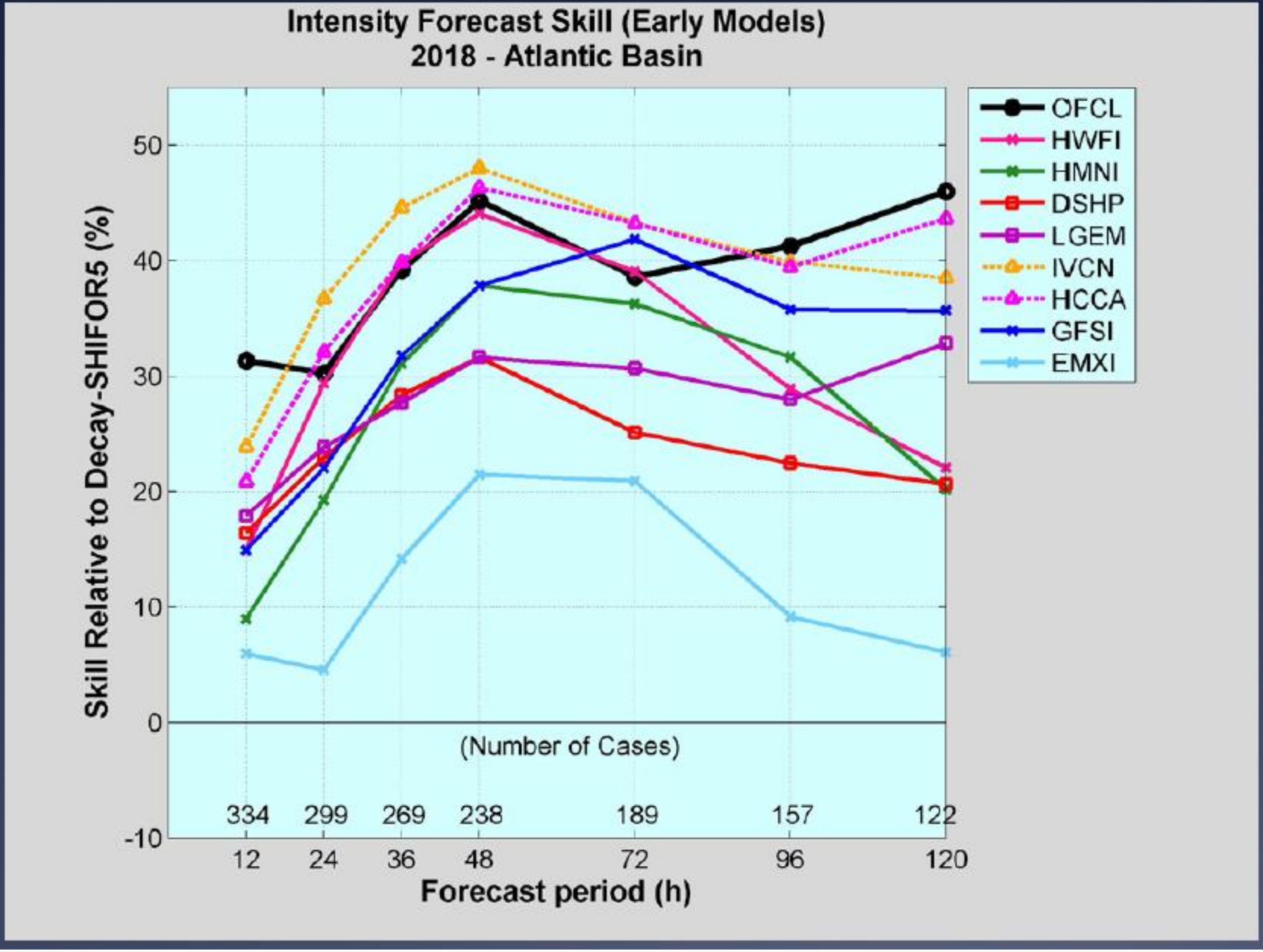




- NHC track forecasts (in black) performed quite well.
- For the high-impact storms, better than the season average, and much better than the 5-year mean.
- ECMWF outperformed by GFS for this sample

2018 Intensity Guidance

State of the art on Atlantic TC Forecasts: 2018 Season



Official forecasts better than all of the guidance at 12 h, 96 and 120 h.

IVCN and HCCA were the best models. IVCN best from 12 to 48 h. HCCA was best at 120 h.

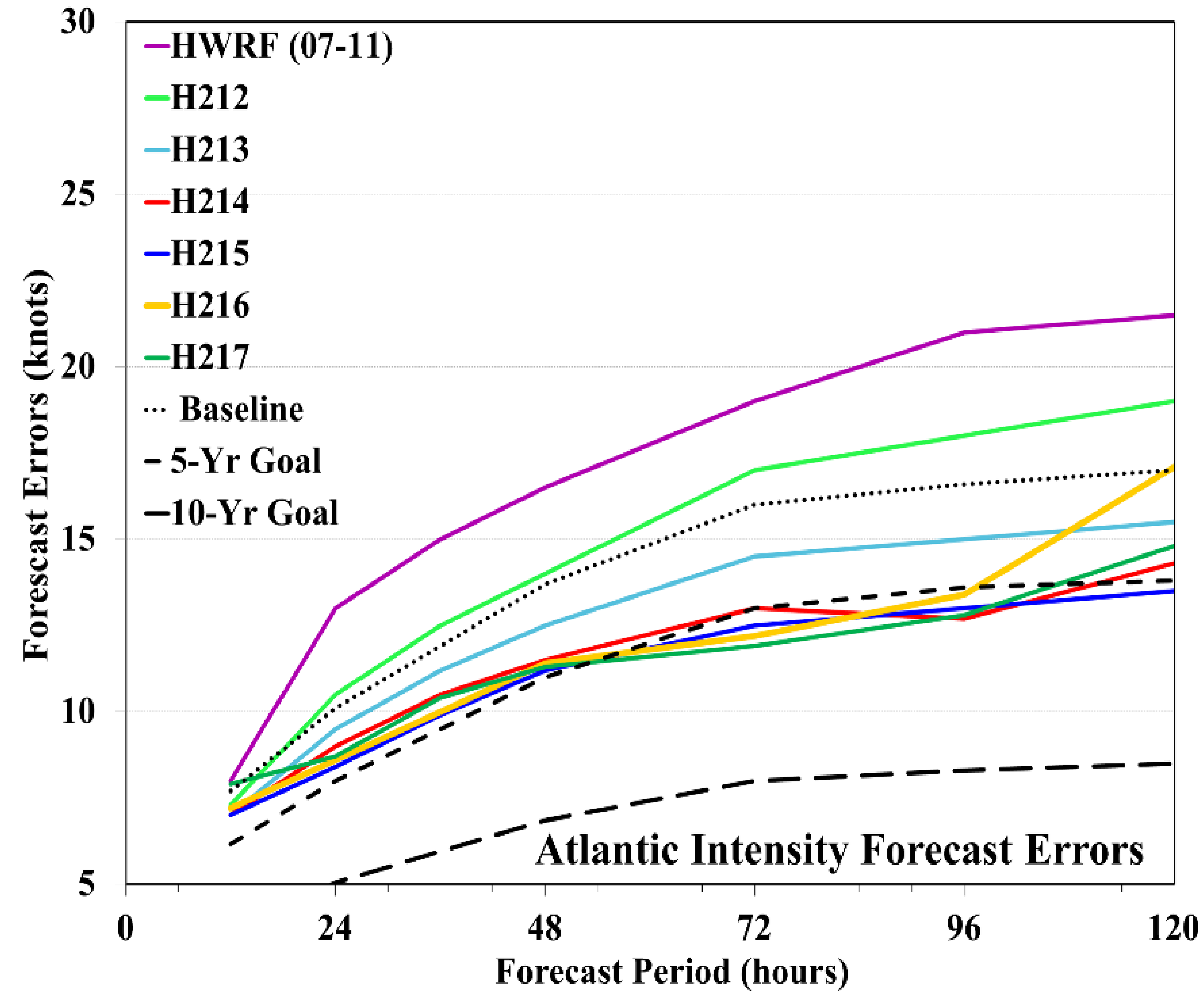
HWFI best individual model through 48 h. GFSI best individual model after that!

HMNI not as good as HWFI or GFSI, but beat statistical aids.

DSHP and LGEM were skillful, but had less skill than dynamical models at most time periods.

EMXI had some skill, but not competitive

Continuous improvements to HWRF intensity forecasts



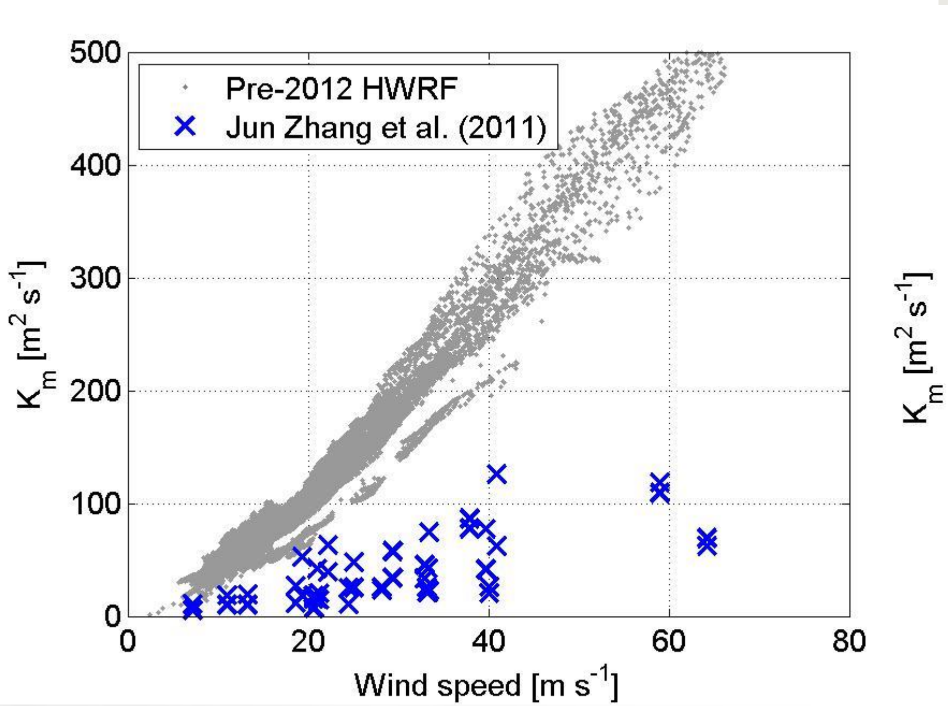
HWRF is the only operational model in the world that assimilates inner core TDR data from NOAA-P3 and NOAA-GIV

Also assimilates inner core and environmental dropsondes, SFMR, flight level data, HDOBS, AXBTs and other in-situ measurements

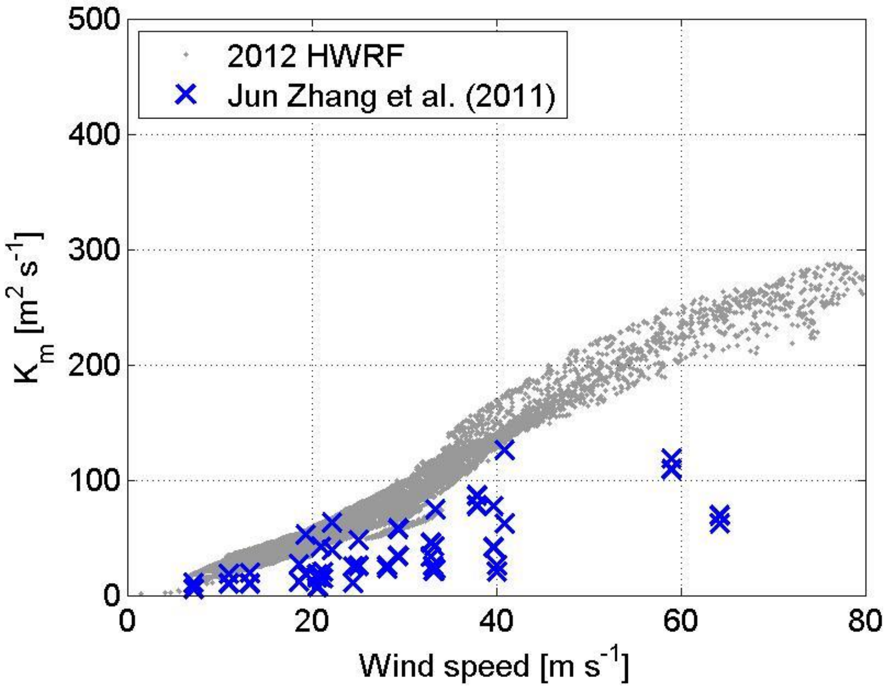
Aircraft based observations directly help improve the initial state and indirectly help improve model physics

Use aircraft observations to improve PBL physics in the operational hurricane HWRF

Before modification (HWRF 2011 and prior)



After modification (HWRF 2012)



$$\langle u'w' \rangle = - K_m \, du/dz$$

$$K_m = k \, (U_*/\Phi_m) \, Z \, \{\alpha(1 - Z/h)^2\}$$

(Gopal et al. 2013, JAS; Jun Zhang et al. 2012, TCRR)

