UTOPUS INSIGHTS

8.5

A Globally Relocatable High-Resolution WRF Realtime Forecast System for Renewable Energy

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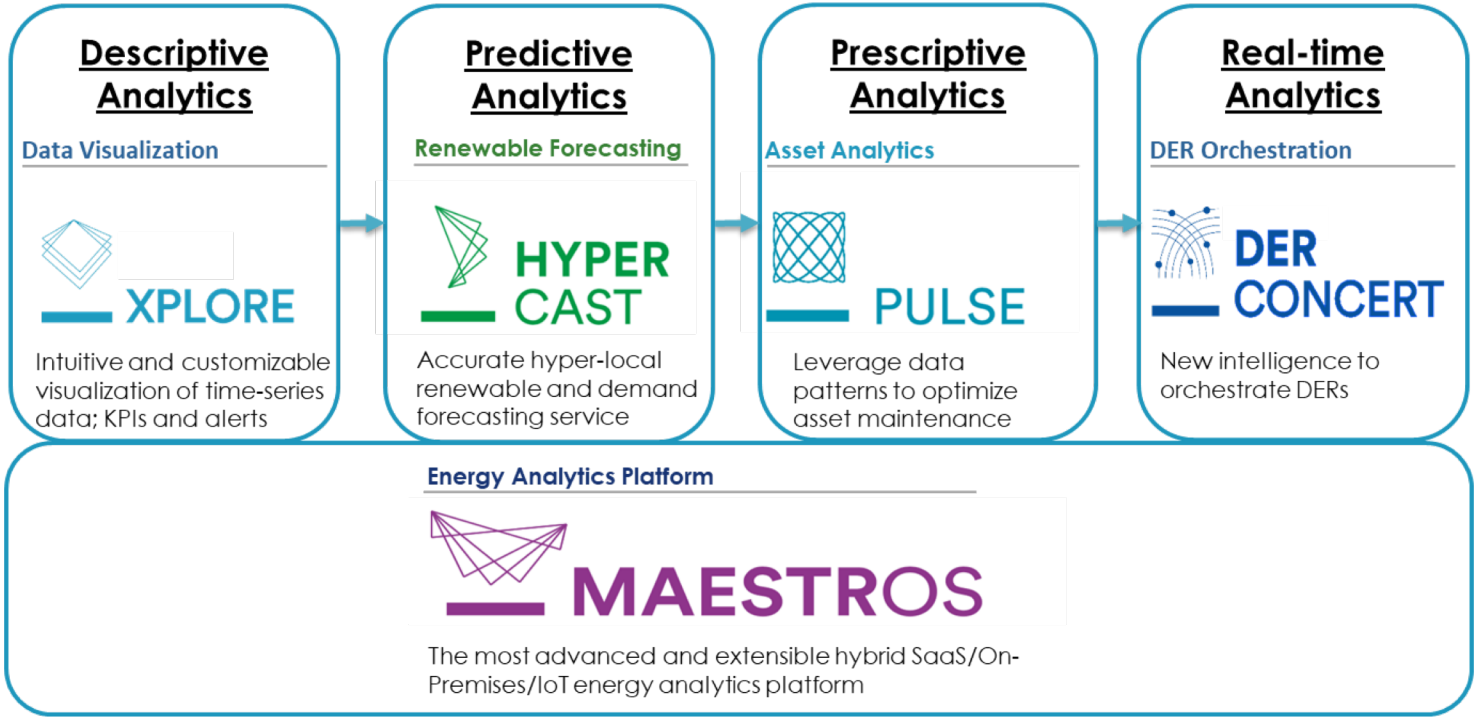
2018 Joint WRF and MPAS Users' Workshop

Outline

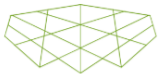
- Utopus Insights Products overview
- Utopus Insights' weather forecasting system: *Nostradamus*
- Sample Applications
- Case study results for Vermont
- Summary and Conclusions

