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Current MPAS Development and Forecast Skill Improvement for Weather Company Operations

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In collaboration with:

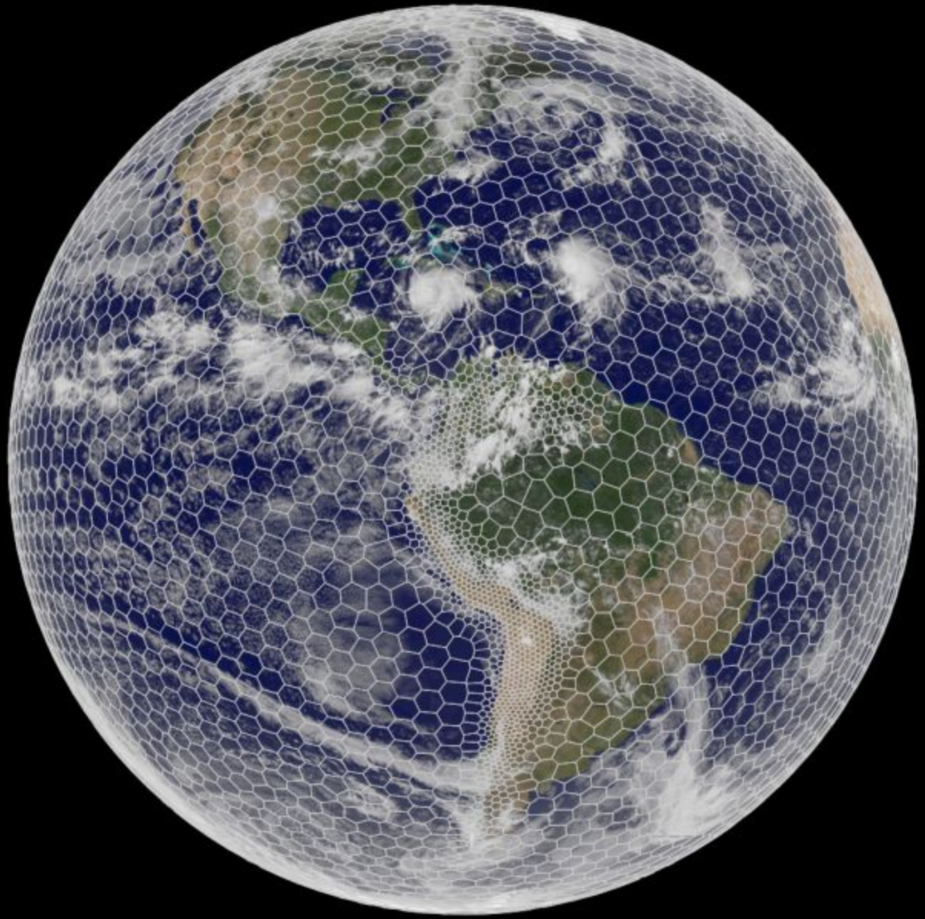
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

WRF / MPAS
June 2018

Topics

1. The MPAS Implementation at The Weather Company
2. Interfacing the GSI with MPAS and Cell Phone Pressure Impacts
3. MPAS Post-processing Considerations

The MPAS Implementation at The Weather Company



MPAS @ TWC

(1) TWC / IBM products to be driven by the NCAR Model for Prediction Across Scales (MPAS):
  - (a) Running at 15-km MPAS operationally: 4x daily (cold start), out to 72 hours.
  - (b) Near-term goal: Replace 13-km Global WRF with 15-km Uniform Mesh.
  - (c) Primary goal: Hourly updating convective allowing forecasts (15 / 3 km Variable Mesh).

(2) Continually making improvements through data ingest, post-processing, and MPAS physics modifications, within our re-forecasting environment.

(3) Developing data assimilation capabilities using GSI (3.6) and its EnKF:
  - (a) Initially based on an NCAR version (GSI-3.3 + EnKF-0.0).
  - (b) Hourly-updating Hybrid-EnVAR DA system.
  - (c) Looking to potentially leverage the “JEDI” system.

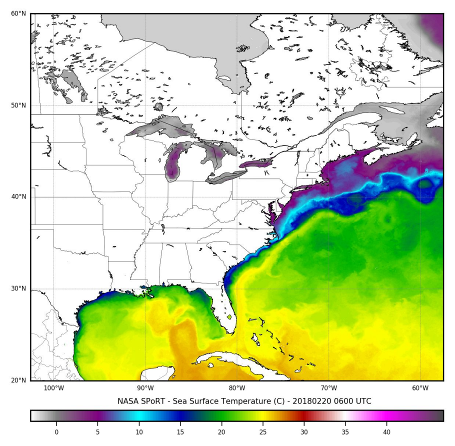
(4) Post-processing considerations for the unstructured mesh of MPAS.

(5) NCAR Collaboration: MPAS GPU Code Optimization.

MPAS Development (April 2017 - September 2017)

- April
  - → Precipitation buckets & 2-m dewpoint used for csv files and verification
- May
  - → Physics consistent dynamic snow ratio option (Cobb, Kuchera, NOAH, NOAH-MP)
- June
  - → 2-km NASA SPoRT high resolution sea surface temperatures ("GHR" @ 2.5-km)
  - → Surface layer and NOAH modifications
- July
  - → NOAA NESDIS VIIRS (Green Vegetation Fraction @ 4.0-km)
- August
  - → VIIRS calibration and YSU PBL background mixing
  - → CSV land/water interpolation (masking options)
- September
  - → Precipitation analysis and task definitions
  - → Grell vs Kain-Fritsch convective issues

NASA SPoRT SST @ 2-km

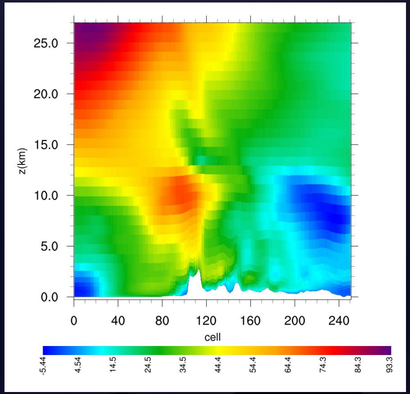


MPAS Development (October 2017 - April 2018)

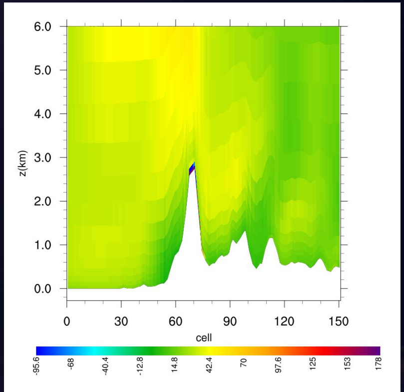
- October
  - → V1 Lab environment (50 cases from 2014 → 25 high impact, 25 periodic)
  - → GMTED 2010 topography data
- December
  - → V2 Lab environment (50 cases from 2016-17 → 25 high impact, 25 periodic)
  - → Mixing ratio initialization fix
  - → NCEP GFS 0.25 degree cloud analysis
- January / February (2018)
  - → Improved surface fluxes over deep snow cover
  - → The nTiedtke scale-aware convection (NCAR)
- March / April (2018)
  - → Modified nTiedtke scale-aware convection
  - → Updates to sea-ice and improved initialization

30s Topography Data ‘Issues’ (10/2017)

U (m/s) @ 09/12/2017 06:00:00Z
Up to 27 km, over CONUS



U (m/s) @ 09/12/2017 06:01:30Z
Up to 6 km, over CONUS



MPAS Development (Re-forecasting 2014)

2m Temperature (F)
~ 850 Metar Sites
01-72 Hour Forecast

Lab ID	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
LAB-1	5.31	6.83	6.63	6.54	5.20	4.60	4.68	4.65	4.47	4.25	4.40
LAB-2	4.81	5.92	5.63	5.72	4.87	4.50	4.41	4.23	4.19	4.08	4.26
LAB-3	4.75	5.80	5.47	5.61	4.83	4.46	4.38	4.22	4.13	4.04	4.25
LAB-4	4.60	5.38	5.12	5.17	4.71	4.45	4.37	4.22	4.13	4.04	4.25
LAB-5	4.54	5.37	5.05	5.13	4.60	4.32	4.28	4.17	4.04	3.95	4.24

- RMSE	0	+ RMSE

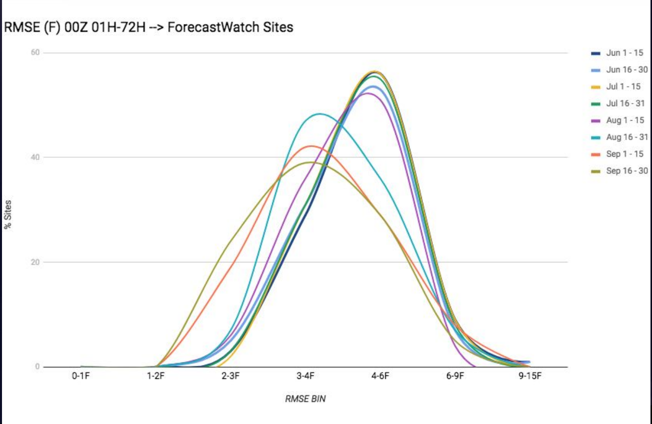
LAB-1 → NCAR MPAS 5.0

LAB-2 → MPAS 5.2 + Surface Layer Modifications, YSU PBL Modifications, NASA 2.5km SST, NASA 4km VIIRS, Land Mask