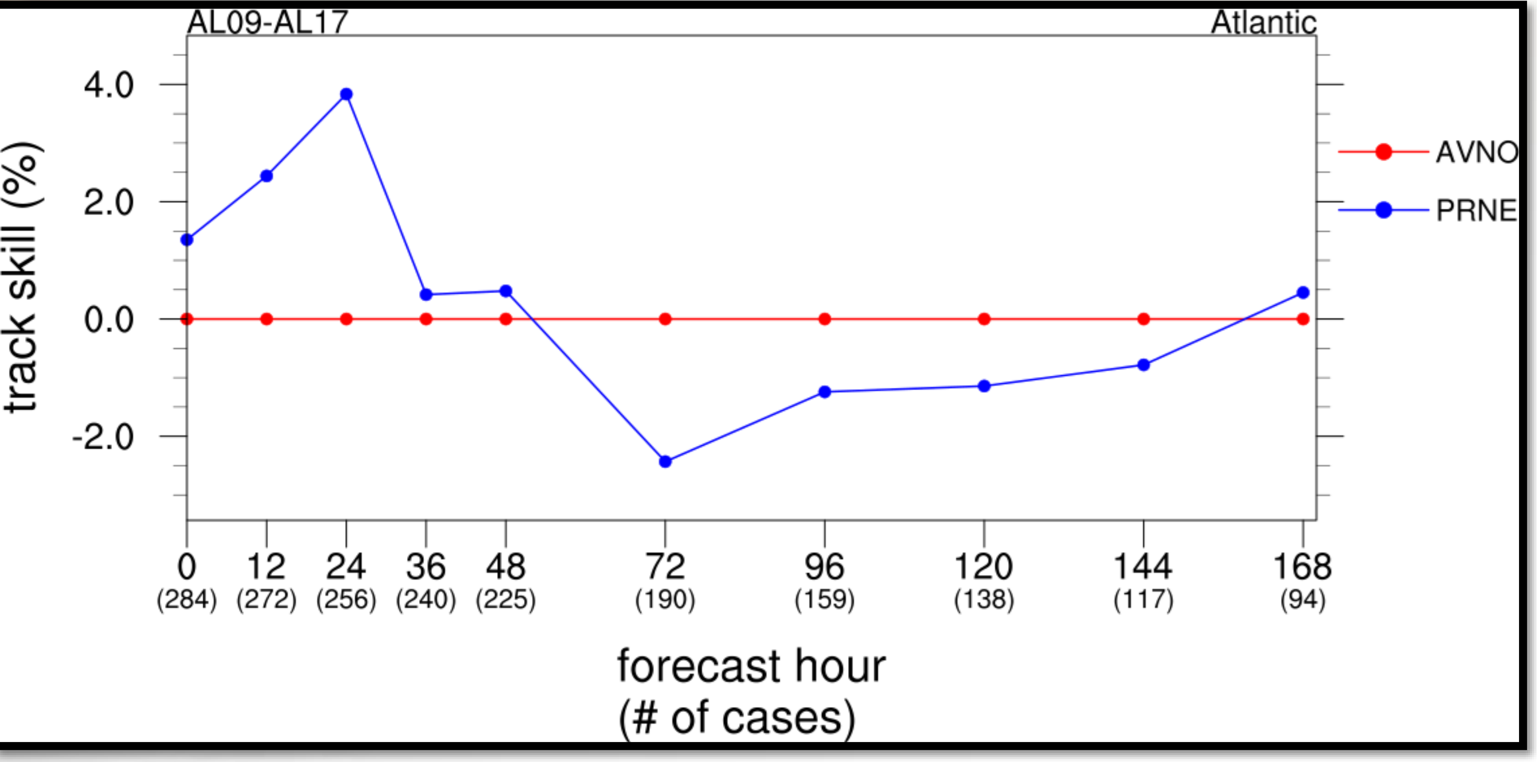
Observations were collected by P3 aircraft at ~450 m in Cat5 Hurricanes Hugo (1989) and Allen (1980). (Marks 1985; Marks et al. 2008; Jun Zhang et al. 2011a)

Recent Results of GFS Supplemental G-IV Dropsonde Data Denial Experiment

Background

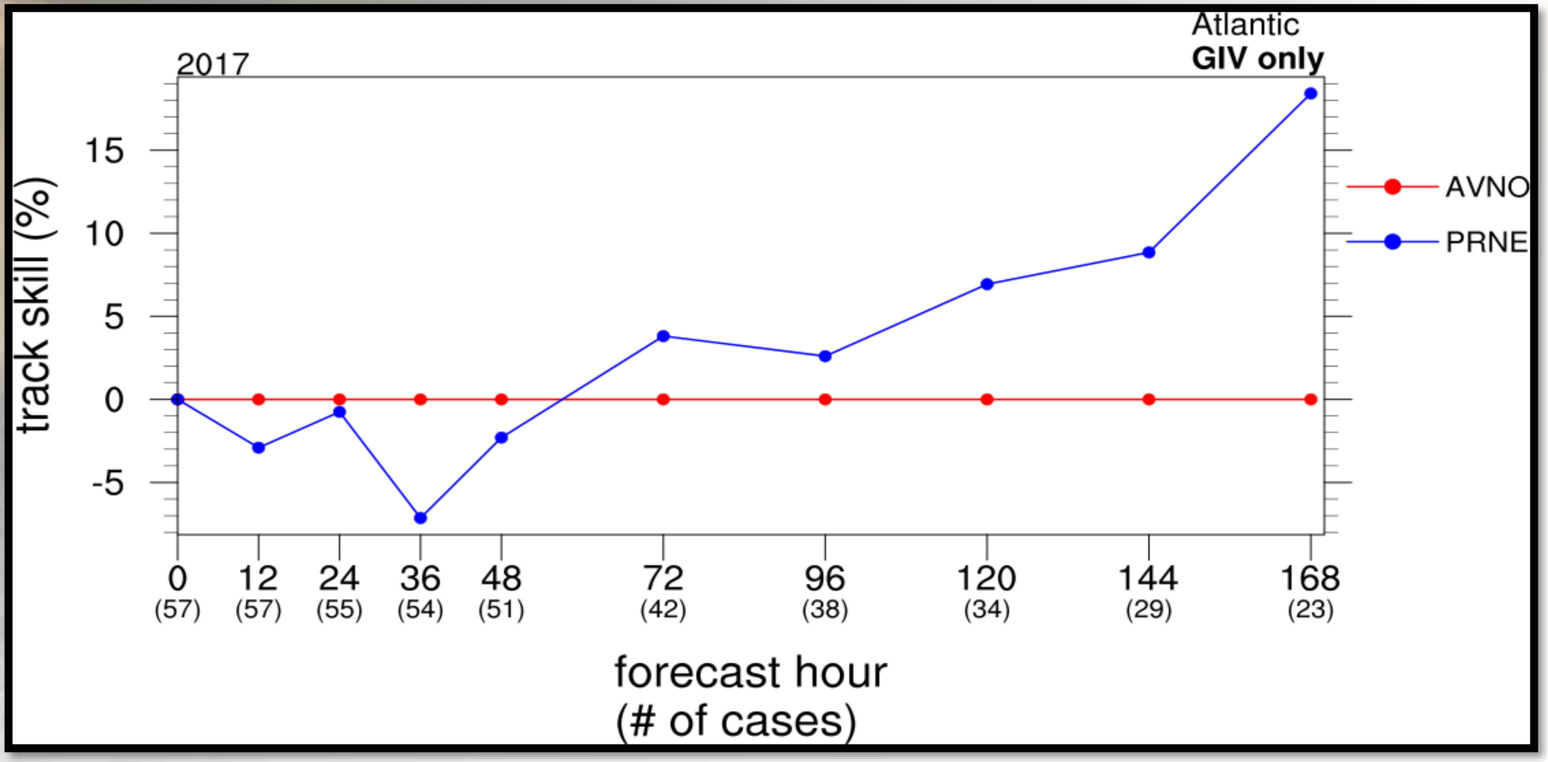
- NHC tasks "synoptic surveillance" missions using NOAA's G-IV jet to measure the environment around tropical cyclones (TCs)
- Missions are flown every 12 or 24 hours to improve model forecasts when a hurricane threatens the United States or U.S. territories such as Puerto Rico or the U.S. Virgin Islands
- **Previous work has shown that G-IV dropsonde data resulted in a 10-15% improvement in GFS track model forecasts during the first 60 h during the period from 1997-2006 (Aberson et al. 2010, 2011)**
- The GFS model and its underlying DA methodology have changed significantly in the least 10 years and many new observation types have become available, so it is unknown what impact the G-IV dropsonde data currently have

All Cases (including storms with no G-IV data; 22 Aug – 10 Oct. 2017)



- Overall average results show little impact with no statistical significance
- Lack of impact in this large sample isn't surprising given that many cycles did not include storms where G-IV data were collected

All Cases (including storms only with G-IV data; 22 Aug – 10 Oct. 2017)



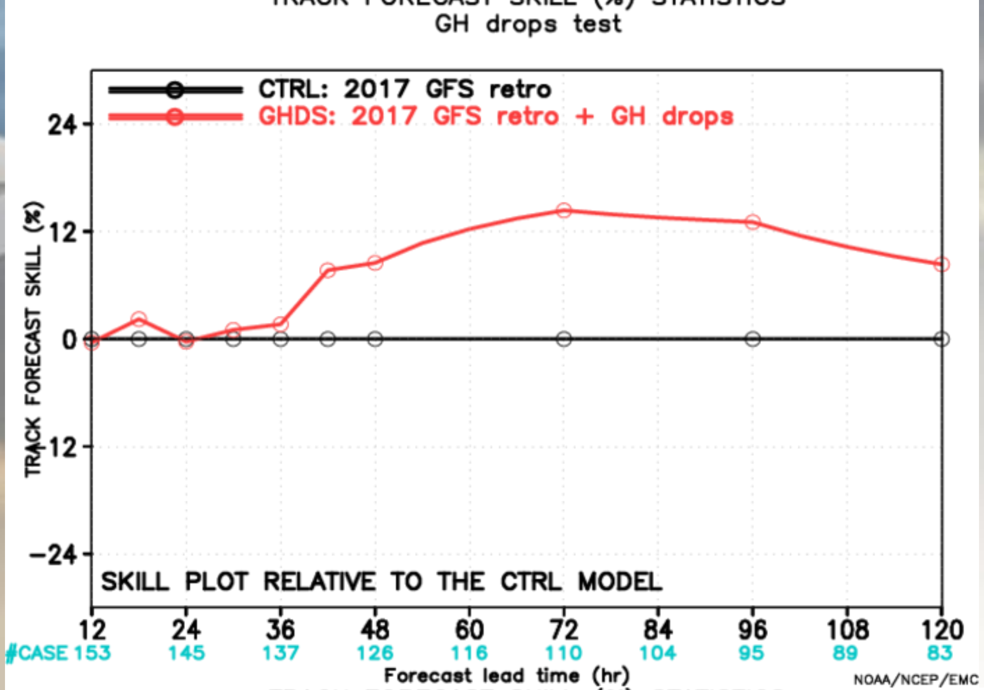
- **Cycles with direct assimilation of G-IV data show negative impact with statistically significant degradation beyond day 5**
- Only gain is at 36hr forecast time
- This suggests we need to take a hard look at how we are doing TC initialization in the global model. We also should do a better job of designing flight paths on the fly using things like ensemble sensitivity instead of past practice and intuition

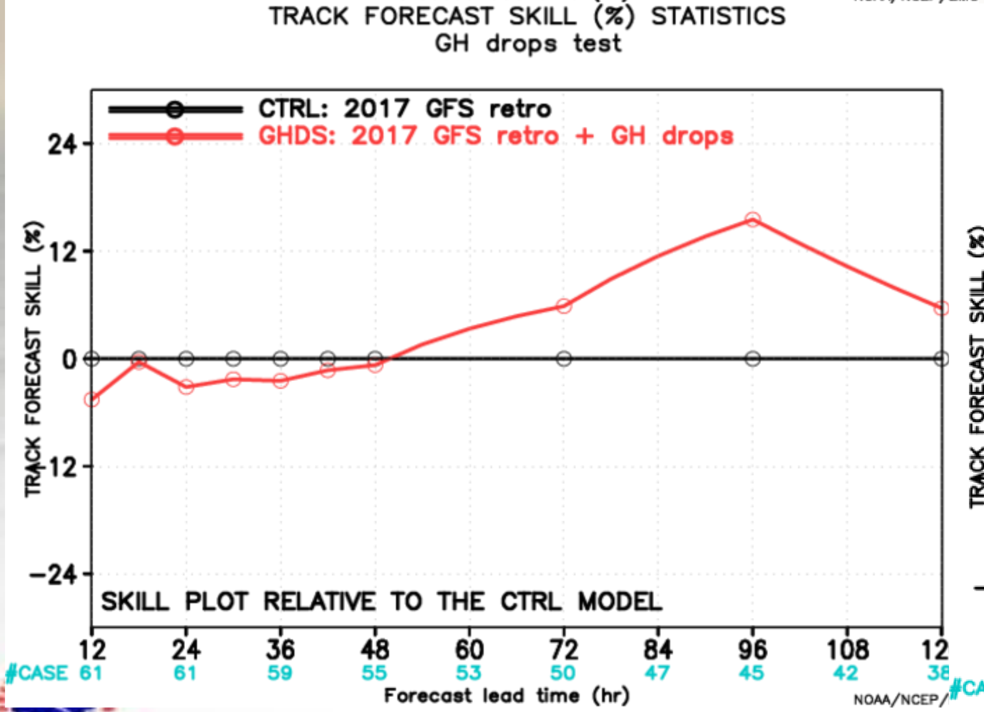
Recent Results of GFS Global Hawk Dropsonde Data Impact Experiment