Utopus Insights Energy Analytics Products



Nostradamus Weather Forecasting System

- WRF-based, real-time weather forecasting system
- Designed exclusively for wind/soar renewable energy
- Globally Highly scalable/deployable on both HPCC and AWS cloud platforms
- Delivers short-term, mid-term (1-3 days), and long-term (4-10 days) weather forecasts



Weather Insights

Weather analytics for your assets

Features

Powered by Nostradamus

HyperCast

PREDICT

Future generation performance

Features

Wind HyperCast / Solar HyperCast

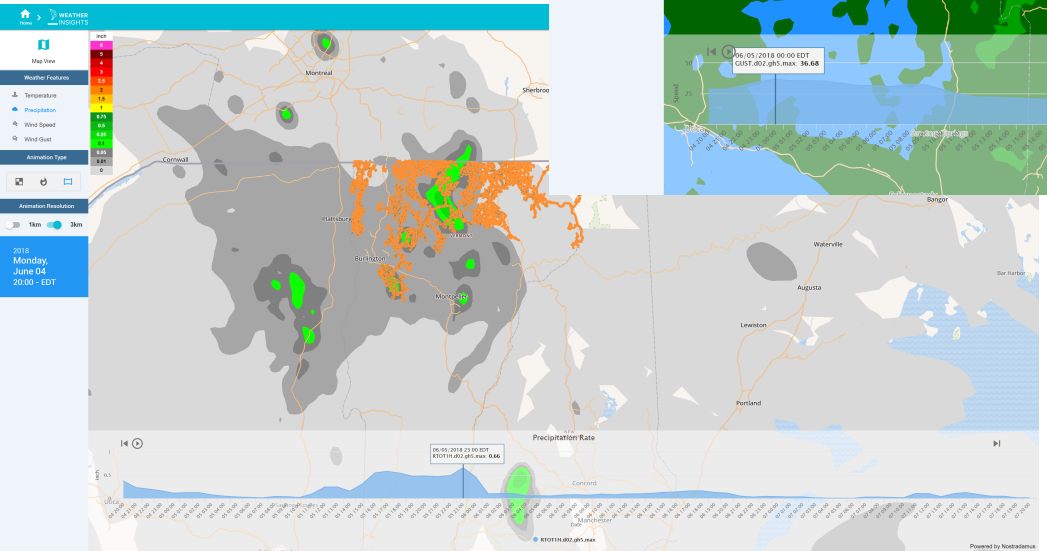
Powered by Nostradamus

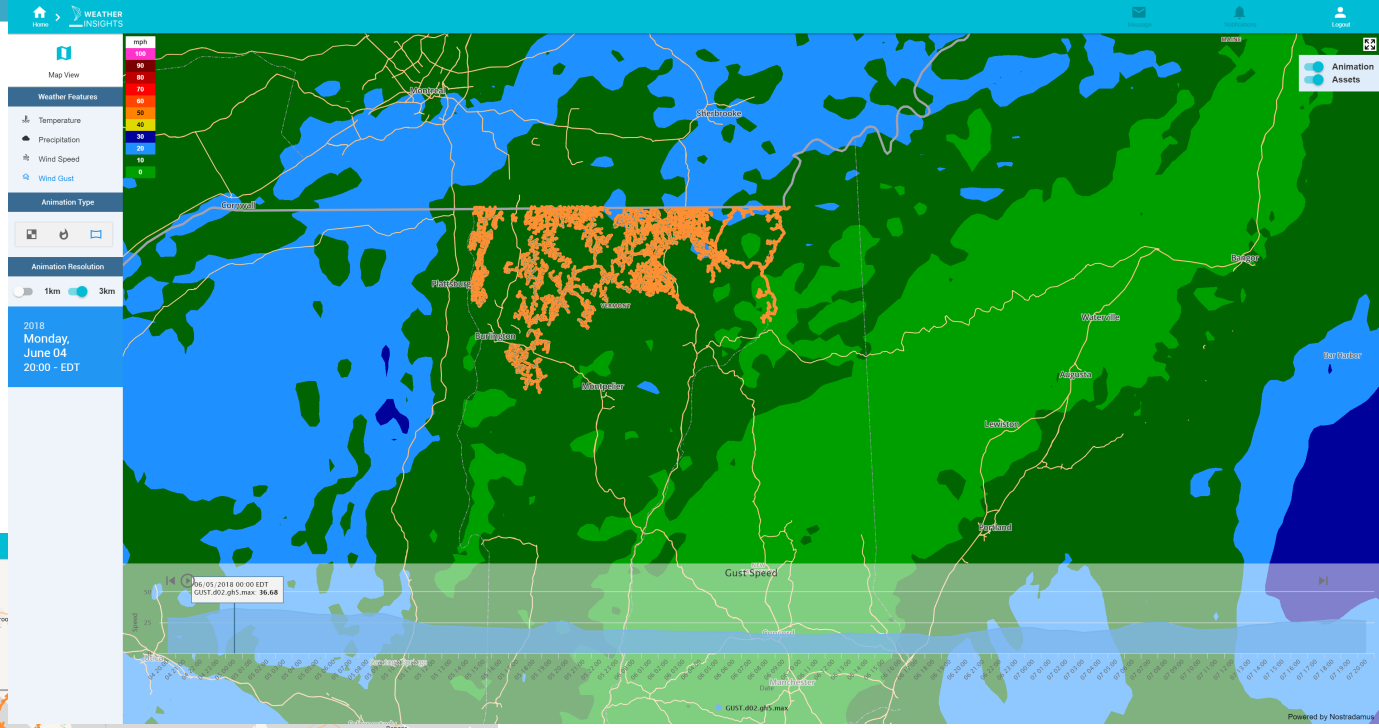
Driven by Nostradamus and observed power input, and using machine learning-based energy analytical models:

- **Solar HyperCast**
- **Wind HyperCast**
- **Demand Forecasting**
- **Peak Load Forecasting**