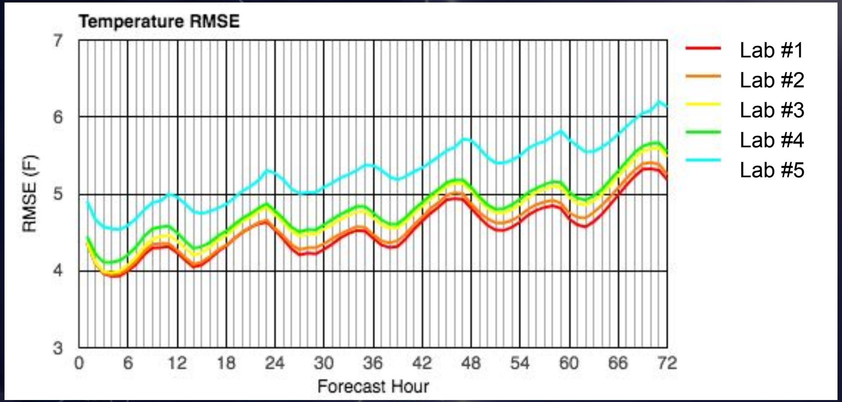
LAB-3 → Mixing Ratio Initialization Fix, GFS Cloud Analysis (QC)

LAB-4 → NOAH Snow/Soil Heat Flux Modification, Albedo

LAB-5 → nTiedtke Scale Aware, Cobb_Kuchera Snow Ratio



MPAS R2O



Each line represents one "lab" run.

A lab run consists of 50 cases (throughout 2014 and now 2017).

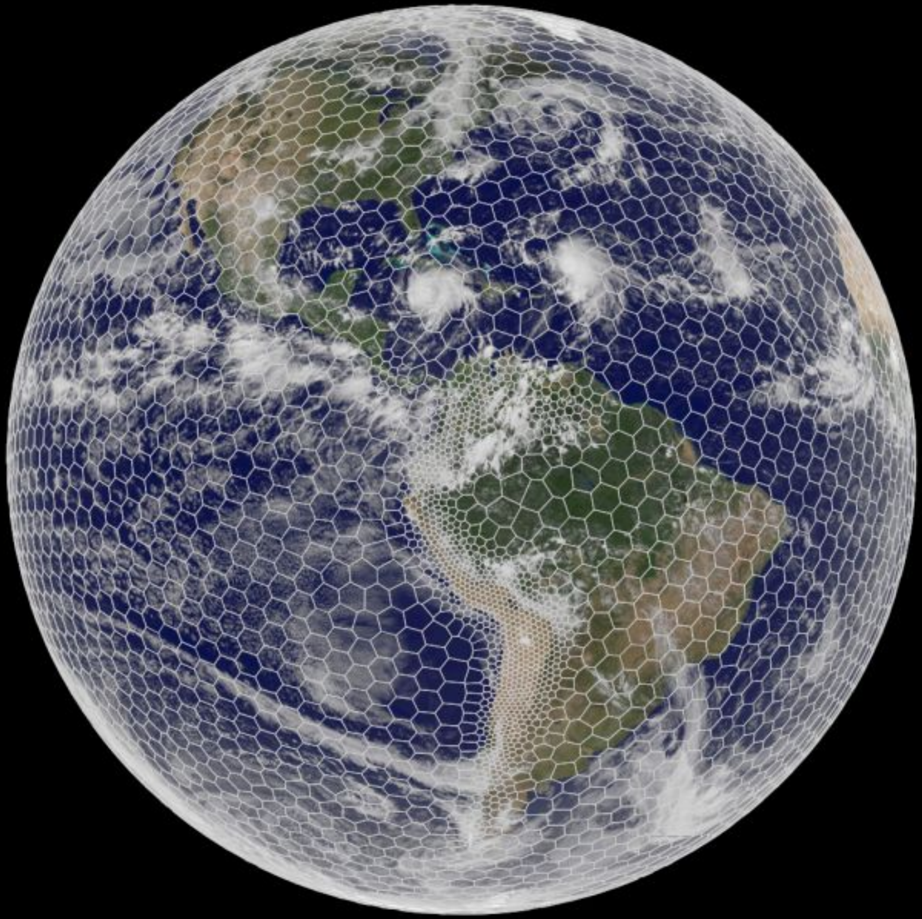
RMSE and Bias statistics are averages over ~850 U.S. METARs (“Forecast Watch”) and 50 cases.

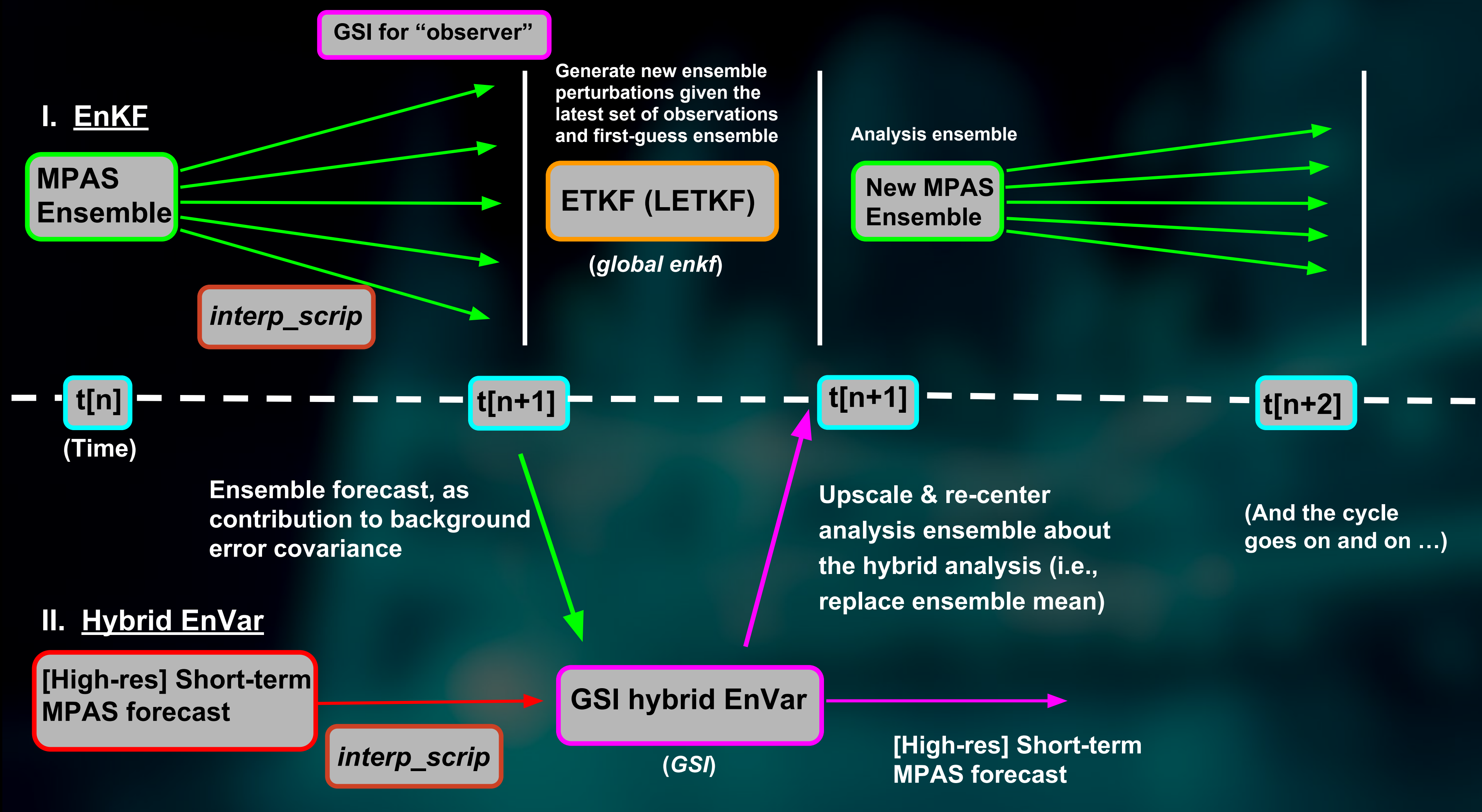
Output is evaluated statistically and subjectively. Once accepted as an improvement over the current baseline, that update is pushed to operations.