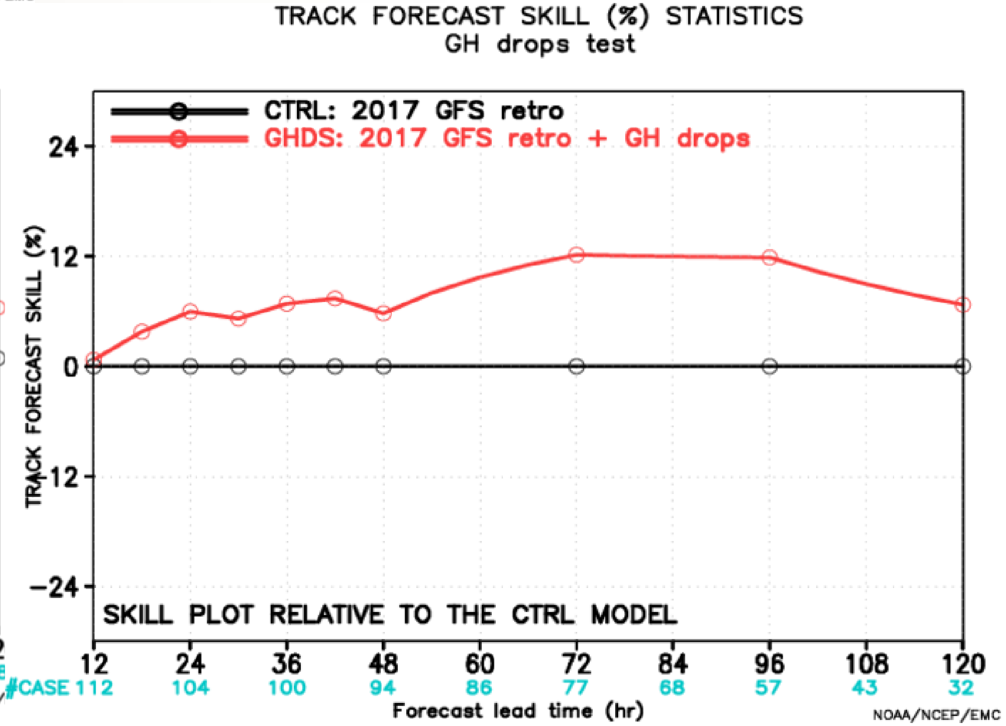
Impact of Global Hawk Dropsondes (HS3/SHOUT)

- **Quite different compared to impacts from G-IV dropsonde data**
- **>10% improvement globally**

- **High altitude?**
- **Longer duration?**
- **Targeted observing strategies?**



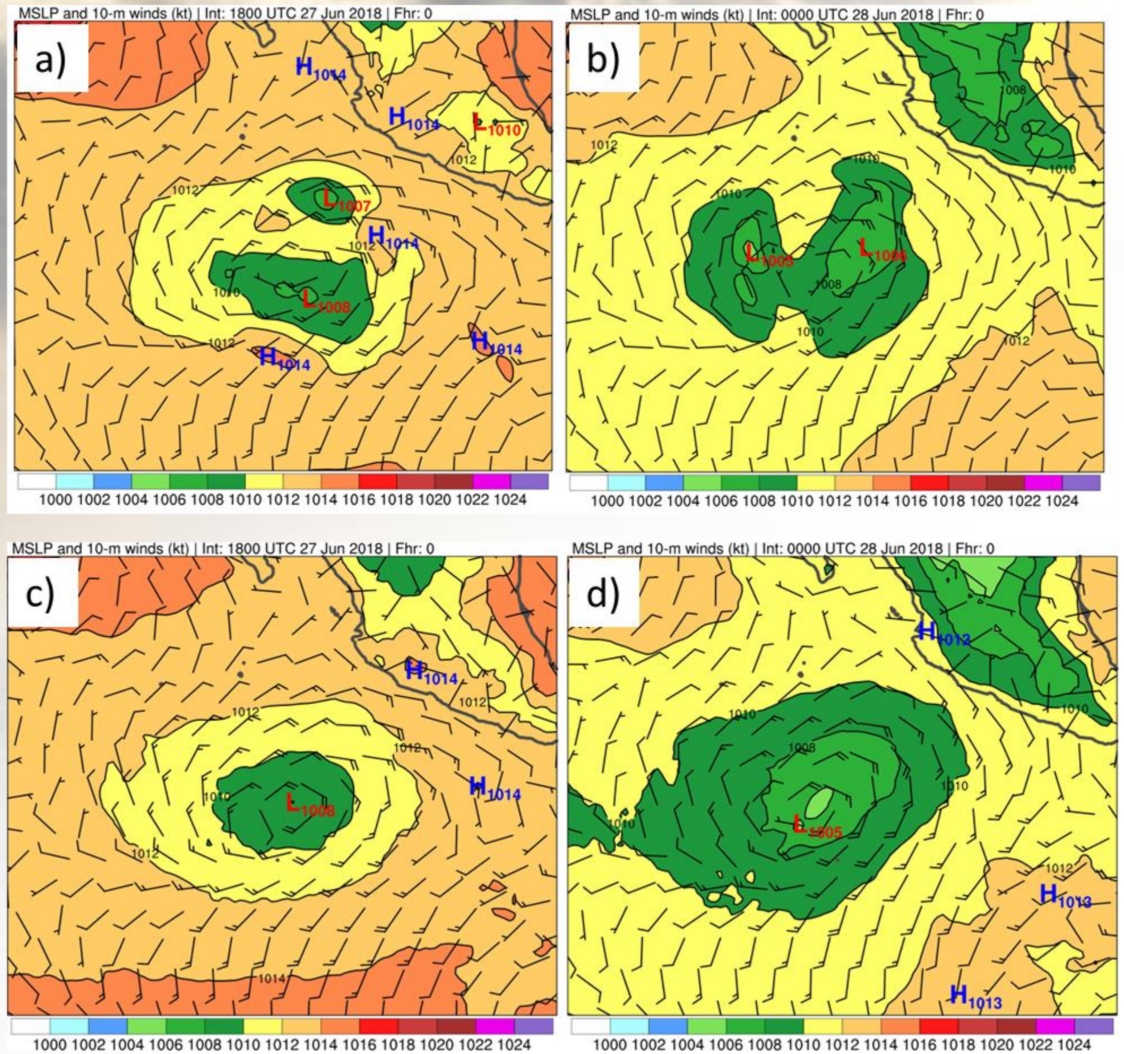




Tropical Cyclone Initialization

GFS

FV3-GFS



1800 UTC
27 June 2018

0000 UTC
28 June 2018

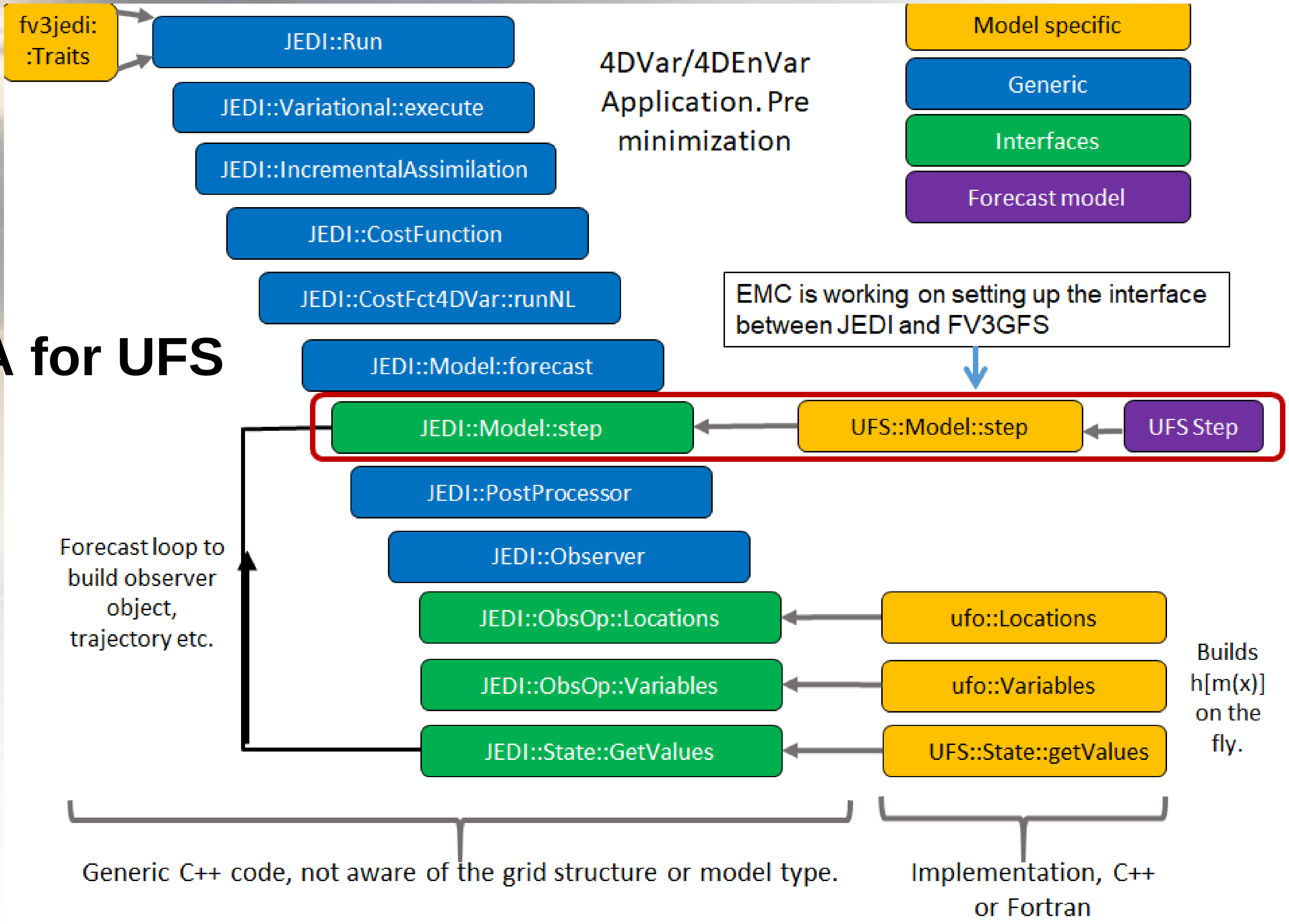
Vortex Relocation + MinSLP Assimilation

MinSLP Assimilation Only

Revisiting Observing Strategies & DA Techniques

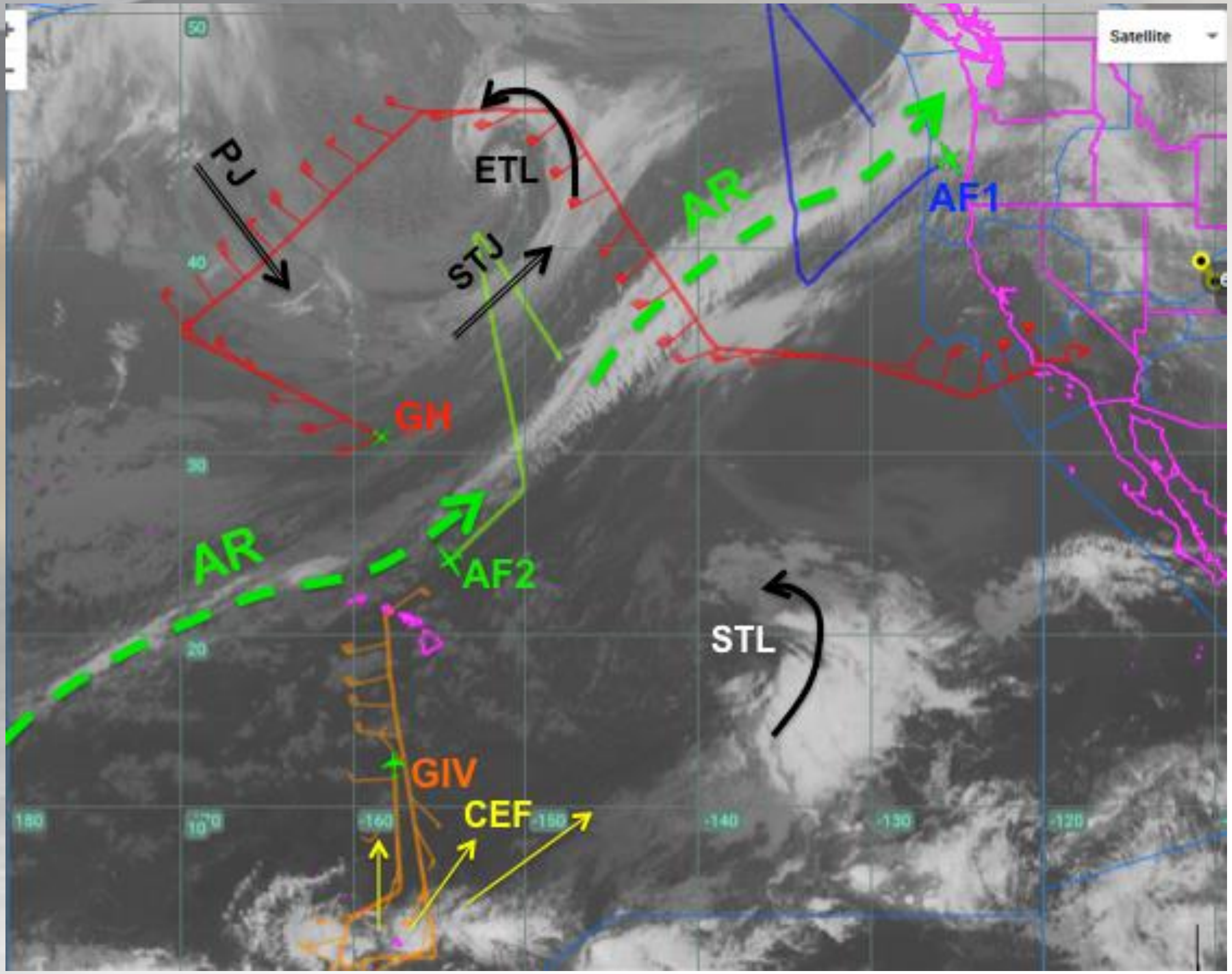
- Continuous improvements to NWP models and DA techniques
- A new aircraft observing strategy for obtaining atmospheric dropsonde observations for TCs (Ryan’s talk).
  - New and improved dropsonde targeting strategies that employ targeting regions of model uncertainty using operational global ensemble forecast models.
- Expand the same technique(s) for Atmospheric Rivers and Winter Storms