Weather Insights

Powered by Nostradamus



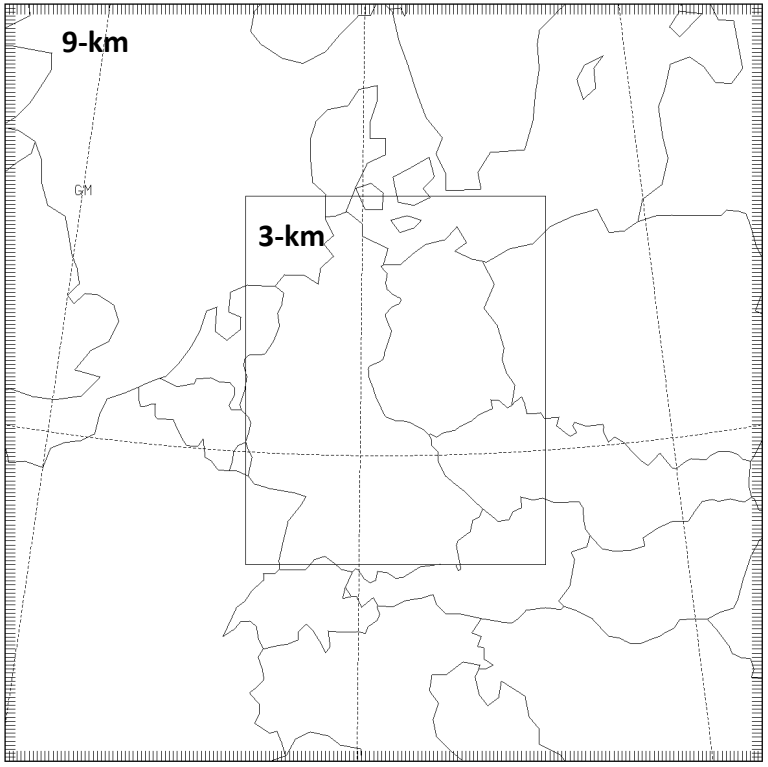


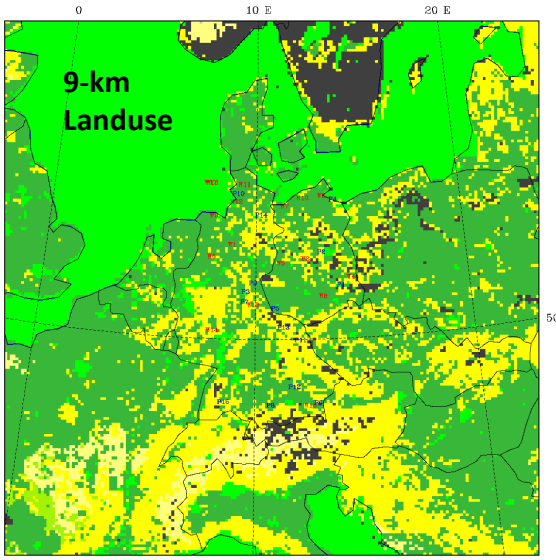
Nostradamus Weather Forecasting System

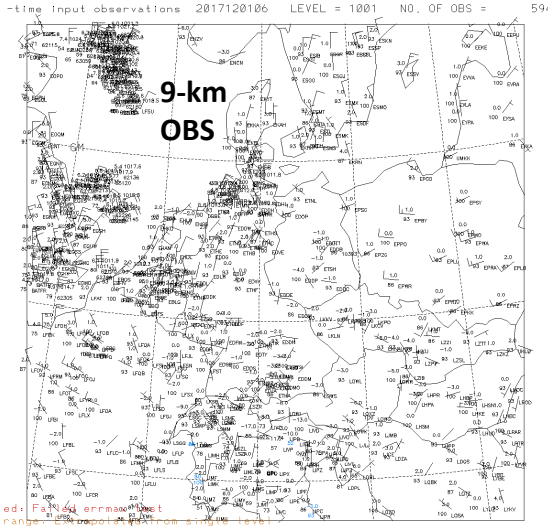
- WRF-based realtime weather forecasting system.
- Designed for renewable energy, both wind and solar, predicting hub-height wind, surface wind gust, and solar total, direct and diffuse irradiances, etc.
- Model physics similar to those in RAP/HRRR except for LSM
- Turbine drag effect on mesoscale winds is to be explored.
- Highly scalable/deployable on both HPCC and AWS cloud platforms
- Globally rapidly relocatable
- Assimilating meteorological observations with FDDA, benefiting wind and solar nowcast and short-term forecasting.
- Automated meteorology validation-on-the-fly to inform clients how Nostradamus performs
- ……..