June 1 2017 - April 30 2018 Operations

2m Temperature (F)
~ 850 Metar Sites
01-72 Hour Forecast

Interfacing the GSI with MPAS and Cell Phone Pressure Impacts

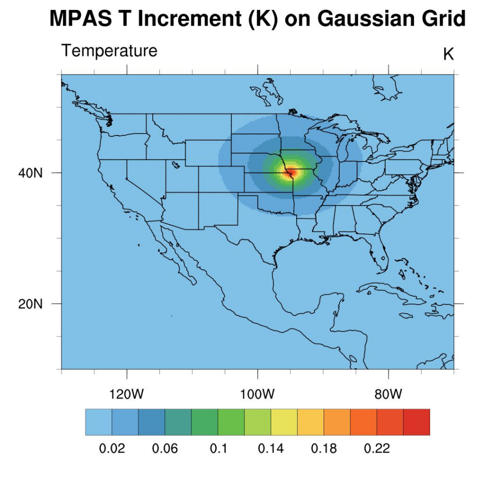


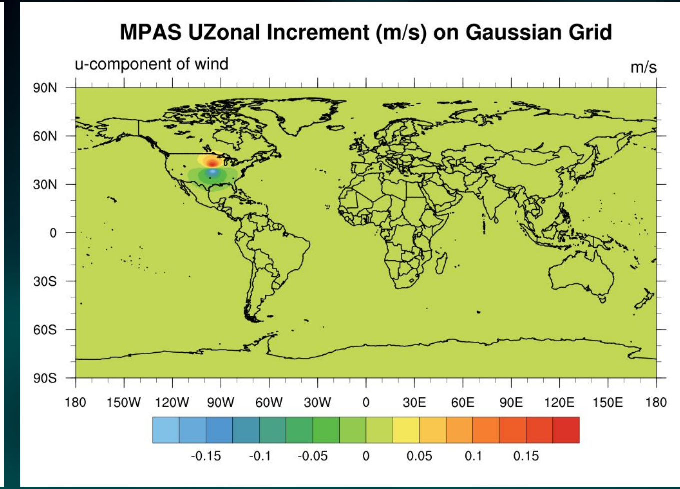


GSI for “observer”
I. EnKF
MPAS Ensemble
interp_scrip
Generate new ensemble perturbations given the latest set of observations and first-guess ensemble
ETKF (LETKF)
(global enkf)
Analysis ensemble
New MPAS Ensemble
t[n]
(Time)
t[n+1]
t[n+1]
t[n+2]
Ensemble forecast, as contribution to background error covariance
Upscale & re-center analysis ensemble about the hybrid analysis (i.e., replace ensemble mean)
(And the cycle goes on and on …)
II. Hybrid EnVar
[High-res] Short-term MPAS forecast
interp_scrip
GSI hybrid EnVar
(GSI)
[High-res] Short-term MPAS forecast

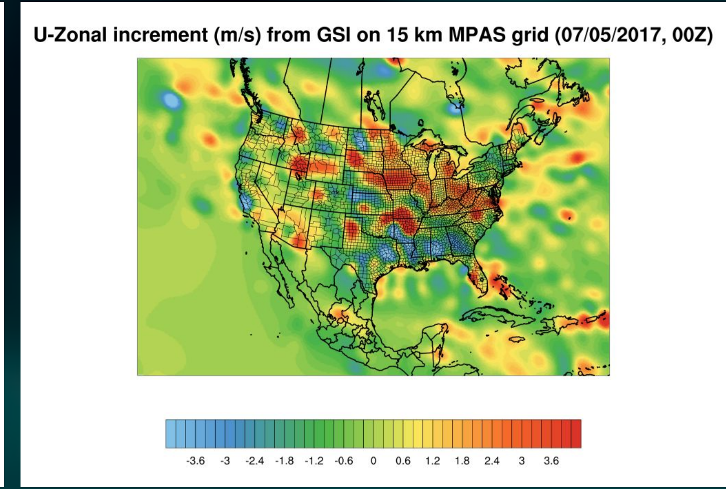
15-km MPAS Driven by GSI: interpolation to and from a 0.2045 degree Gaussian grid.

Pseudo-observation Test: 1-K temperature perturbation with a 0.8-K observation error, applied at (40N, 265E) and @ 500 mb.





1-K Pseudo-observation Test
k = 13



15-km U-Zonal increment @ vertical level 2
NCEP Conventional obs only.

The GSI cannot operate on the unstructured mesh of MPAS. We must first select a target Gaussian grid (0.2045 degree) and generate weight files using ESMF functions (NCL). We then interpolate and output the analysis variables (*interp_scrip*) to the target grid in NEMS-IO format and run the GSI globally. Only the analysis increments are interpolated (*interp_scrip*) back to the 15-km mesh. The following MPAS variables are modified by the DA system: *U, V, density, Qv, Ps, Theta, and U-normal*.

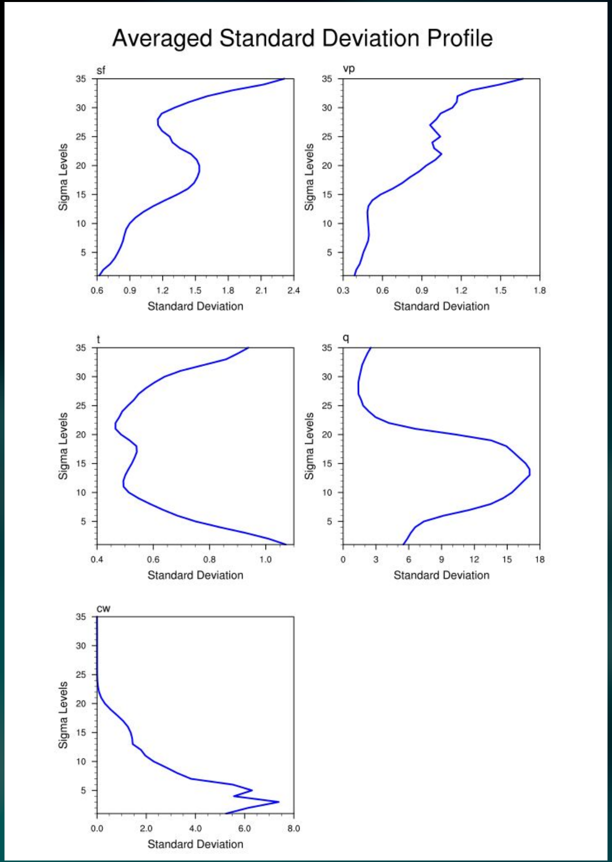
The 0.2045 deg Background Error Covariance Matrix

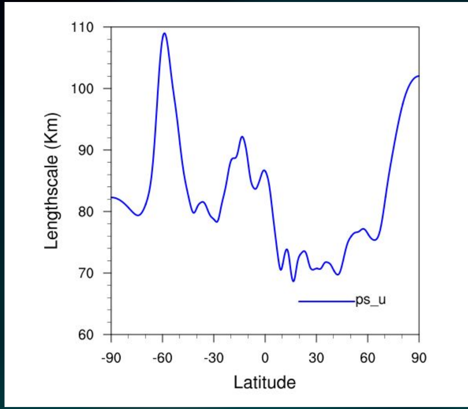
The BEC matrix is based on approximately one month of cold start MPAS forecasts, initialized at 00Z, 06Z, 12Z, and 18Z.

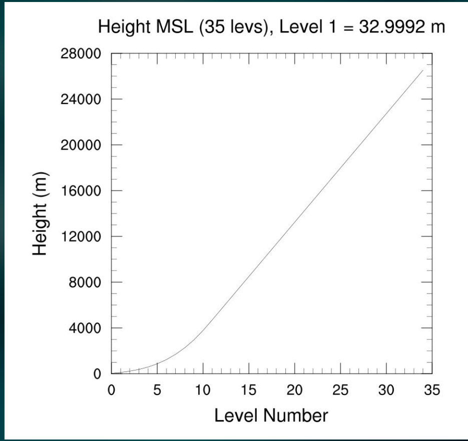
Using the National Meteorological Center (NMC) method: 48-hr and 24-hr forecasts (valid at the same time) to generate the perturbations, as input to the regression, etc.

Similar vertical structure to the operational 64-level GFS BEC matrix (not shown).

BEC matrix is being continually updated with retrospective MPAS forecast data.