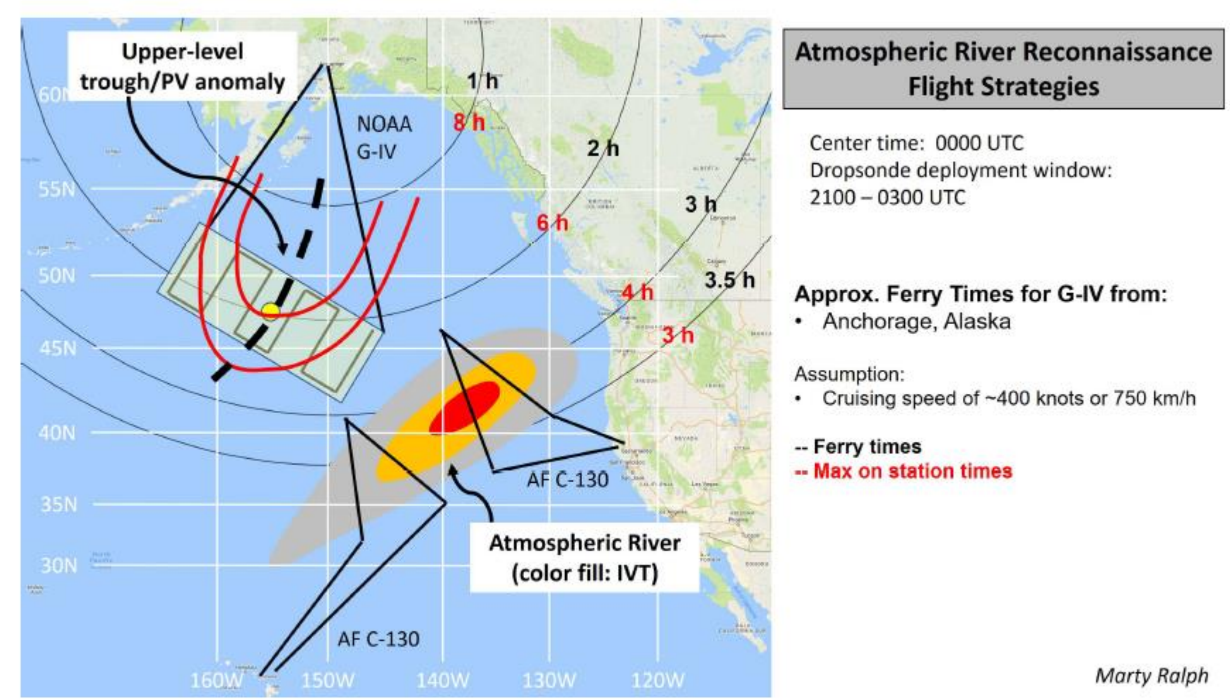
JEDI: Next Gen DA for UFS



Focus on Winter Storms (primarily Atmospheric Rivers) for Targeted Observations

AR Recon Strategy



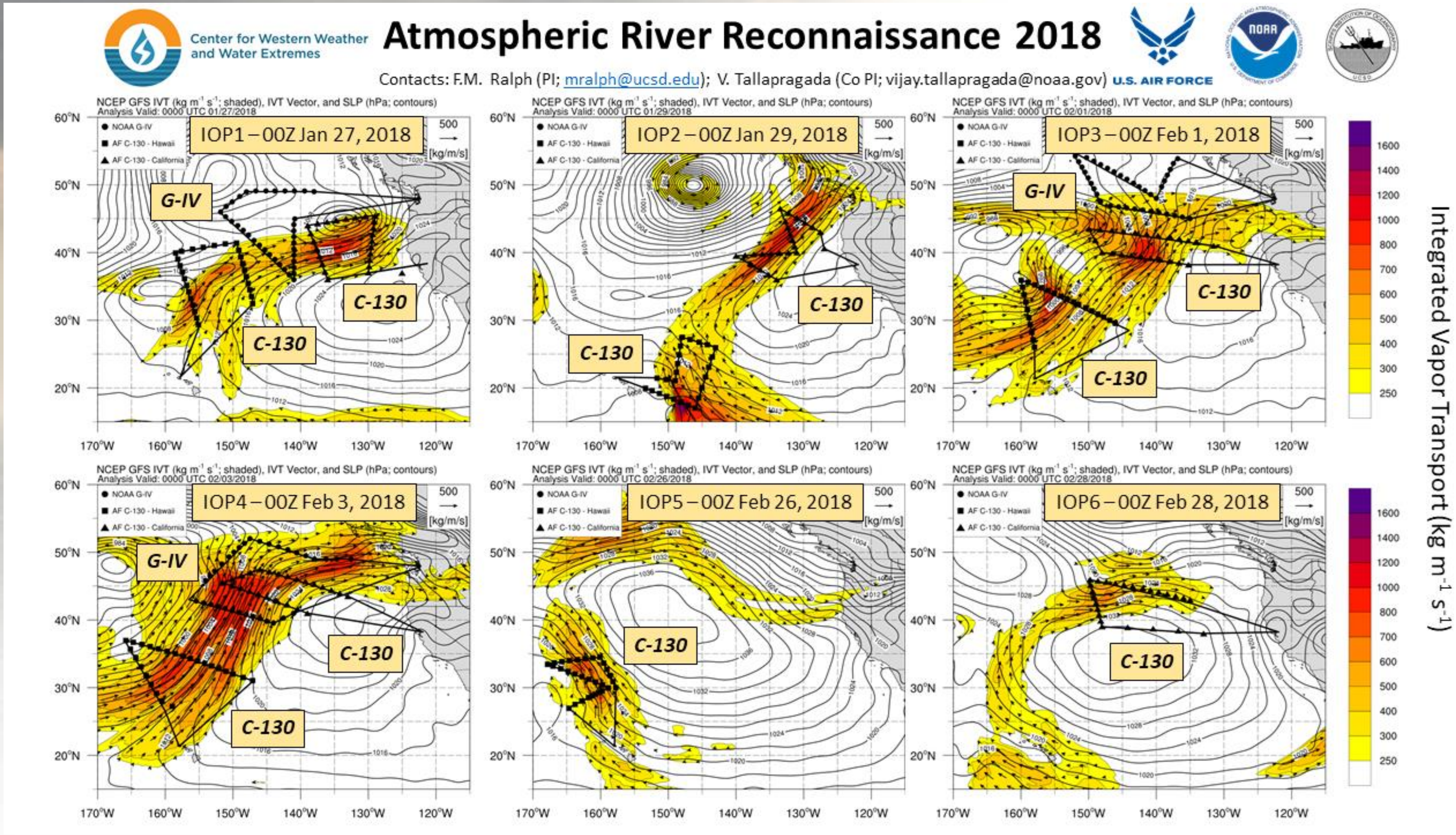


An atmospheric river (AR; thick green curve), atmospheric jet features (black arrows) associated with a polar jet (PJ), subtropical jet (SJ), extratropical low (ETL), and subtropical low (STL), and an area of upper-level cross equatorial flow (CEF; yellow arrows)

Data Impact Experiments for Atmospheric Rivers Reconnaissance with FV3GFS

A case study for 2018

Second AR Recon Experiment in 2018



AR Recon Data Impact Experiment with FV3GFS

- Study periods and location:
  - January 24 – March 2, 2018 (G-IV and C-130)
  - Northeastern Pacific
- Supplemental obs types to be included or denied:
  - Dropwindsonde - NOAA G-IV, C-130

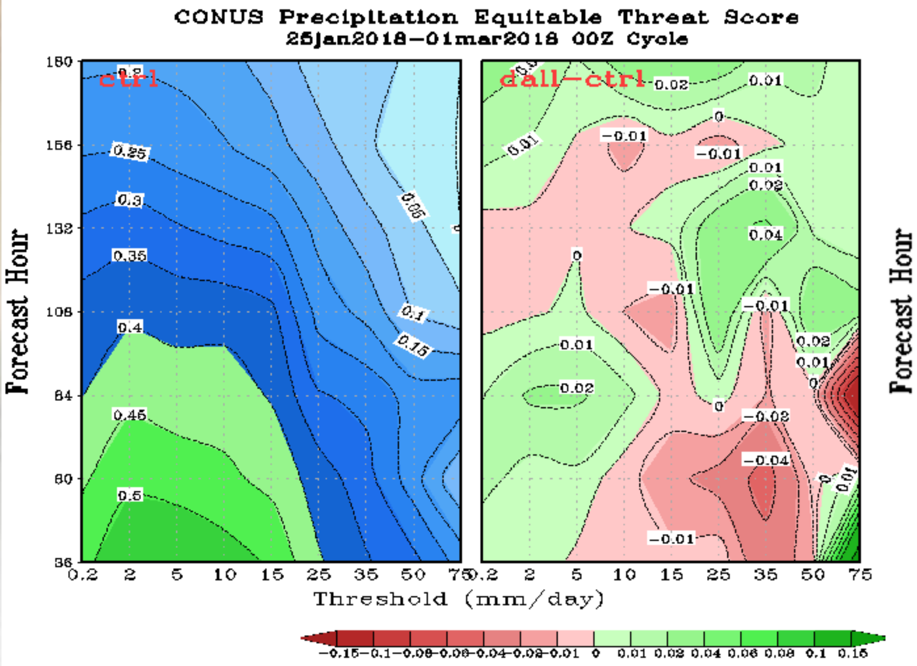
1) IOP1 - Jan 27:	**87** (51 C130 and 36 G-IV)
2) IOP2 - Jan 29:	**47** (47 C130)
3) IOP3 - Feb 1:	**88** (49 C130 and 39 G-IV)
4) IOP4 - Feb 3:	**86** (49 C130 and 37 G-IV)
5) IOP5 - Feb 26:	**0**
6) IOP6 - Feb 28:	**25** (25 C130)

- Modeling system:
  - FV3GFS

CONUS PRECIP ETS and BIAS Scores :
FV3GFS Control (CTRL) vs Denial all (DALL): AR 2018

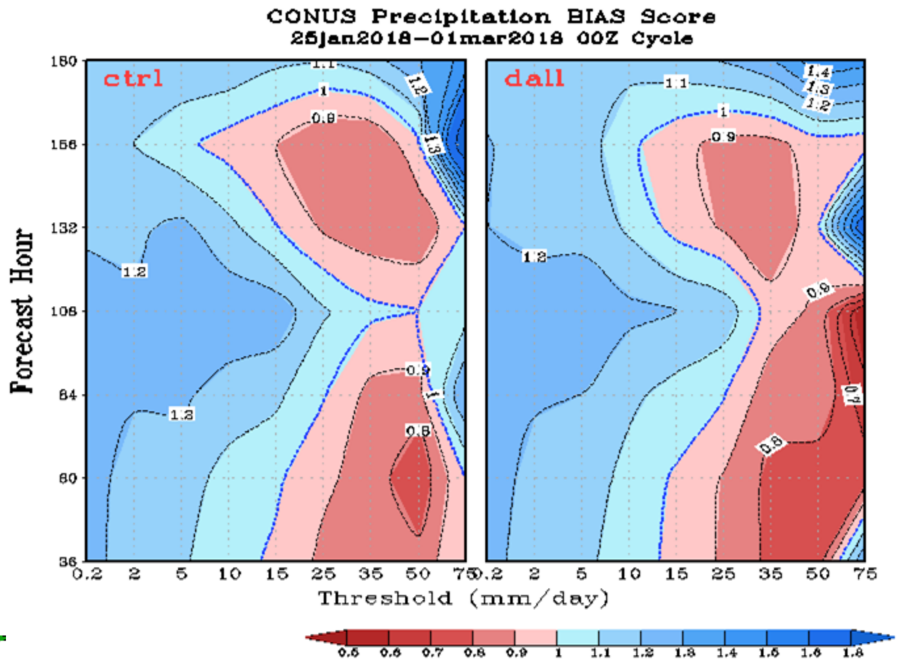
https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/vsdb/ar2018/

Equitable Threat Score



CTRL (left) and DALL-CTRL (right)