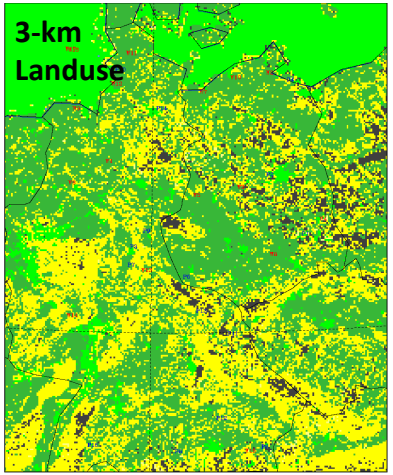
Project Hamburg

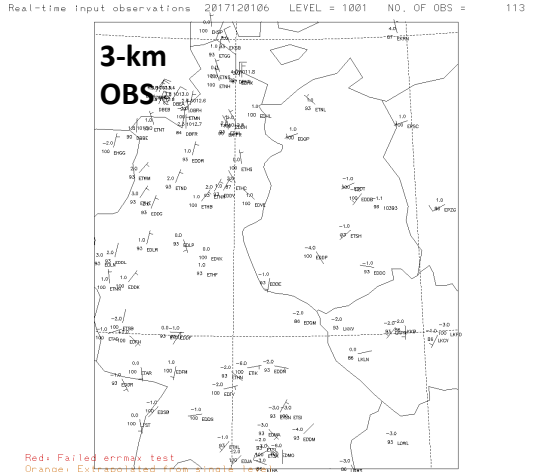
Wind and Solar HyperCast





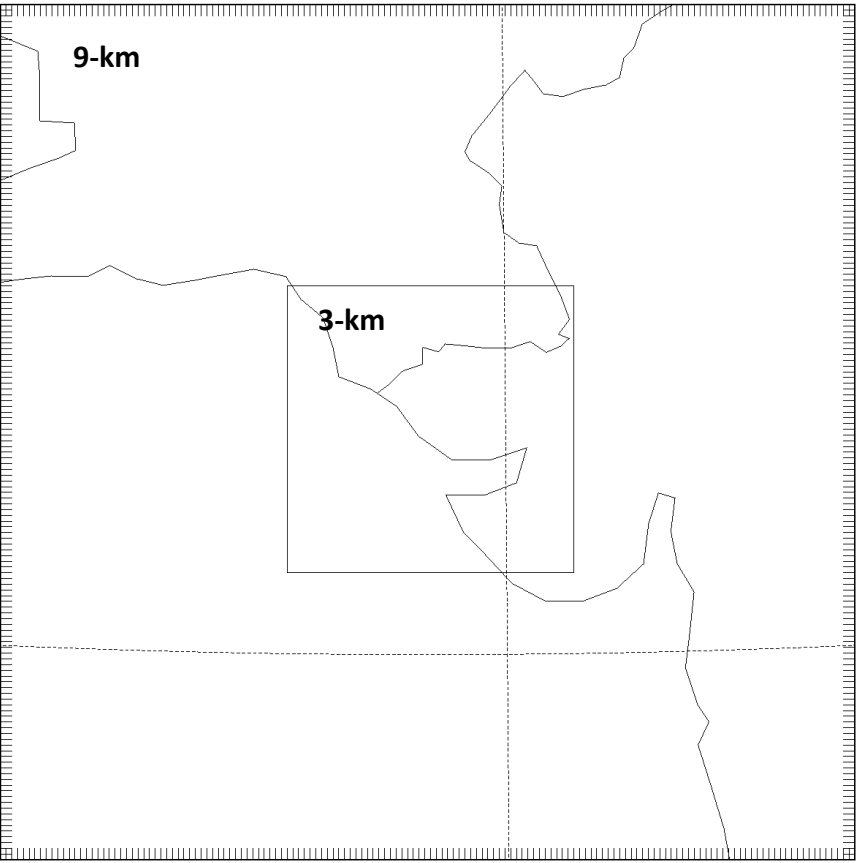


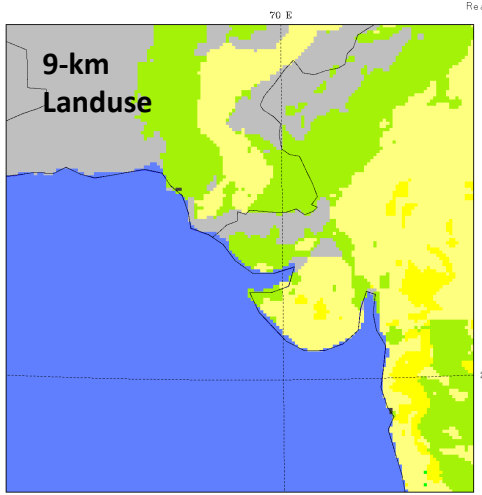