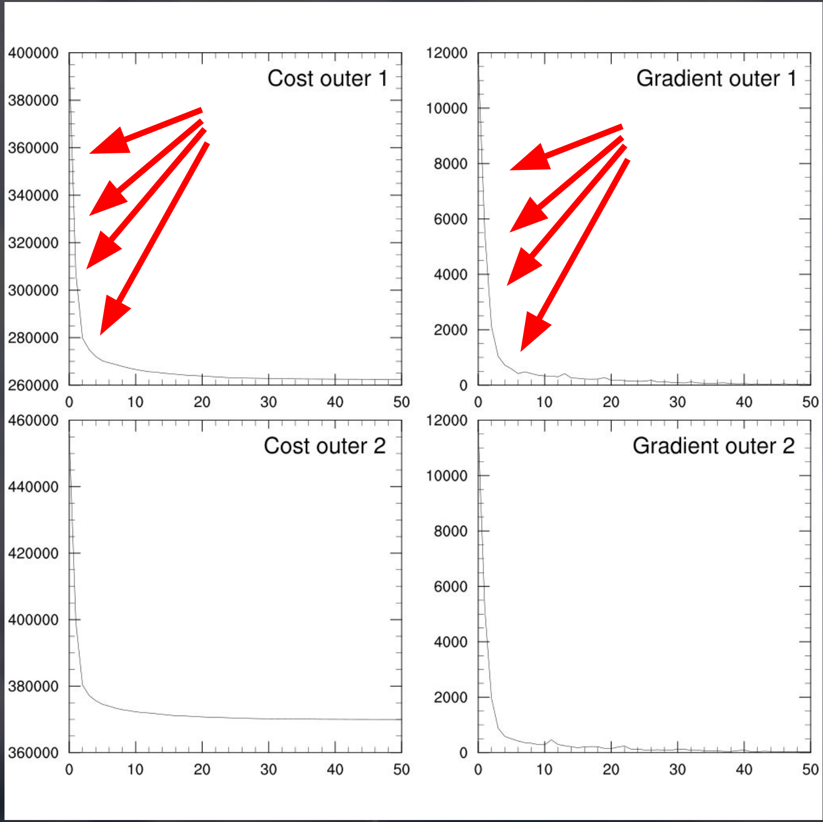
Real Observation Tests with the GSI

(1) Assimilate cell-phone pressure observations with GSI.
  (a) IBM is obtaining pressure obs through the TWC cell-phone mobile application.
  (b) Retrieving 300,000,000+ obs / day, assimilating only a subset.
  (c) We expect extensive quality control and analysis to soon be implemented, in conjunction with ongoing work at the University of Washington.
  (d) The following tests utilize minimal (gross) QC during pre-processing, plus additional QC through the GSI directly.

(2) Assimilation using 3DVAR only. Extending to hybrid-EnVAR.

(3) Using pressure observations at the top of each hour (but across the 6-hour assimilation window) resulted in GSI running more slowly. Perhaps this is not so surprising, given the 1 million+ number of obs processed.

Cost Function Minimization

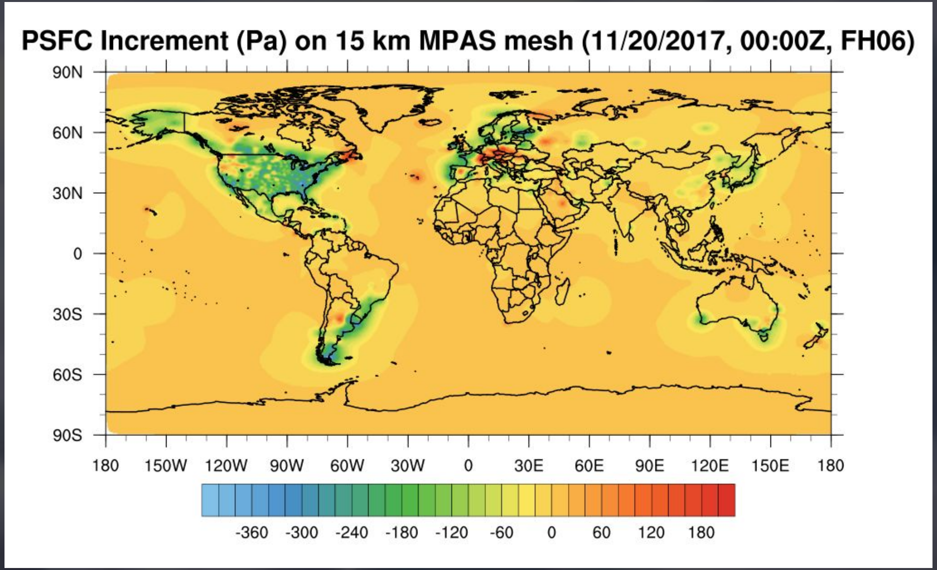


Summary Statistics (GSI Fit) for Ps, Before and After the Assimilation

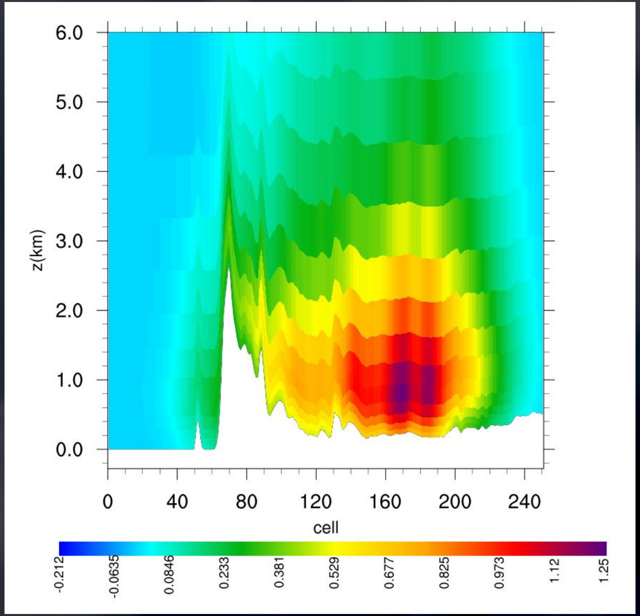
Innovation Loop	Bias (mb)	RMS (mb)	cpen (mb)
O-B (before)	-1.1209	1.9477	2.1601
O-A (1st outer)	-0.3839	1.6988	1.5697
O-A (2nd outer)	-0.1740	1.6954	1.5611

Analysis Increments on the Native 15-km MPAS Mesh

Surface Pressure (Pascals). Note the regions with the greatest concentrations of cell-phone pressure observations (highly populated areas).



Vertical cross section of Theta (K) over CONUS, up to 6 km. Note the impact on the theta increment: -0.212 to 1.25 K