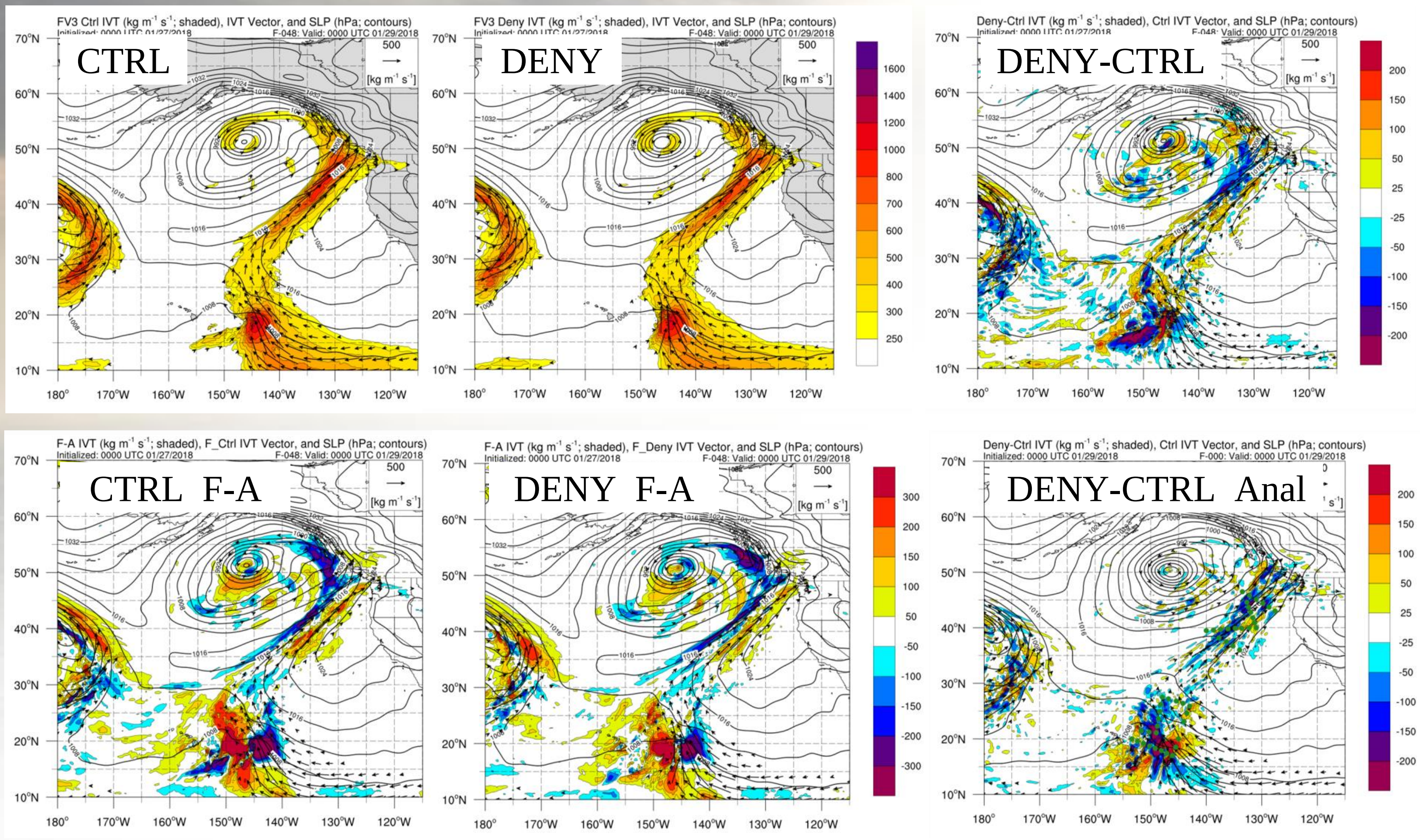
BIAS Score



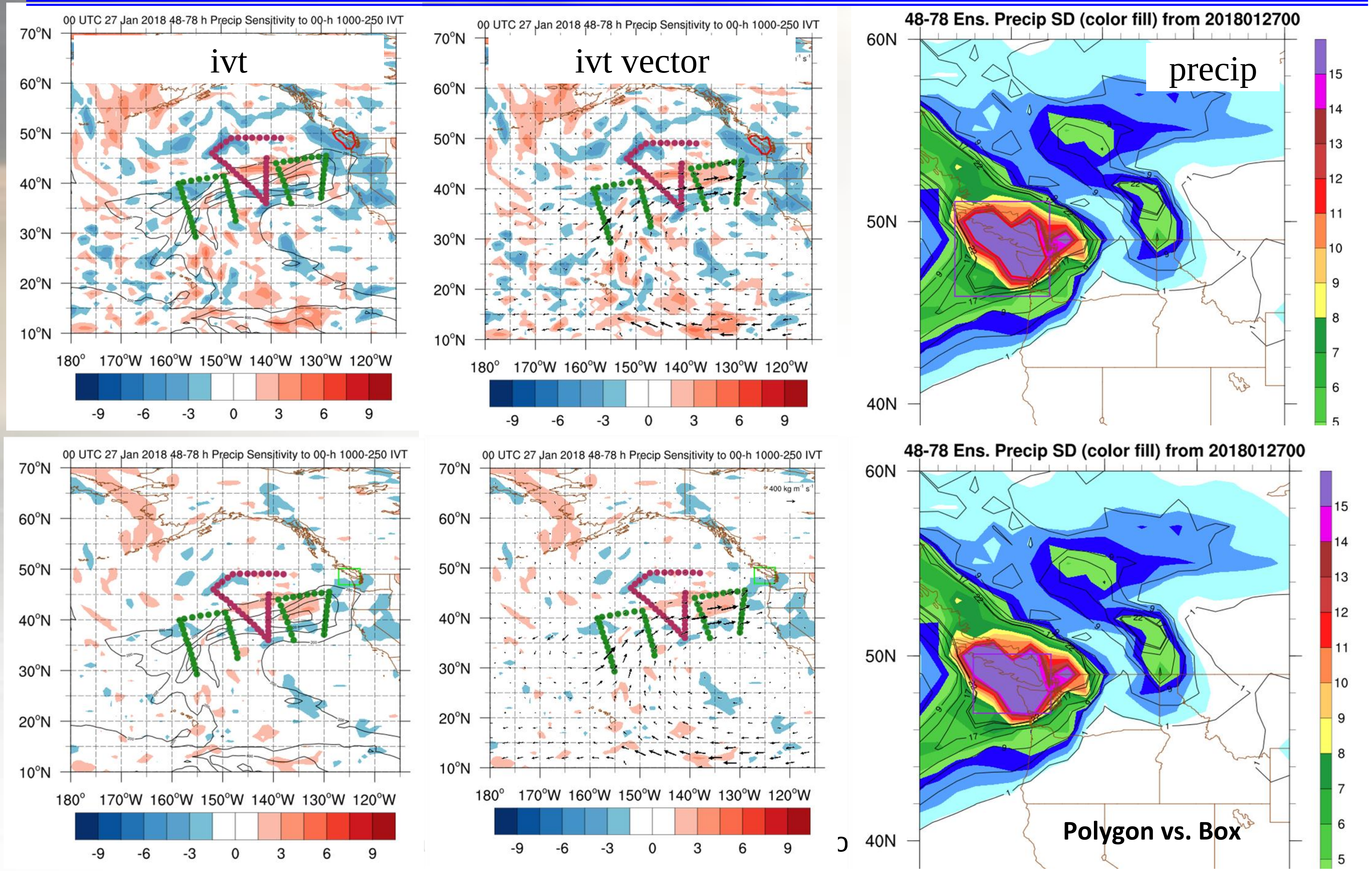
CTRL (left) and DALL (right)

General improvement in Precipitation Forecasts over CONUS for higher thresholds (increased ETS and decreased bias)