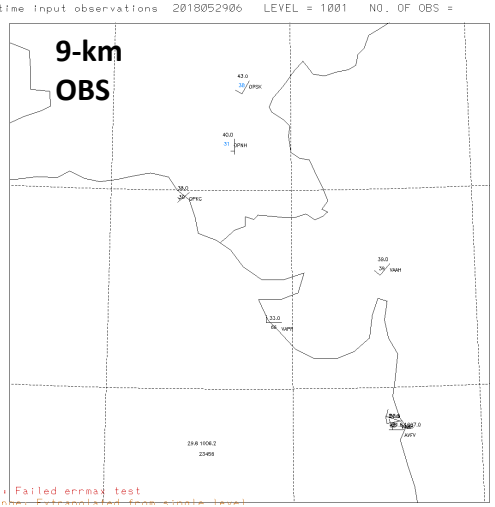


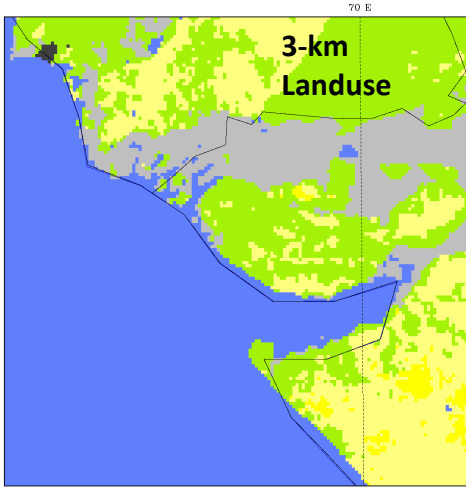
Project ENEL

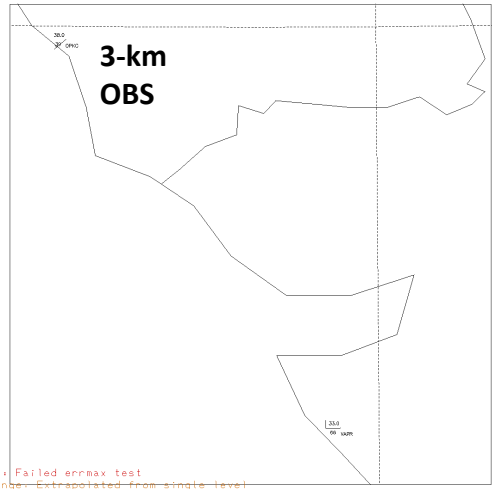
Wind and Solar HyperCast





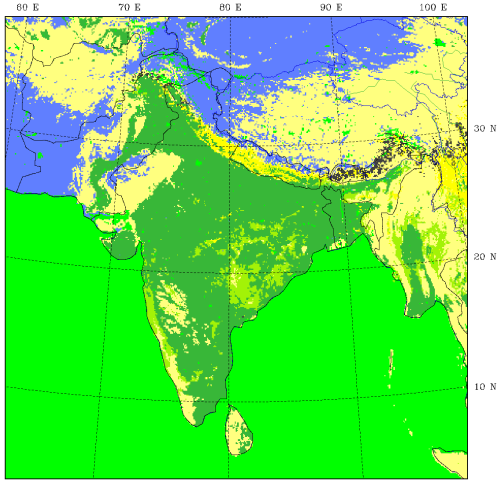