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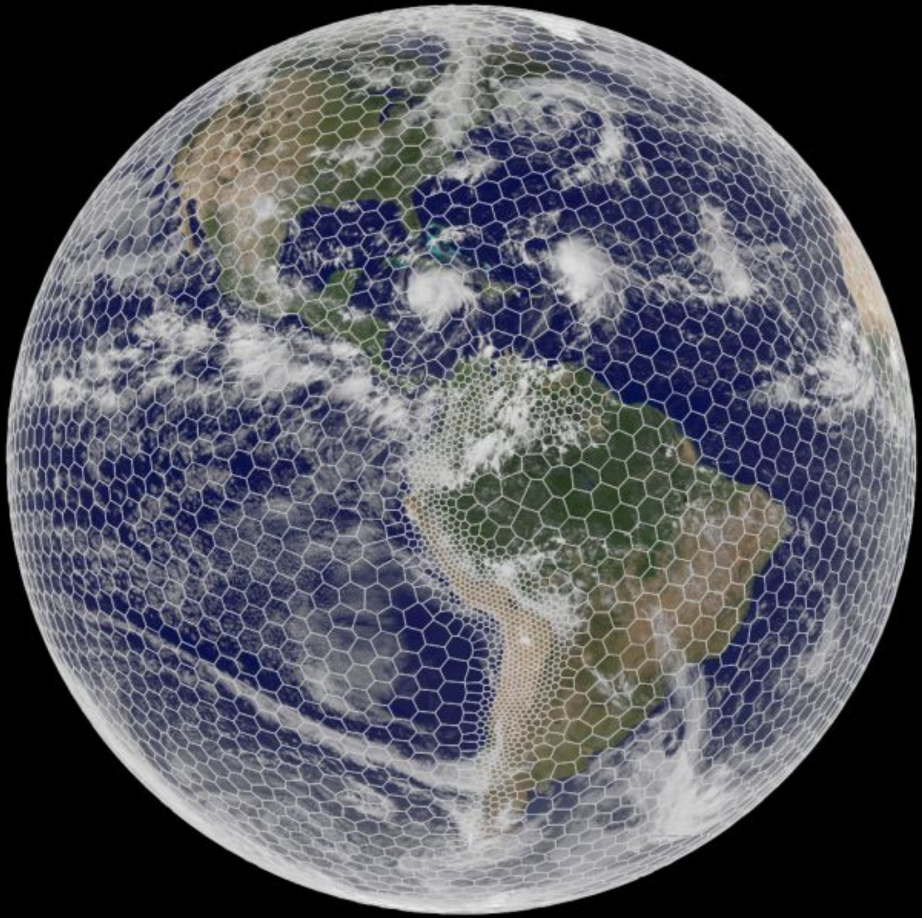
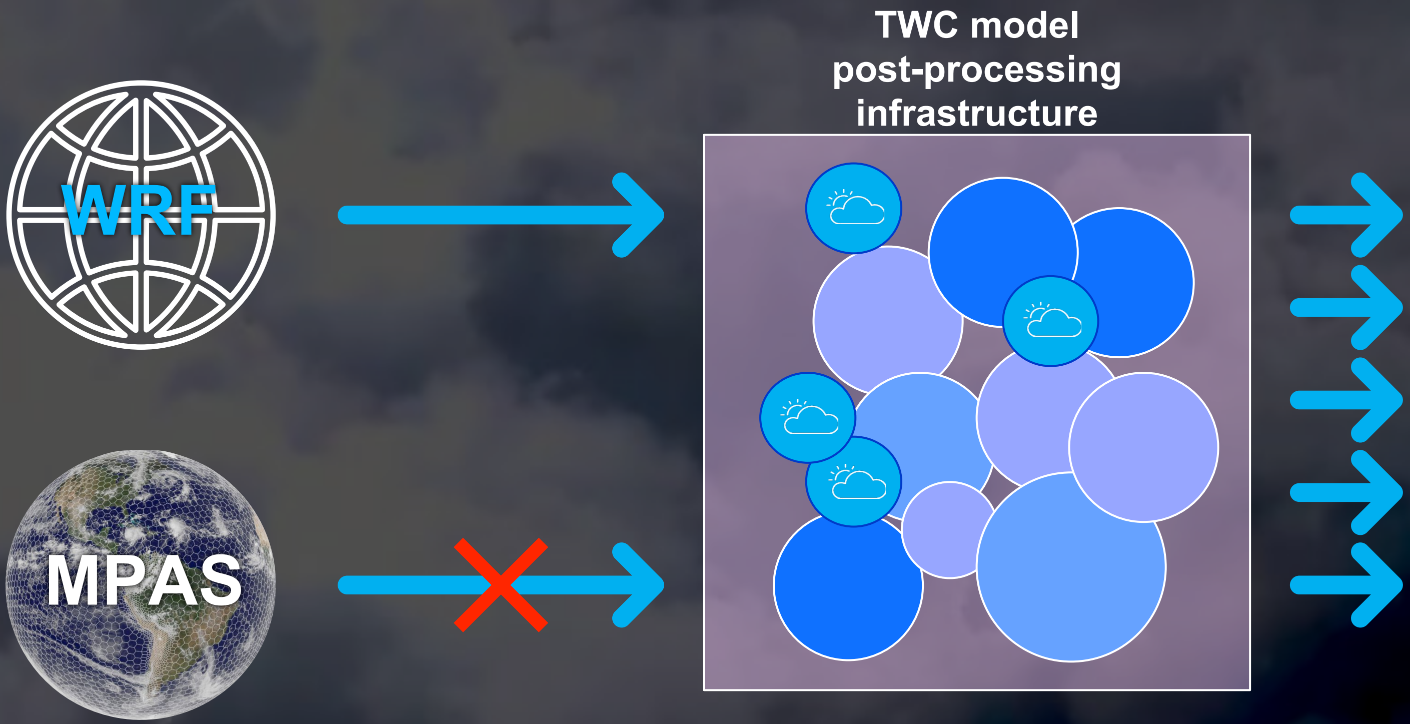
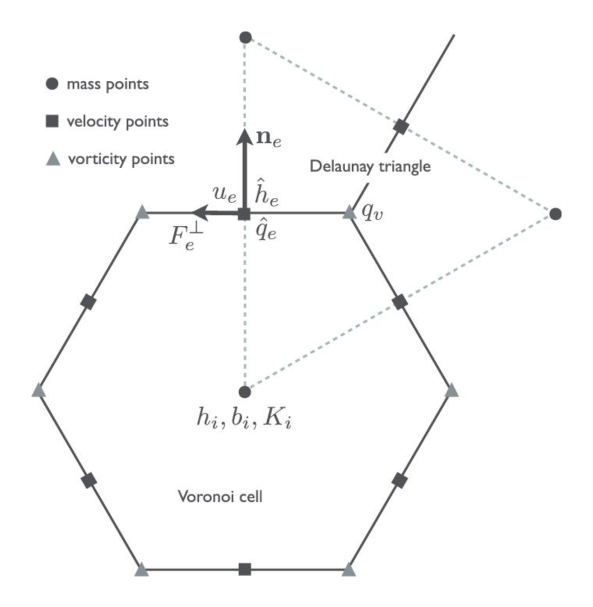
MPAS Post-processing Considerations



Not a Simple Drop-in Replacement ...



The MPAS Mesh

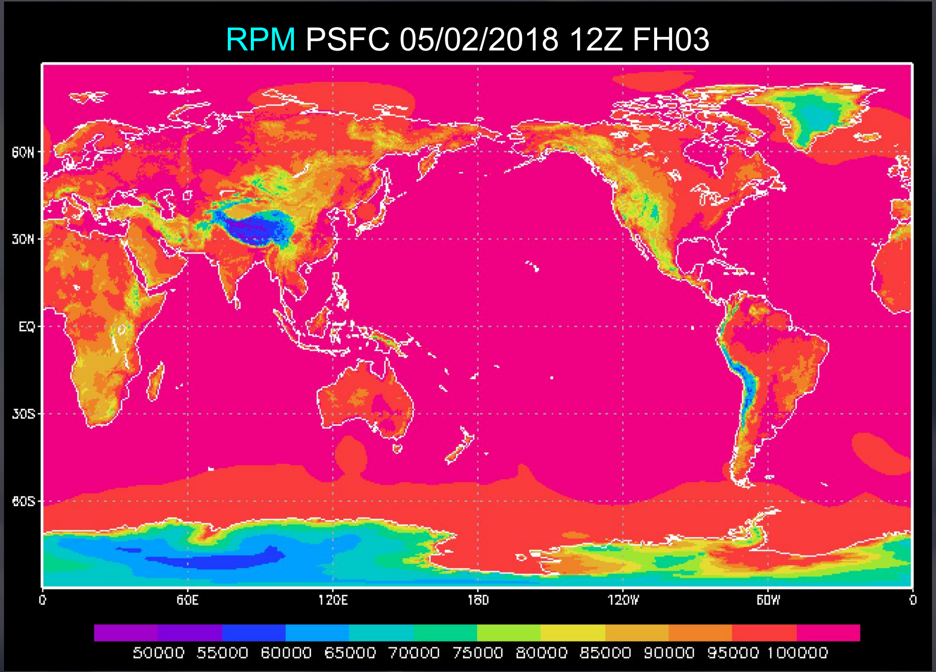


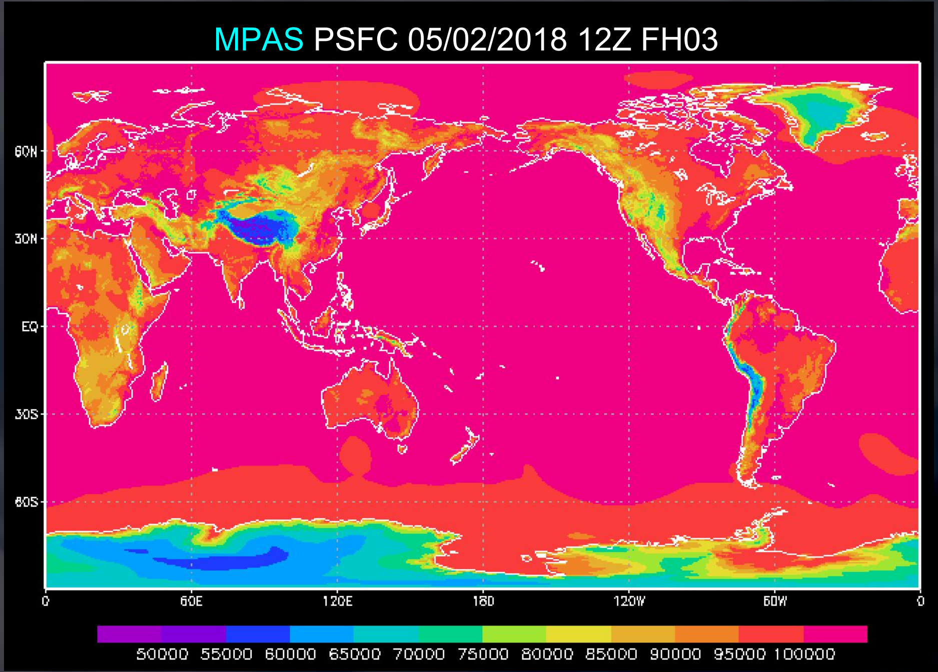
- MPAS computes and generates data on an unstructured mesh
- Interpolating from mesh elements to grid cells for post-processing
  - Barycentric interpolation* from nearest mesh elements
- Generating GRIB2 data compatible to our post-proc software

* Based on strategy implemented by Michael Duda: https://github.com/mgduda/convert_mpas