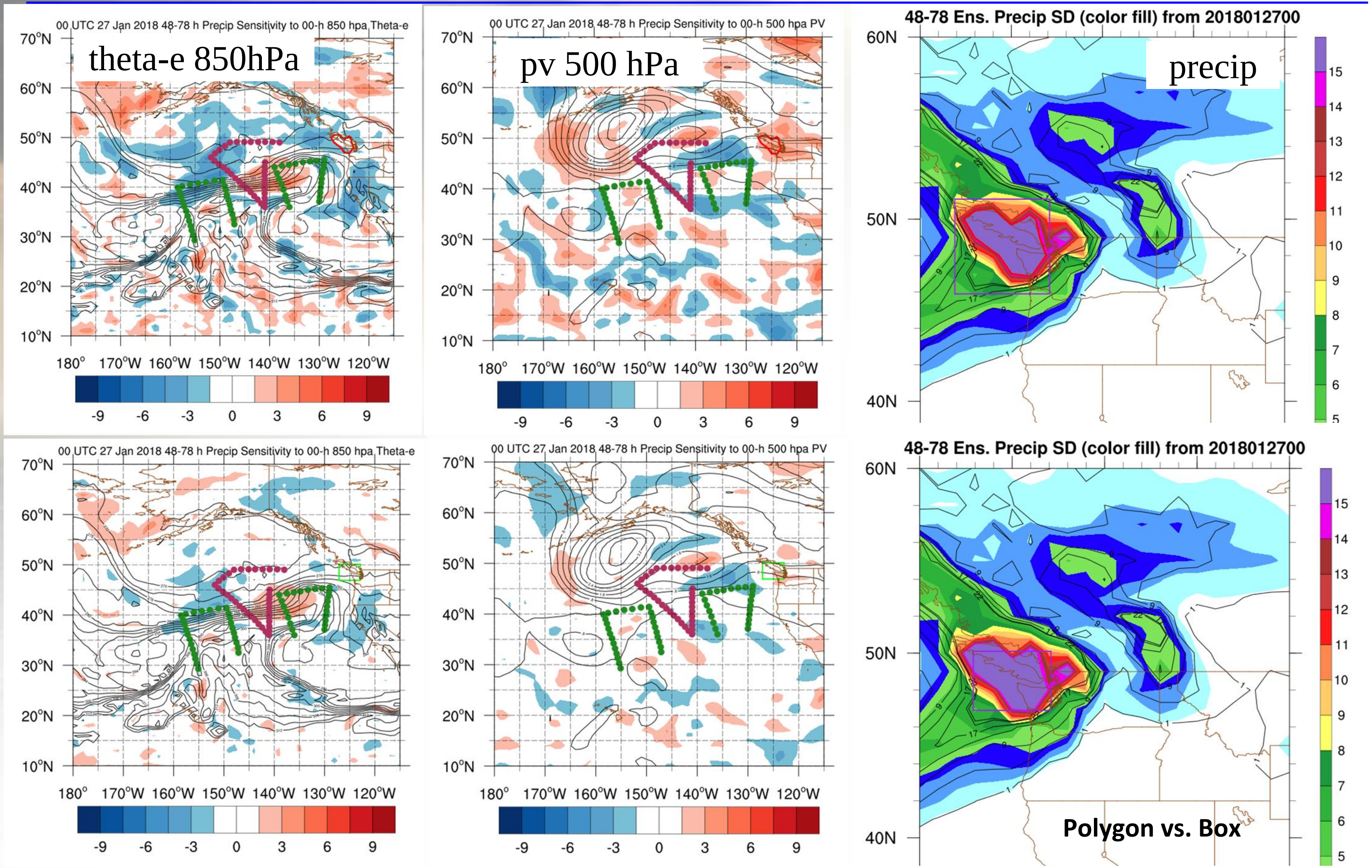
IOP1 – Jan 27, 2018: *IVT (cont. F-48)*

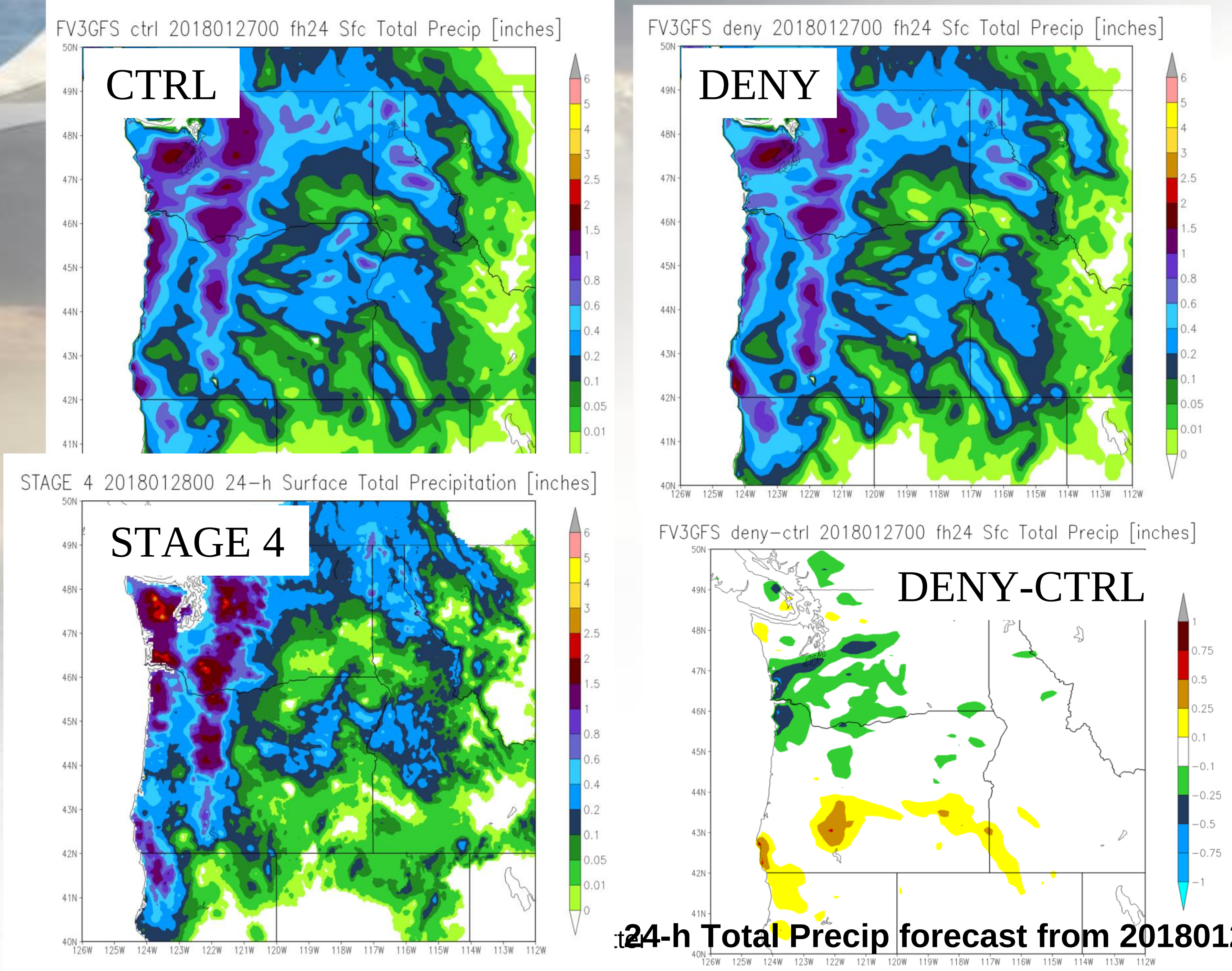


IOP1 – Jan 27, 2018: Sensitivity to 48-78 Precip

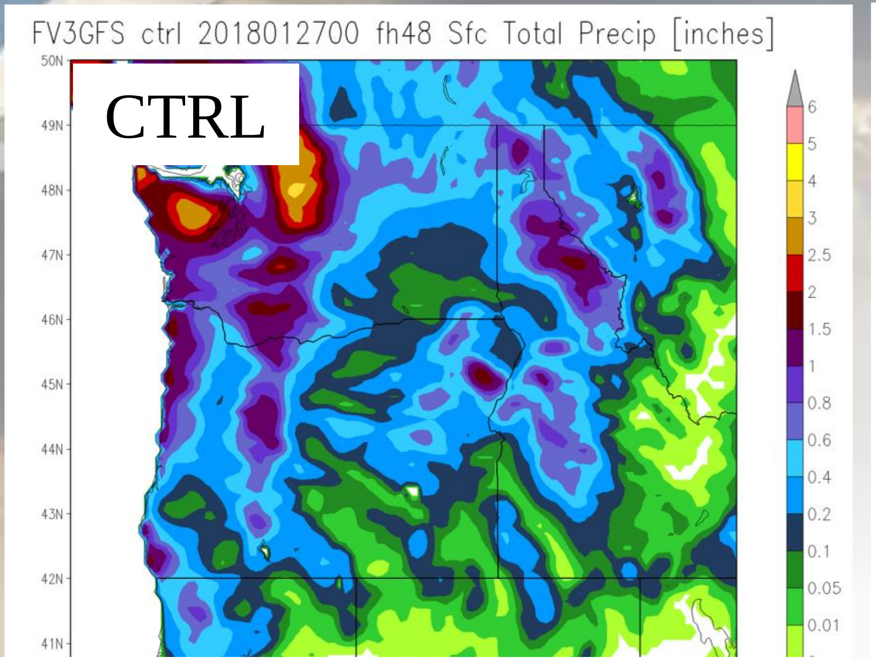


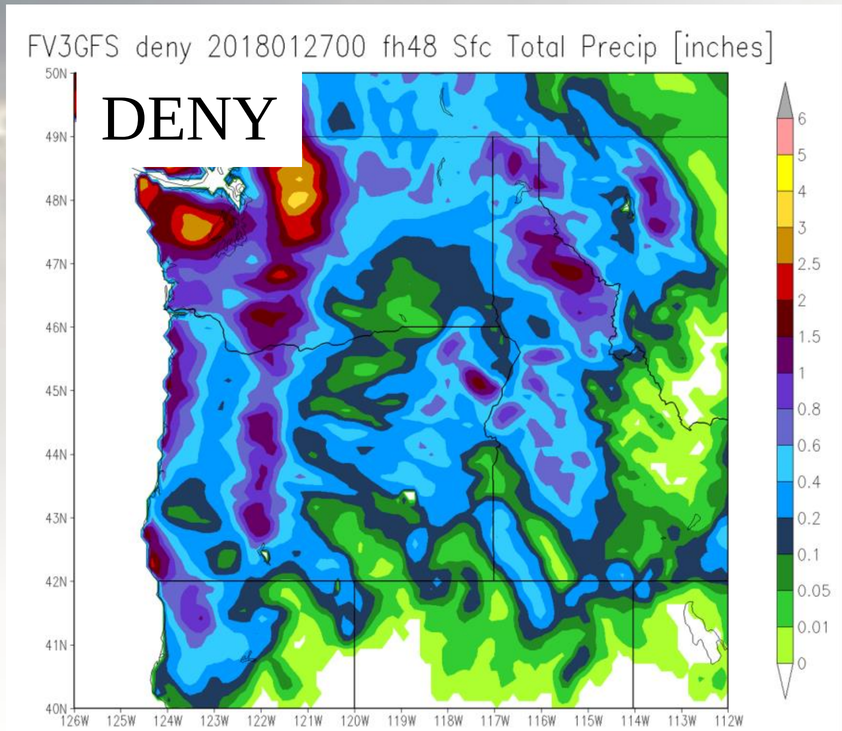
IOP1 – Jan 27, 2018: Sensitivity to 48-78 Precip