13-km WRF (RPM) vs. 15-km MPAS

Interpolated to 2560 x 1280 lat / lon grid

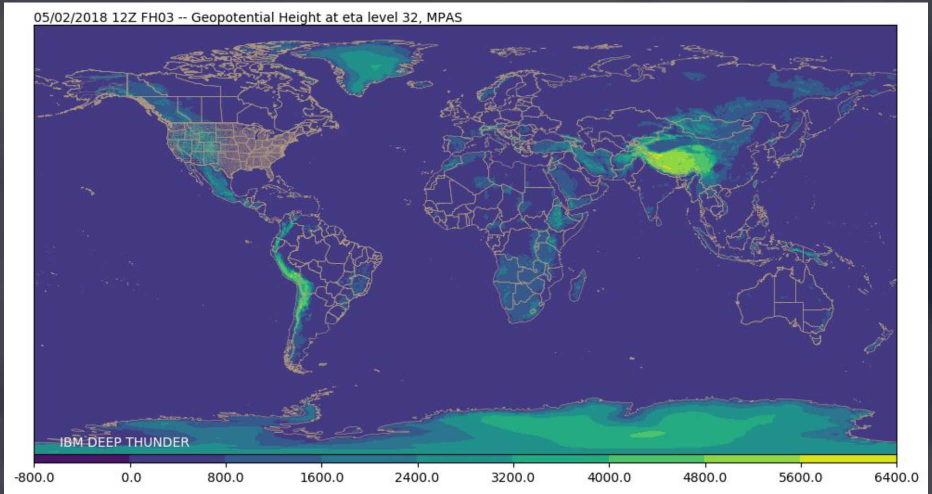


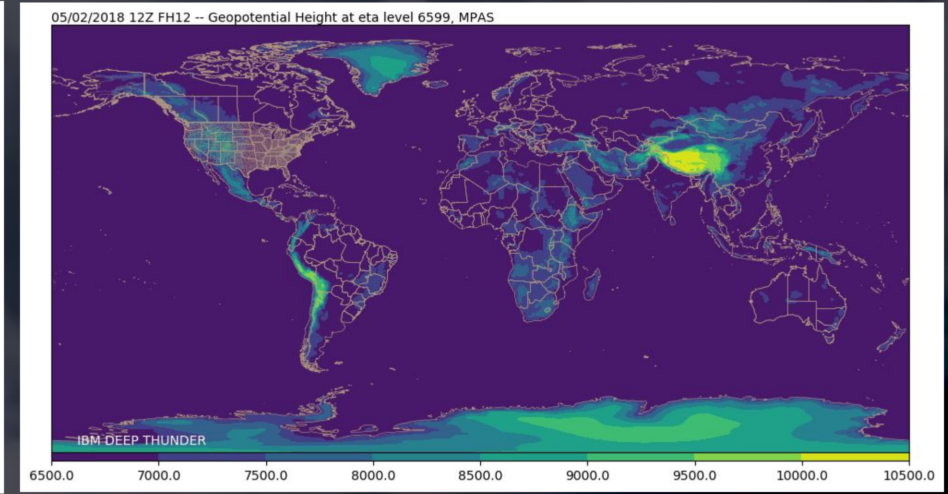


15-km MPAS

Interpolated to 2560 x 1280 lat / lon grid

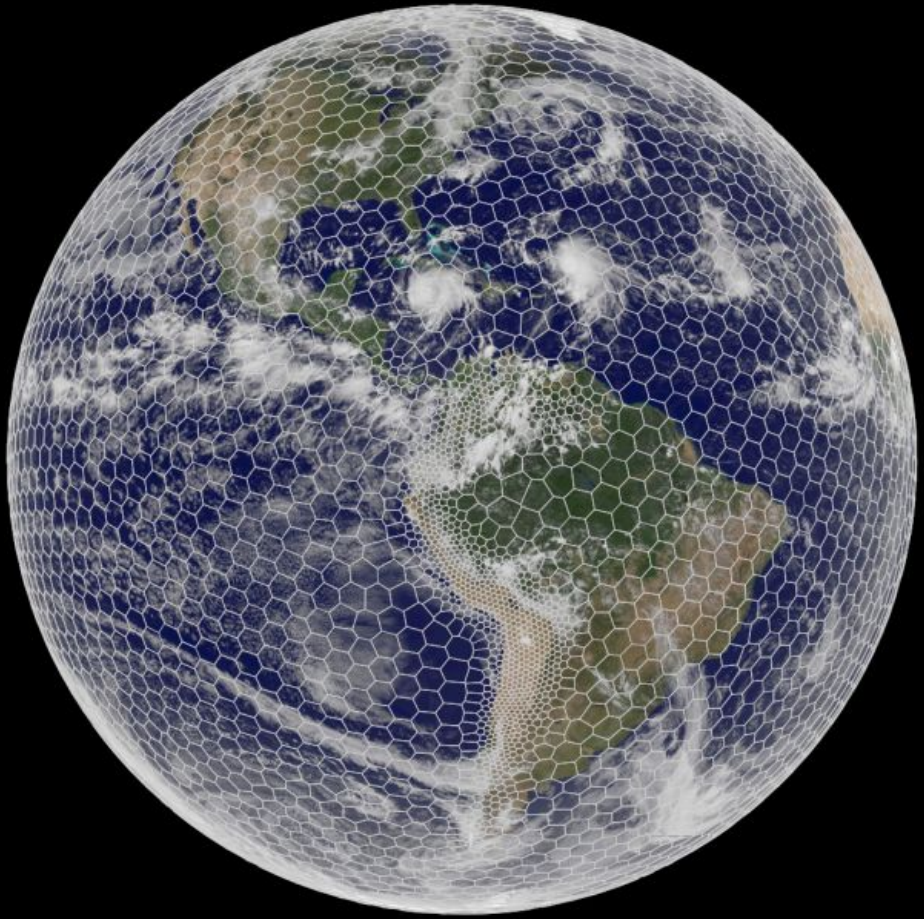
Zeta levels: 32-m (left), 6599-m (right)





Summary

1. The MPAS Implementation at The Weather Company
2. Interfacing the GSI with MPAS and Cell Phone Pressure Impacts
3. MPAS Post-processing Considerations



Backup

Goal #2 Hourly Updating, Convective Allowing Variable MPAS Mesh

Scale-Aware Convection Physics

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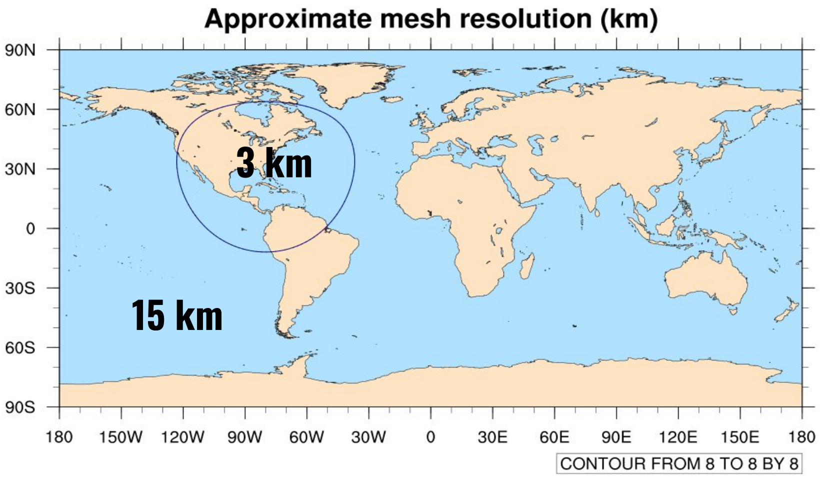
MPAS Experiment Configuration

Microphysics:	WSM6
Land surface:	Noah
Boundary layer:	YSU
Surface layer:	Monin-Obukhov
Radiation, LW:	RRTMG
Radiation, SW:	RRTMG
Cloud fraction:	Xu-Randall
Vertical Levels:	35
Convection:	Kain-Fritsch (orig) Kain-Fritsch (scale aware) New Tiedtke (scale aware) Explicit (grid scale)
Cold Start Analysis:	GFS 0.25 degree + QC
SST Analysis:	NASA SPoRT 2.5 km, GFS

MPAS 15 / 3 km Variable Mesh



Goal #2
Hourly Updating, Convective Allowing Variable MPAS Mesh

Case 1: Hurricane Harvey
00Z 2017-08-23 Initialization, 075h
Kain-Fritsch (non scale-aware)

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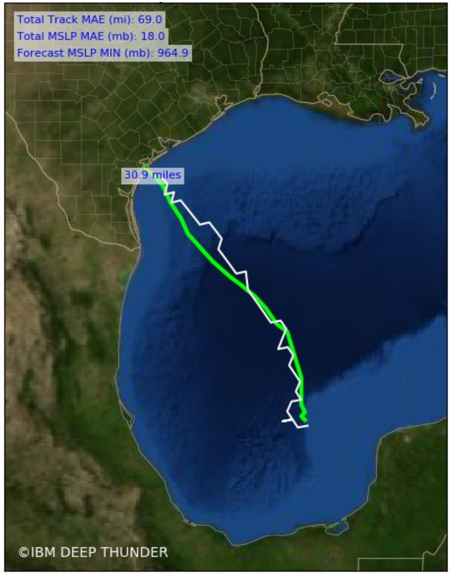
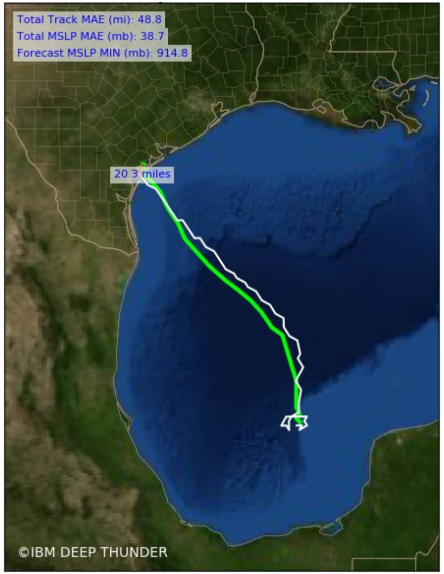
- **Prerequisite** → Determine general predictability BEFORE scale-aware convection physics

Kain-Fritsch 30 km (orig)

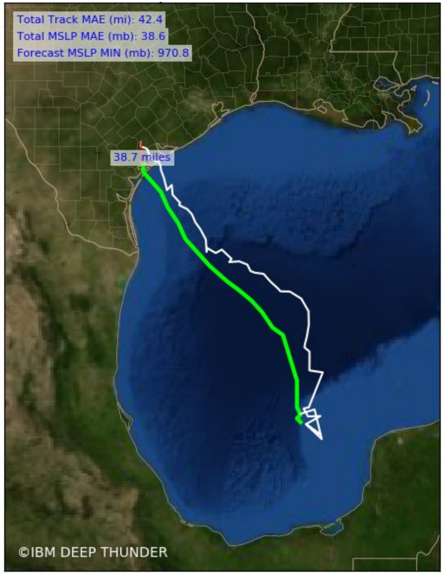


Kain-Fritsch 15 km (orig)



Kain-Fritsch 10 km (orig)

Explicit 3 km (disabled cp)



Kain-Fritsch non scale aware and explicit (disabled cp) simulations confirm reasonable initialization and predictability

Goal #2
Hourly Updating, Convective Allowing Variable MPAS Mesh

Case 1: Hurricane Harvey
00Z 2017-08-23 Initialization, 075h
Kain-Fritsch (scale-aware)

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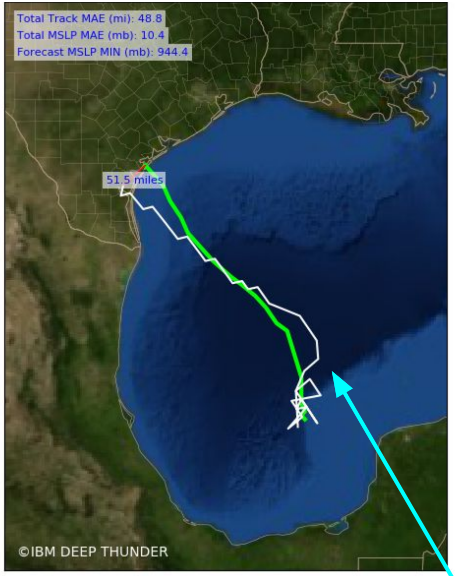
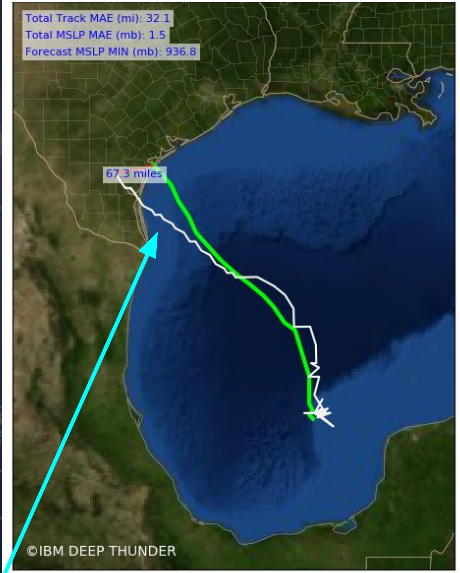
→ All scale aware resolutions display signature of early northward bias due to rapid convective development, late west bias
→ Increasing track speed with increasing scale aware resolution

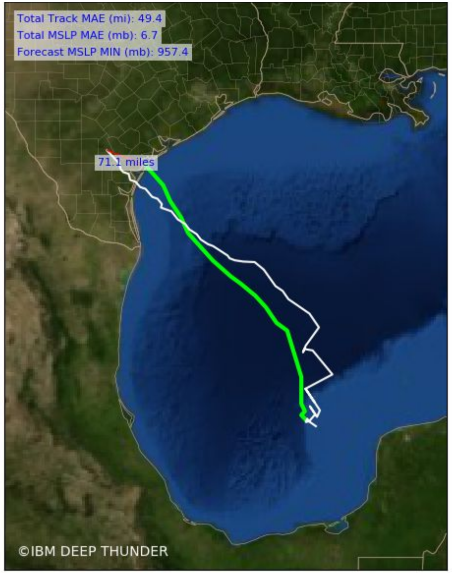
Kain-Fritsch 30 km (scale aware)



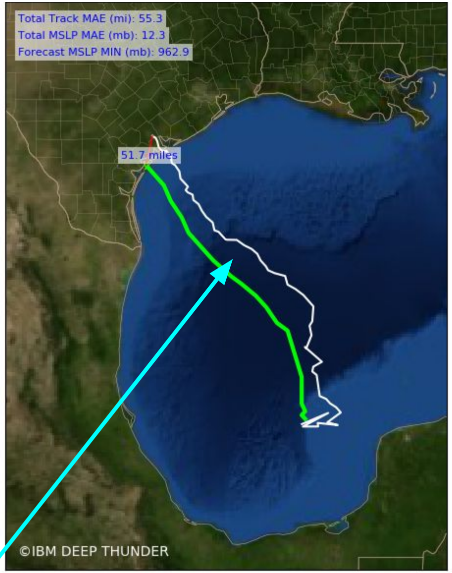
Kain-Fritsch 15 km (scale aware)



Kain-Fritsch 10 km (scale aware)



Kain-Fritsch 3 km (scale aware)



scale aware physics differences vs KF orig (time scale, entrainment, etc.)

scale aware minimizing convective parameterization contribution

Preliminary Impact of the Cell-phone Pressures

Sim1 --> no DA
Sim2 --> DA

Only one assimilation cycle prior to initialization.

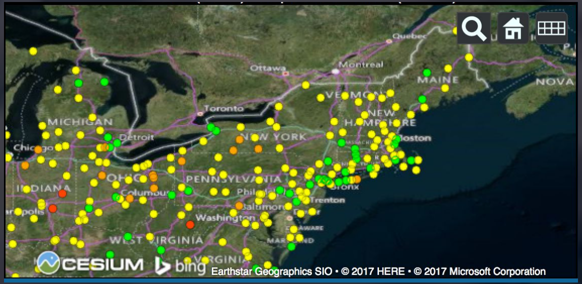
3 simulations (72-hrs):
09/30/2017 12Z
10/01/2017 12Z
10/03/2017 12Z

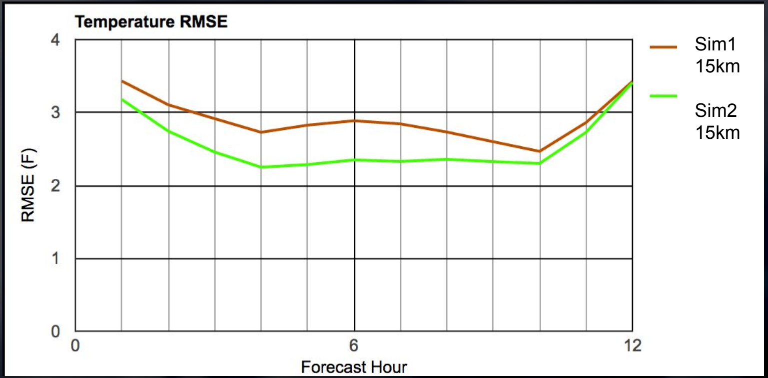
Focus on the short-term (FH <= 12).

Statistics aggregated over the simulations, for the first 12 hours of the Sim1 and Sim2 forecasts. Positive impact overall for temperature (by 0.33 F for RMSE and 0.93 F for Bias) across Northeast CONUS locations.

Model Statistics*

Model	RMSE (F) ▲	Bias (F)
MPASXB (15km)	2.59	-0.37
MPASXA (15km)	2.92	-1.3





Observation Data Sources

Prioritization according to local testing, literature review, etc.