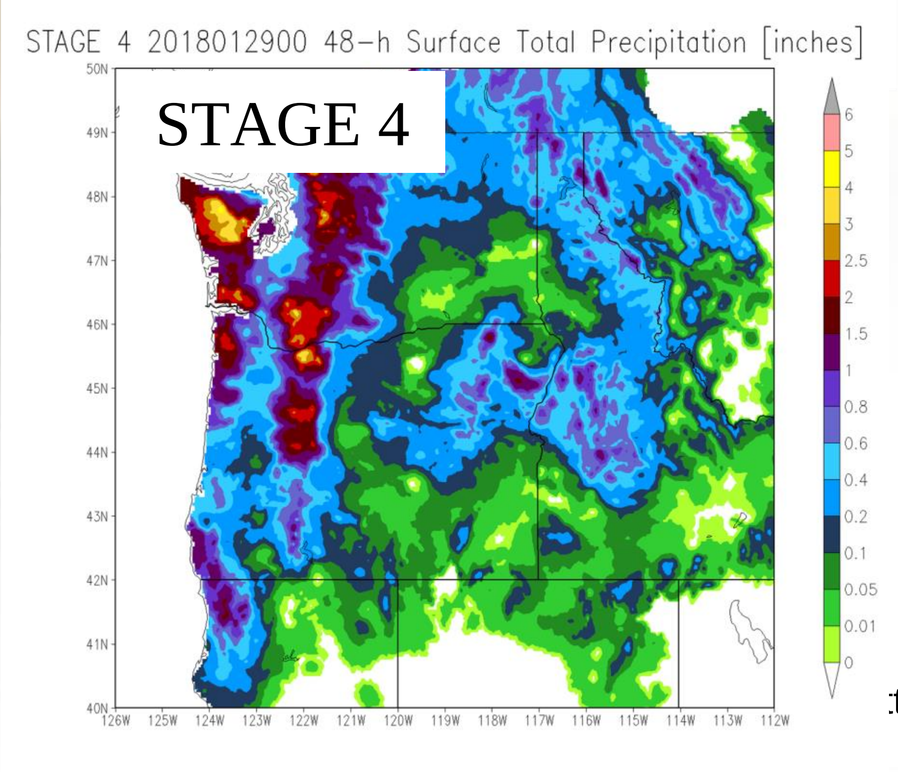


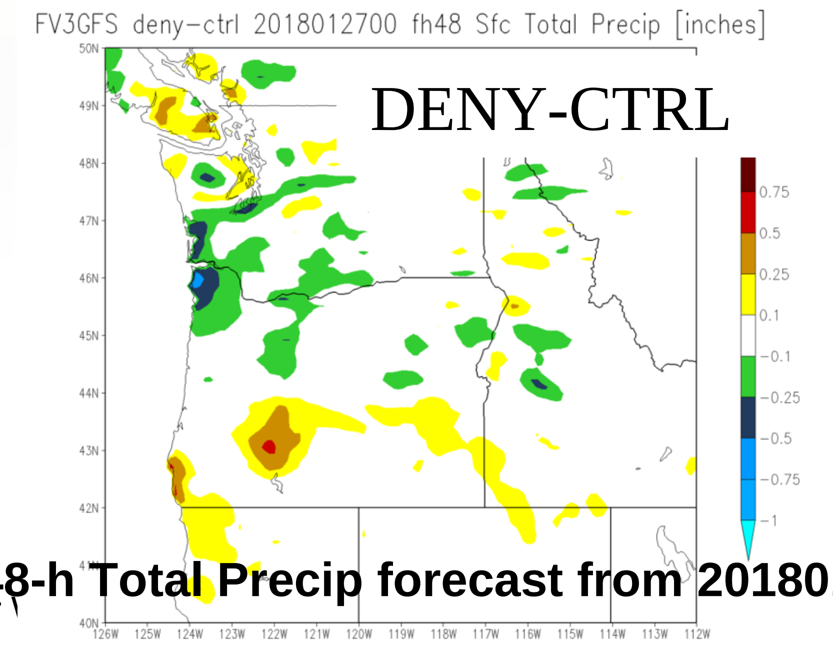


24-h Total Precip forecast from 2018012700

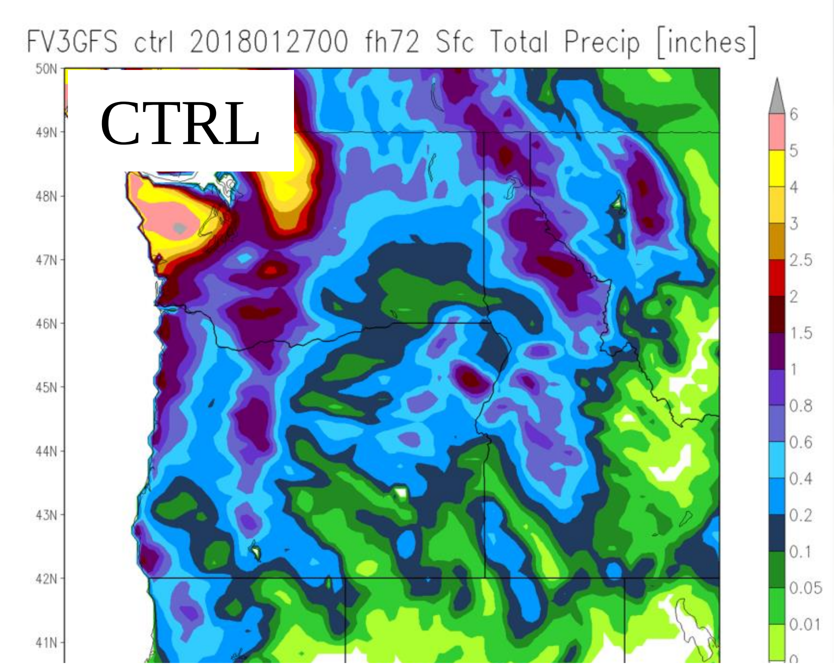


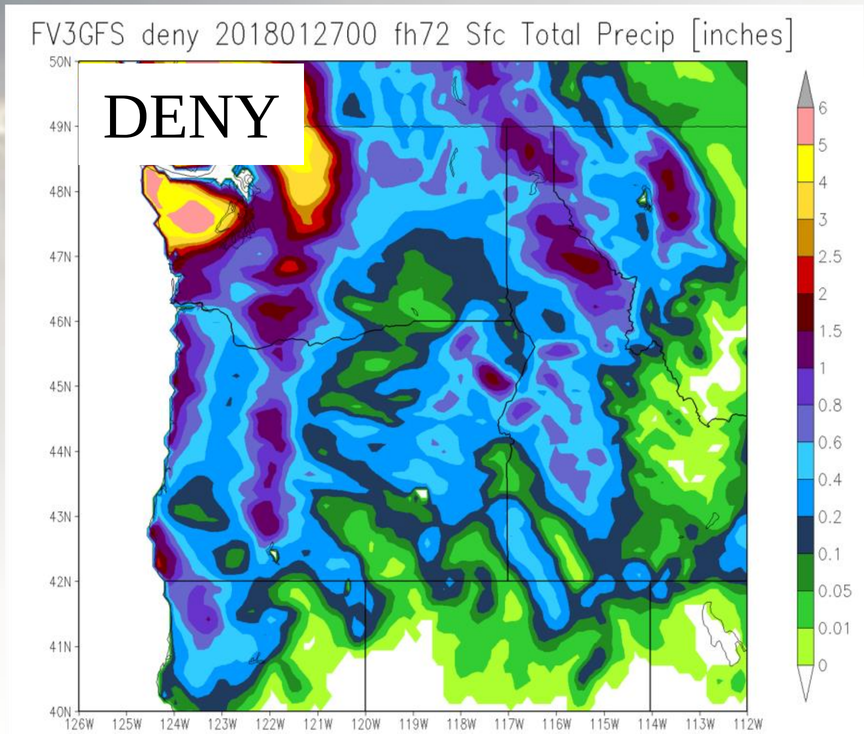


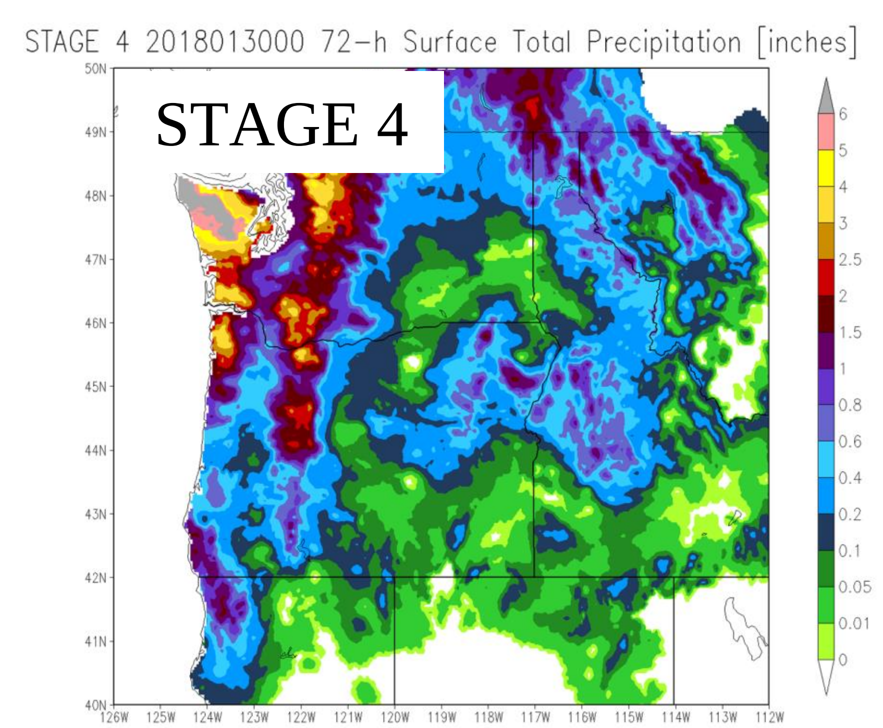


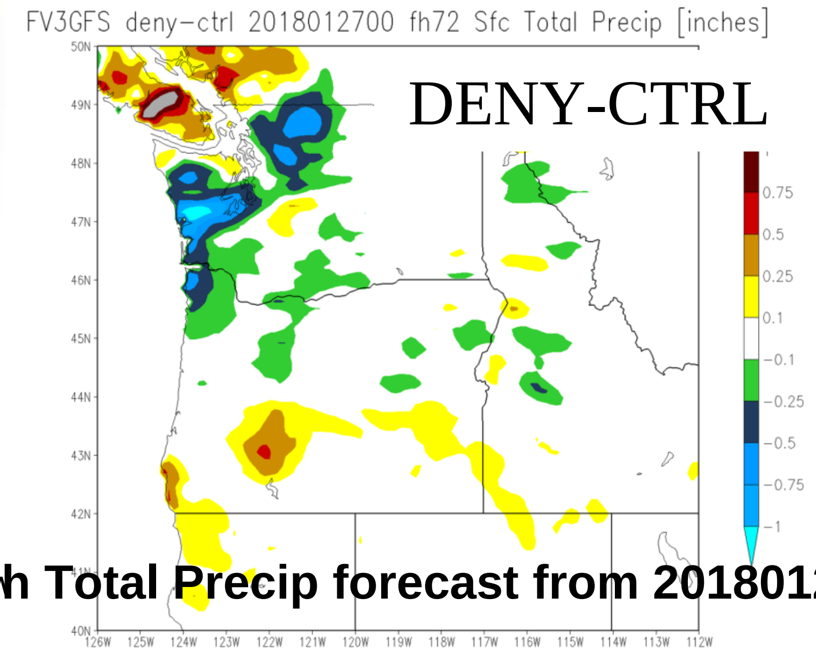


48-h Total Precip forecast from 2018012700



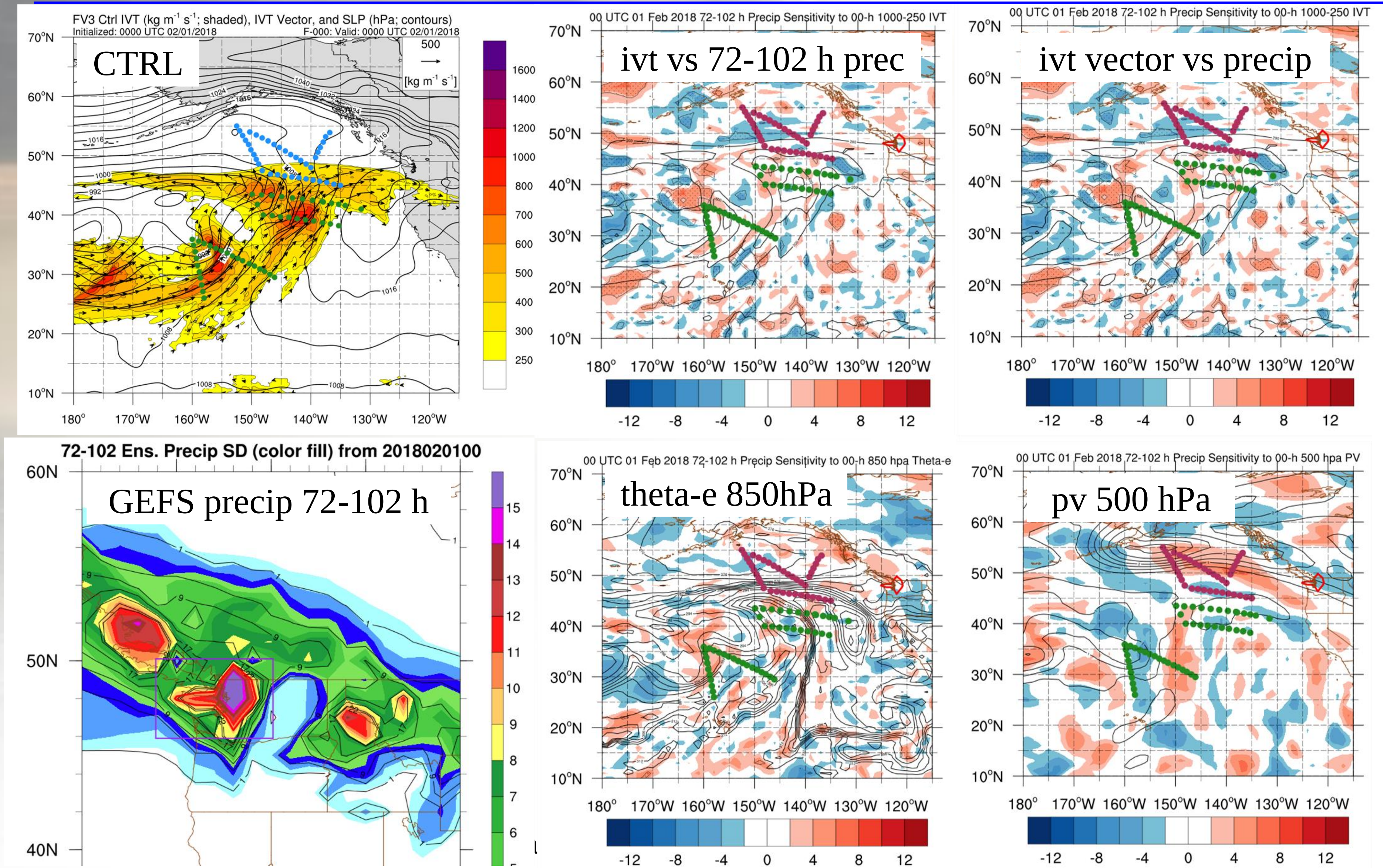




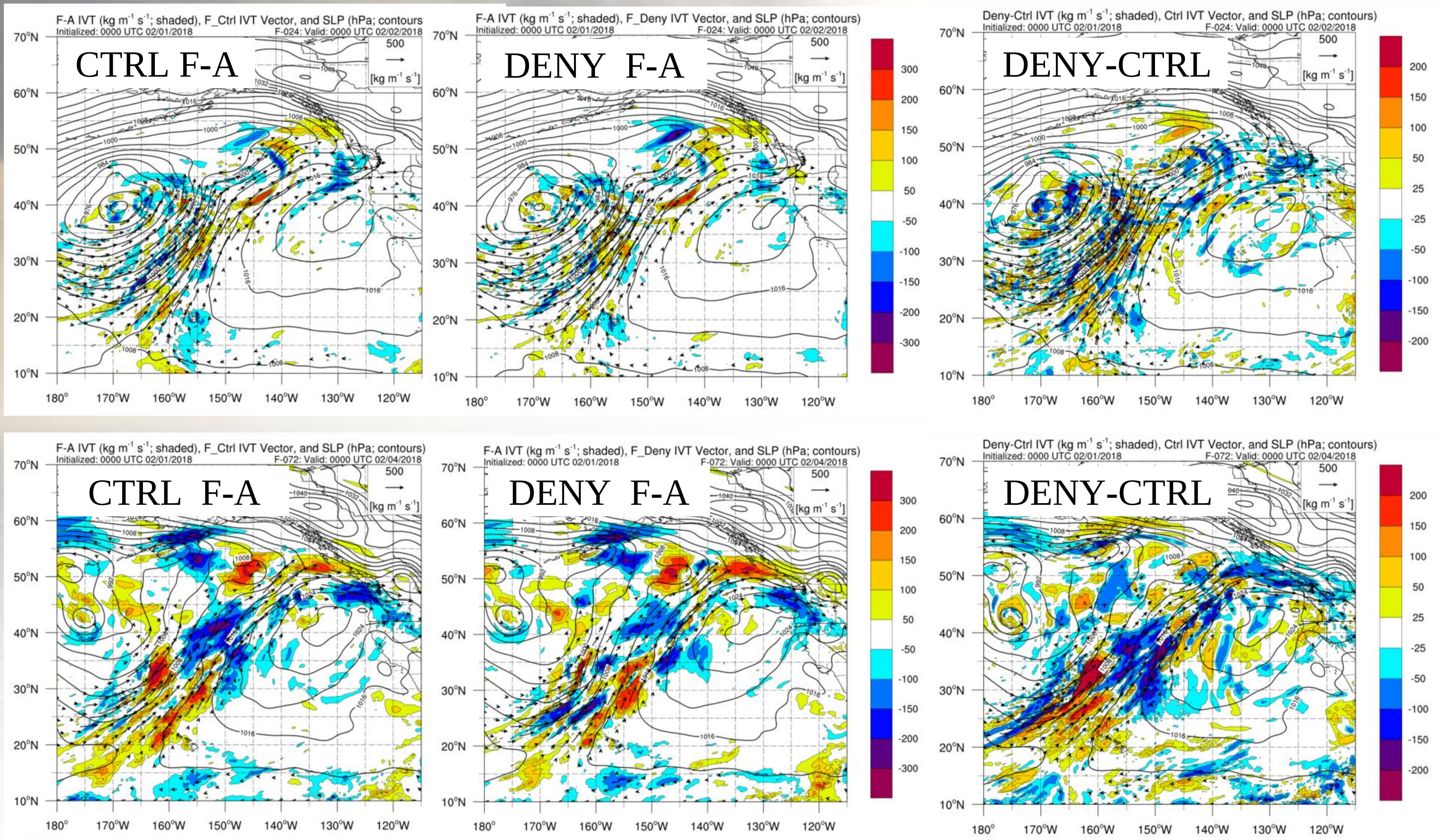


72-h Total Precip forecast from 2018012700

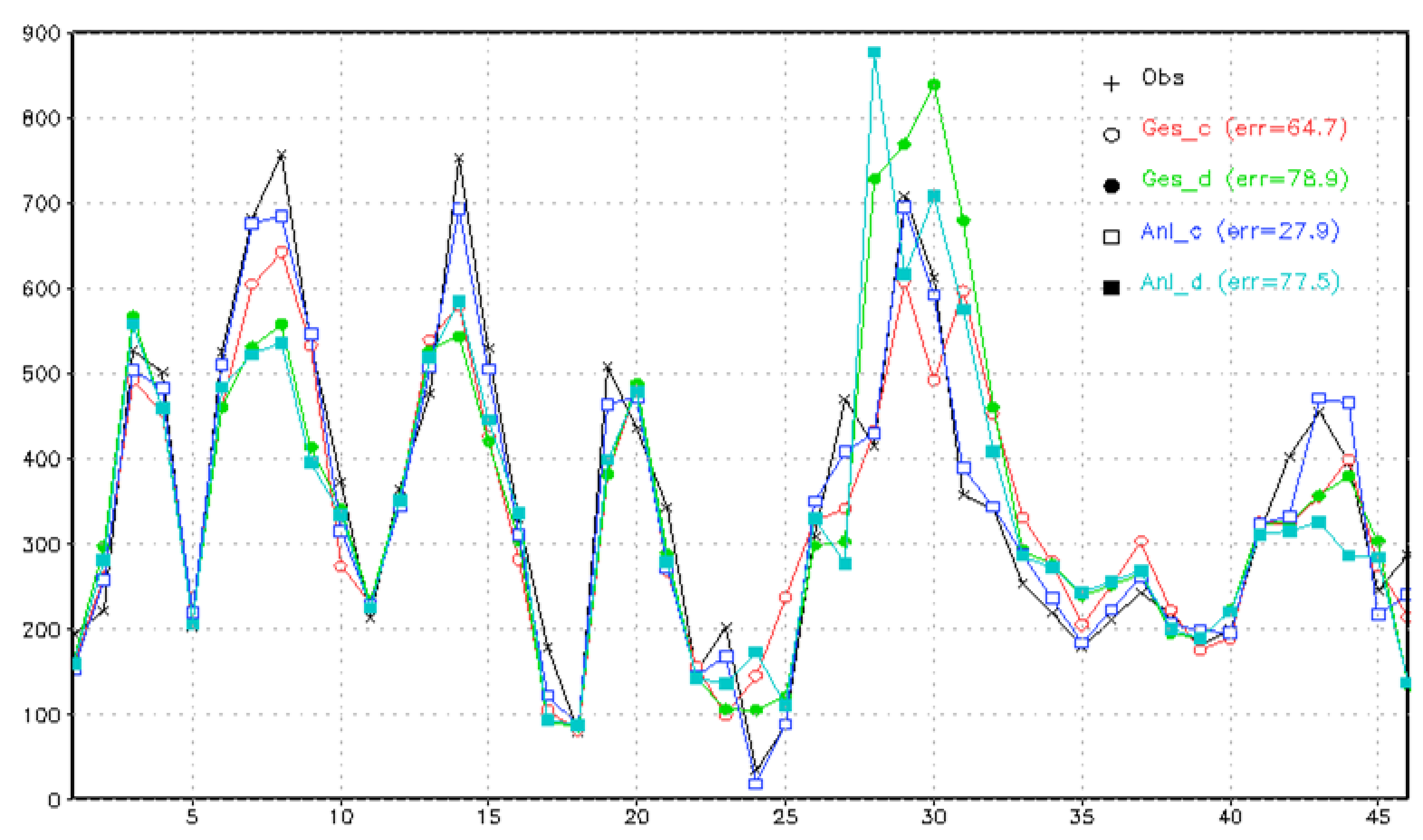
IOP3 – Feb 01, 2018: 88 dropsondes
(*49 C130 and 39 G-IV*)