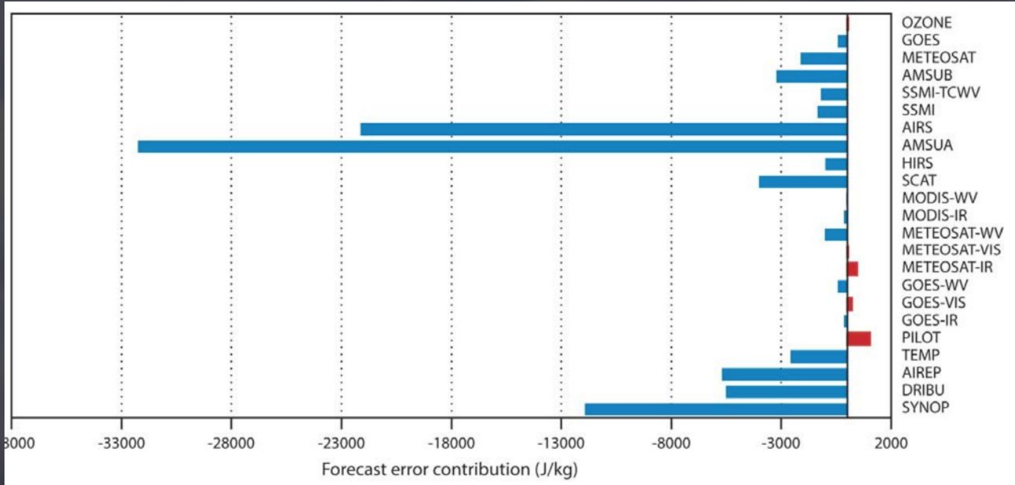


Figure 1: 24-hour forecast error contribution in J/kg of the components (types) of the observing system in summer 2006. Negative (positive) values correspond to a decrease (increase) in the energy norm of forecast error.

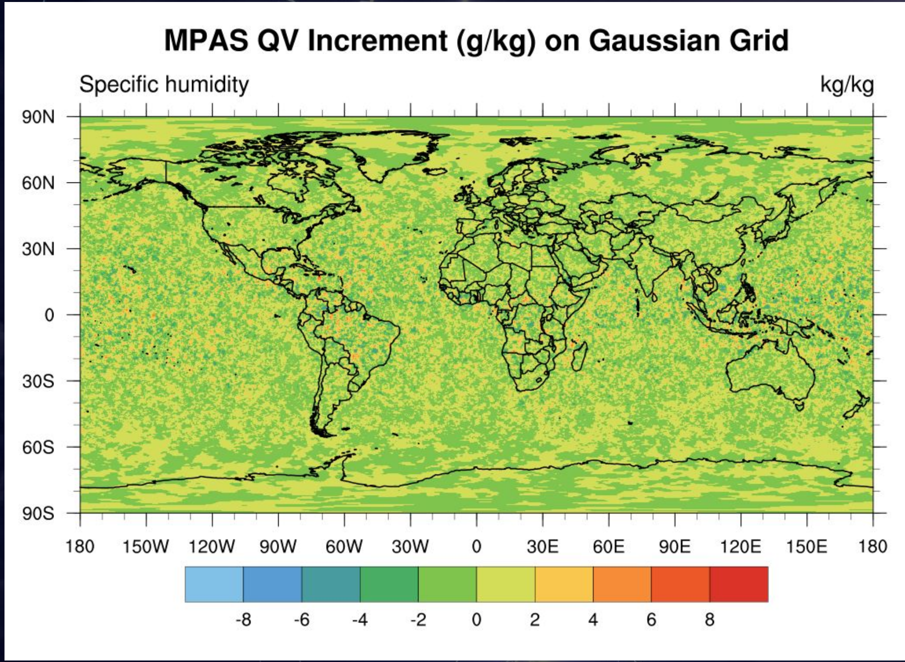
Cardinali & Prates (2009): "Forecast Sensitivity to Observations" (FSO), summer 2006.

Cell-phone Pressures
AMSU-A (Microwave)
AIRS (Infrared)
Radiosondes, Aircraft
SYNOP, Metar, Mesonet
ATMS (Advanced Technology Microwave Sounder on board the Suomi NPP)
IASI (Infrared Atmospheric Sounding Interferometer)
GOES-R, "PWS", Radar, Satellite Derived Winds, GPS-RO

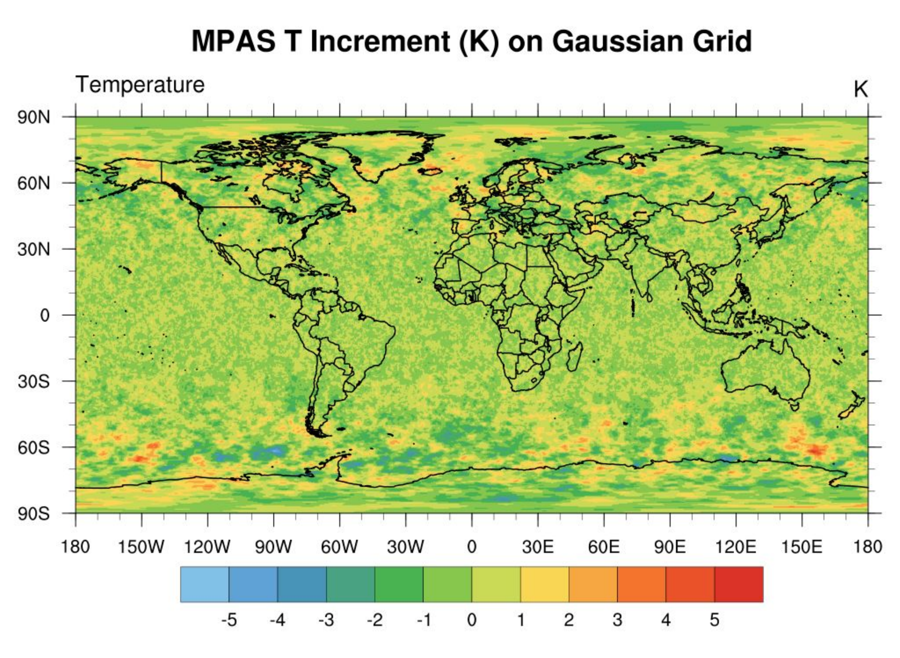
Ongoing DA Work

(1) Observation prioritization (impacts).
(2) Updated verification (tuning) framework (hzscl, vertscl, variance).
(3) Optimization for channel selection (radiance data assimilation).
(4) Assimilation within the re-forecasting environment.
(5) Updating the lower boundary conditions: SST, GVF, TSOIL, SOILW, SNOW.
(6) Migration of the EnKF & Hybrid capabilities to GSI-3.6.
(7) Options for strong constraints in the cost function and / or within MPAS (TLNMC, IAU).
(8) Use of sub 1-hr background files (new to the global GSI).
(9) 3D First Guess at Appropriate Time.
(10) Update p3d and cloud water (qc+qi) and pass back to the GSI interpolation utility.
(11) Frequently-updating convective-allowing forecasts, leveraging the variable resolution mesh capability of MPAS.
(12) Potential transition to the JEDI framework when the time is right (?)

The random CV option in GSI (towards the EnKF)

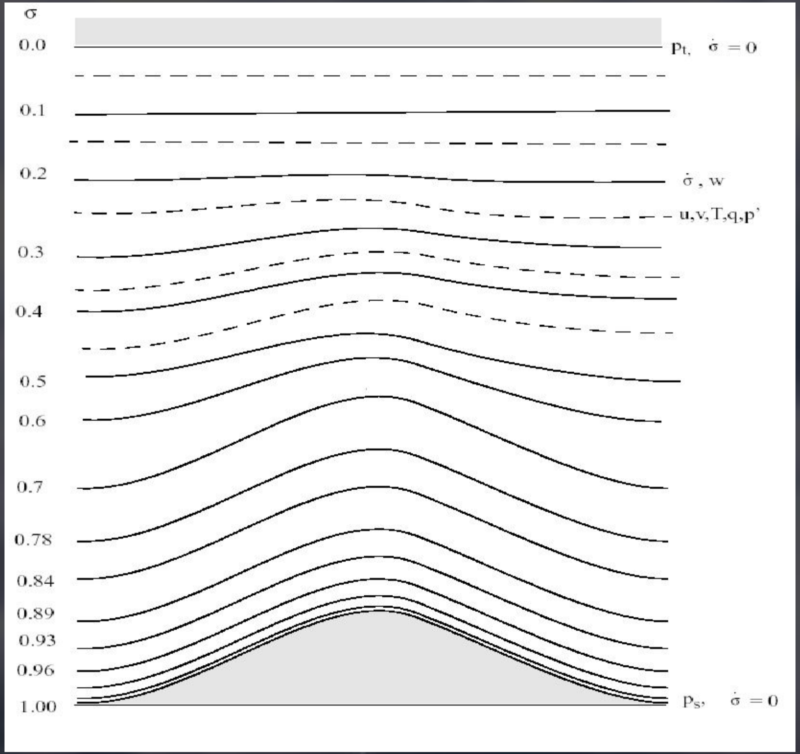


At k = 5



At k = 5

Vertical levels: WRF vs. MPAS



WRF

- Pressure-based, sigma
- Terrain-following
- Surface value = 1.0
- Model top = 0.0

MPAS

- Height-based, zeta
- Terrain-following
- Smoothed
- Surface value = 0
- Model top = Height