IOP3 – Feb 01, 2018: *IVT (cont. F24 and F-72)*

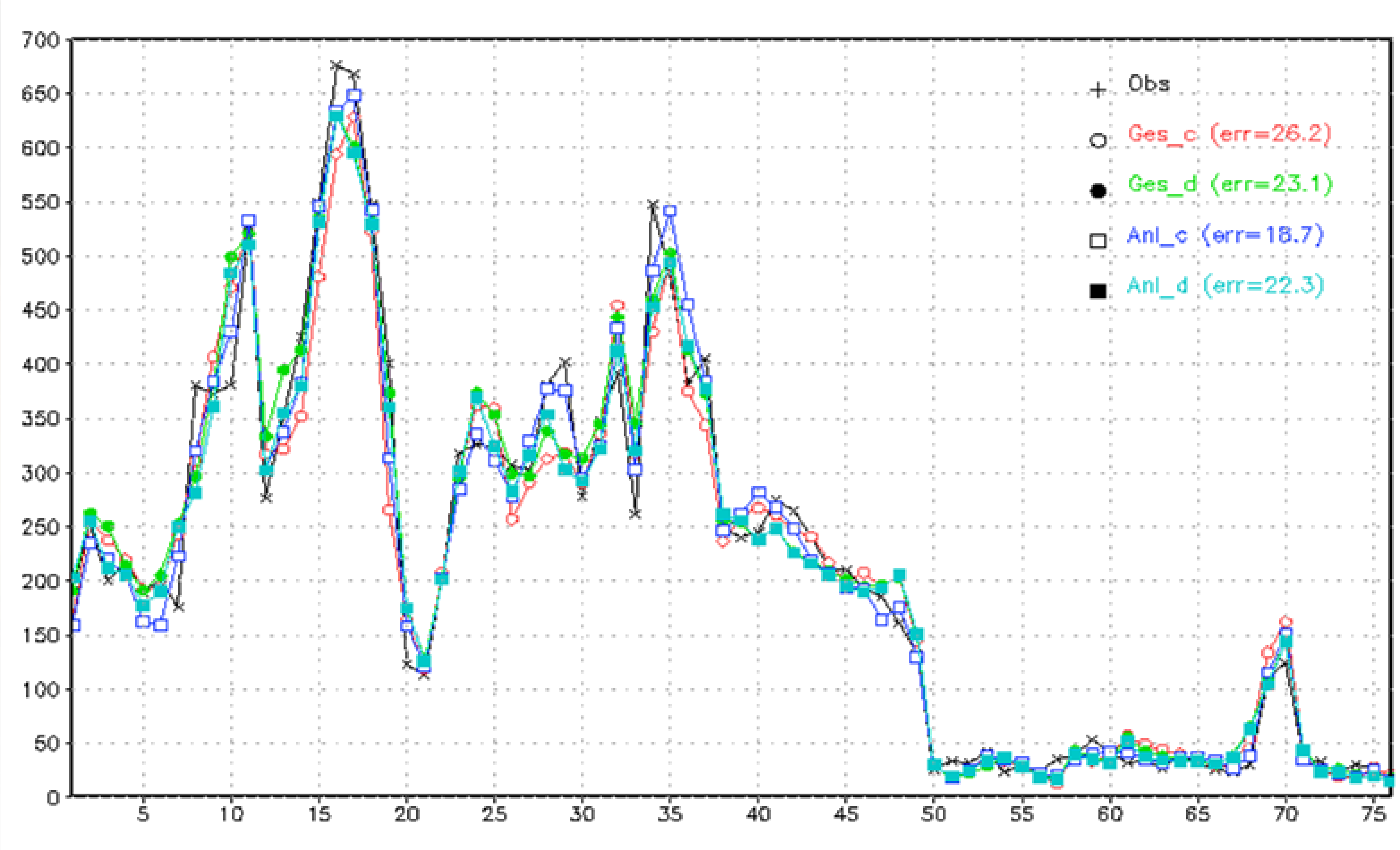


IVT 2018012900



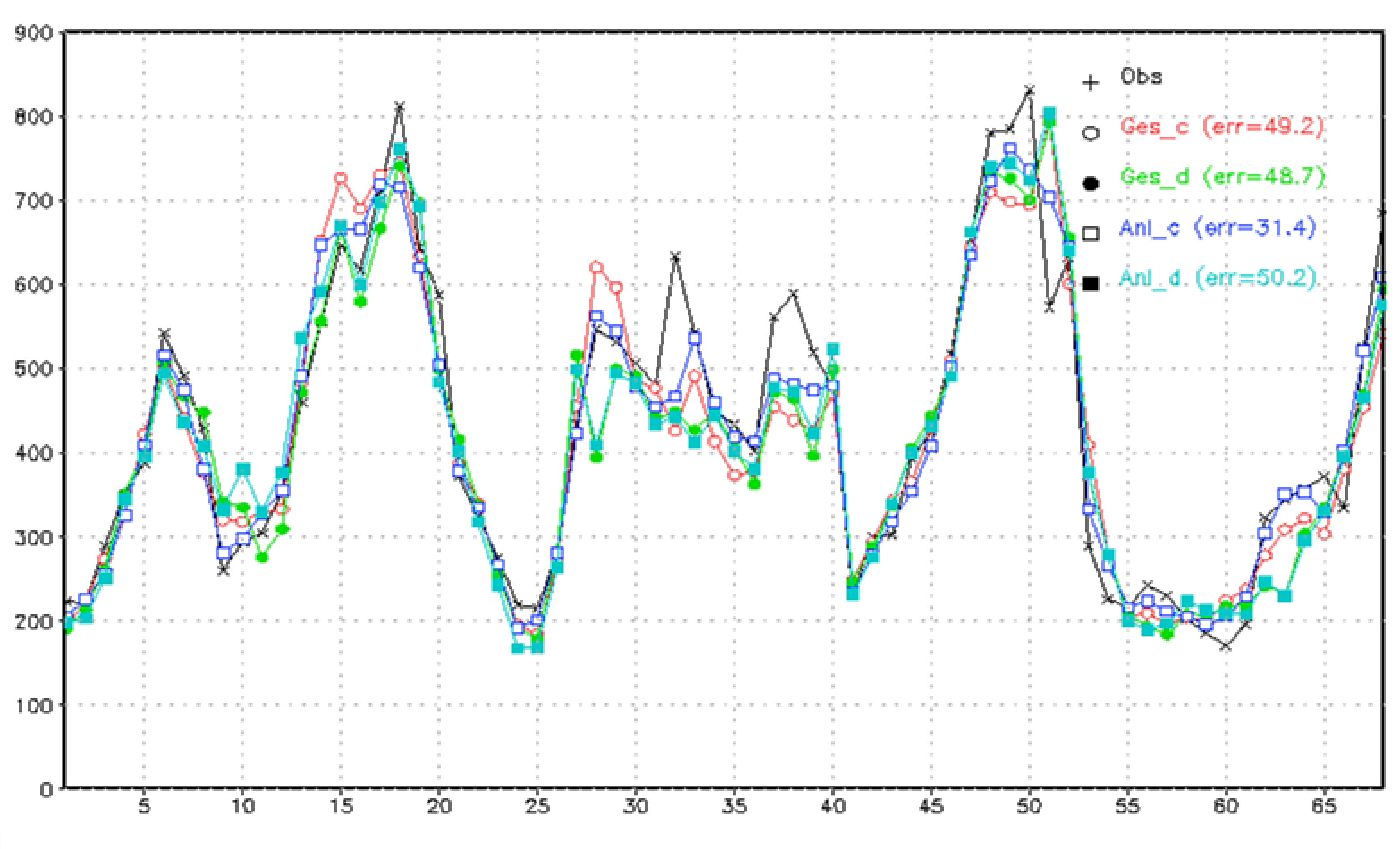
IVT (1000-650 hPa) at each dropsonde of 2018 IOP2 (Jan 29) from observation (Obs), background (Ges), and analysis (Anl) in FV3GFS control (c, using the dropsonde data) and denial (d, denying the dropsonde data) runs

IVT 2018020100



IVT (1000-650 hPa) at each dropsonde of 2018 IOP3 (Feb 1) from observation (Obs), background (Ges), and analysis (Anl) in FV3GFS control (c, using the dropsonde data) and denial (d, denying the dropsonde data) runs

IVT 2018020300



IVT (1000-650 hPa) at each dropsonde of 2018 IOP4 (Feb 3) from observation (Obs), background (Ges), and analysis (Anl) in FV3GFS control (c, using the dropsonde data) and denial (d, denying the dropsonde data) runs

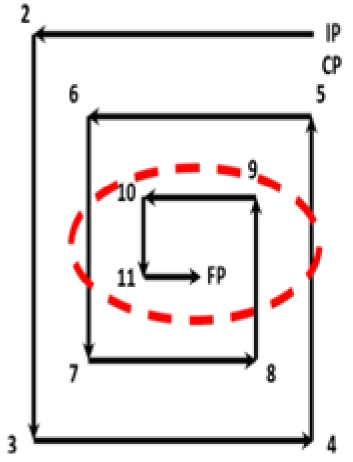
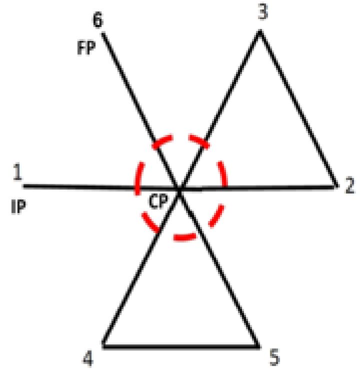
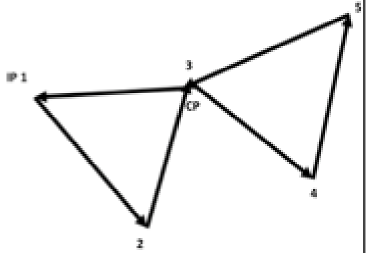
Summary of FV3GFS Data Impact Experiments

- Preliminary analysis indicates that no notable difference was detected in the 5-day forecasts, similar to previous GFS impact studies.
- There was small (but not significant) positive impact on the GFS forecast skill for the Pacific-North American region.
- For two AR 2018 IOP cases, the predicted precip seems to have bias increased when dropsonde data were denied.
- Based on preliminary analysis from data impact experiments, supplemental observations from AR influences local precip, which has implications on downstream applications.
- Impact of additional observations on model forecasts appear to be fading away within the first few forecast hours → model background not consistent with the analysis (need for improving both model and DA)

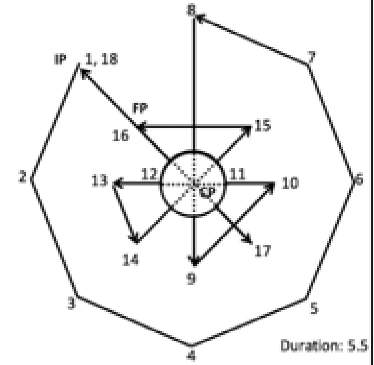
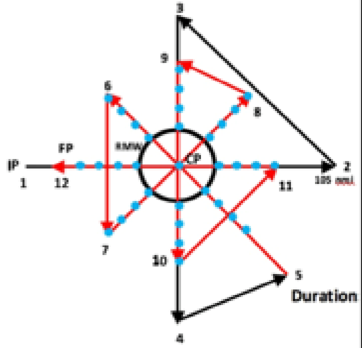
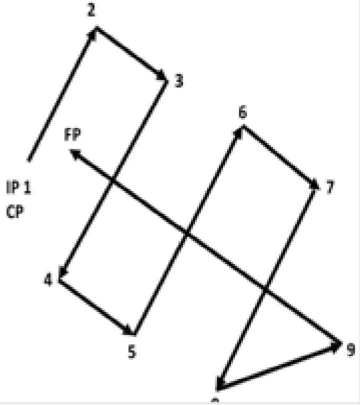
Future Plans

- Complete data impact experiments, run new impact experiments as necessary
- Continue to analyze FV3GFS control and data impact experiments to study the influence of dropsondes data on analysis and forecasts
- Identify sources of model errors that can be rectified or represented in FV3GFS
- Improve tools/method to provide ensemble forecast uncertainty for guiding flight planning

Sample Flight Pattern Templates-1

PATTERN NAME	PATTERN DIAGRAM	TARGETED FEATURE(S)
Square/Rectangular Spiral		• Jet Streak (JS) • Atmospheric River (AR) • Circular/ Elliptical uncertainty maximum Note: This can be flown inward (counter-clockwise) or outward (clockwise).
Butterfly		• Cold Low (CL) • Mid-Level Ridge (MLR) • Winter Storm Center or Occlusion (WSC_O)
Bow Tie		• Wind Shear Region (WSR) • Jet Streak (JS) • Atmospheric River (AR)

Sample Flight Pattern Templates-2

Circumnavigation with Imbedded Rotated Alpha		• Complex Winter Storm with Occlusion (CWSO) Note: The rotated alpha's inner portion may be used in complex uncertainty environments.
Large Alpha with Imbedded Rotated Alpha		• Complex uncertainty pattern • Complex Winter Storm Center (CWSC)
Race Track (Lawnmower)		• Jet Streak (JS) • Atmospheric River (AR)

- Thanks for your attention!

- Questions?