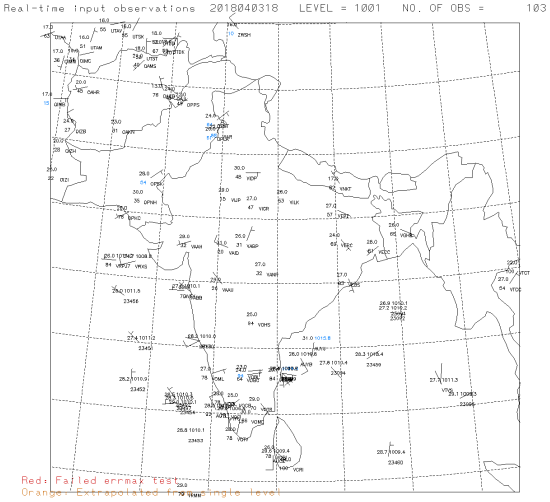




Project BHARAT

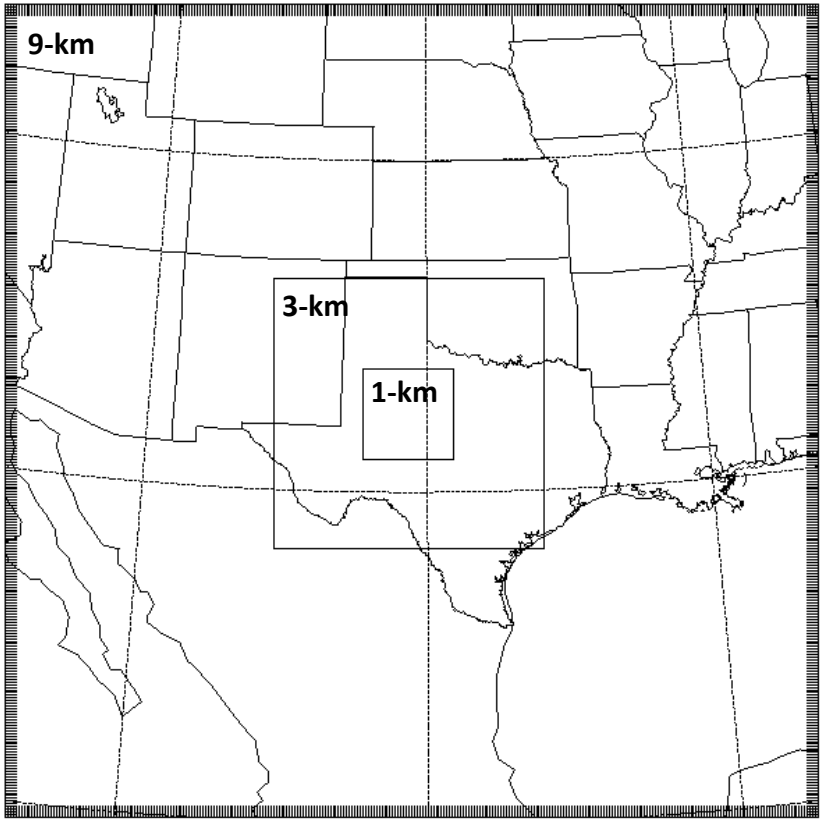
Wind and Solar HyperCast

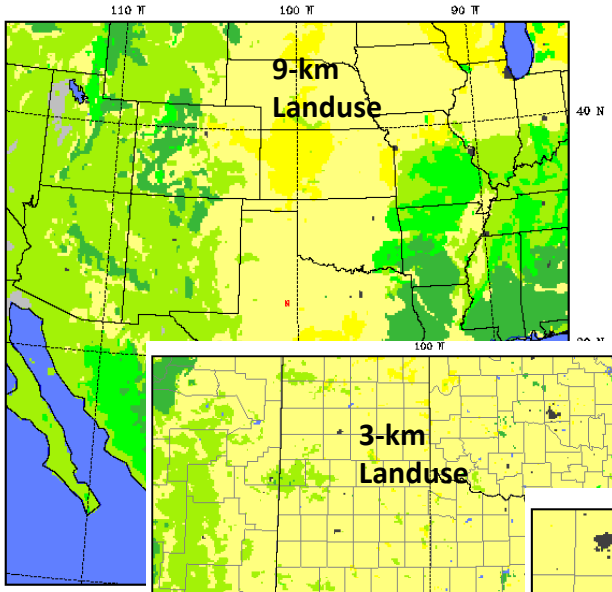




Project Nolan

Convection effect on wind power production



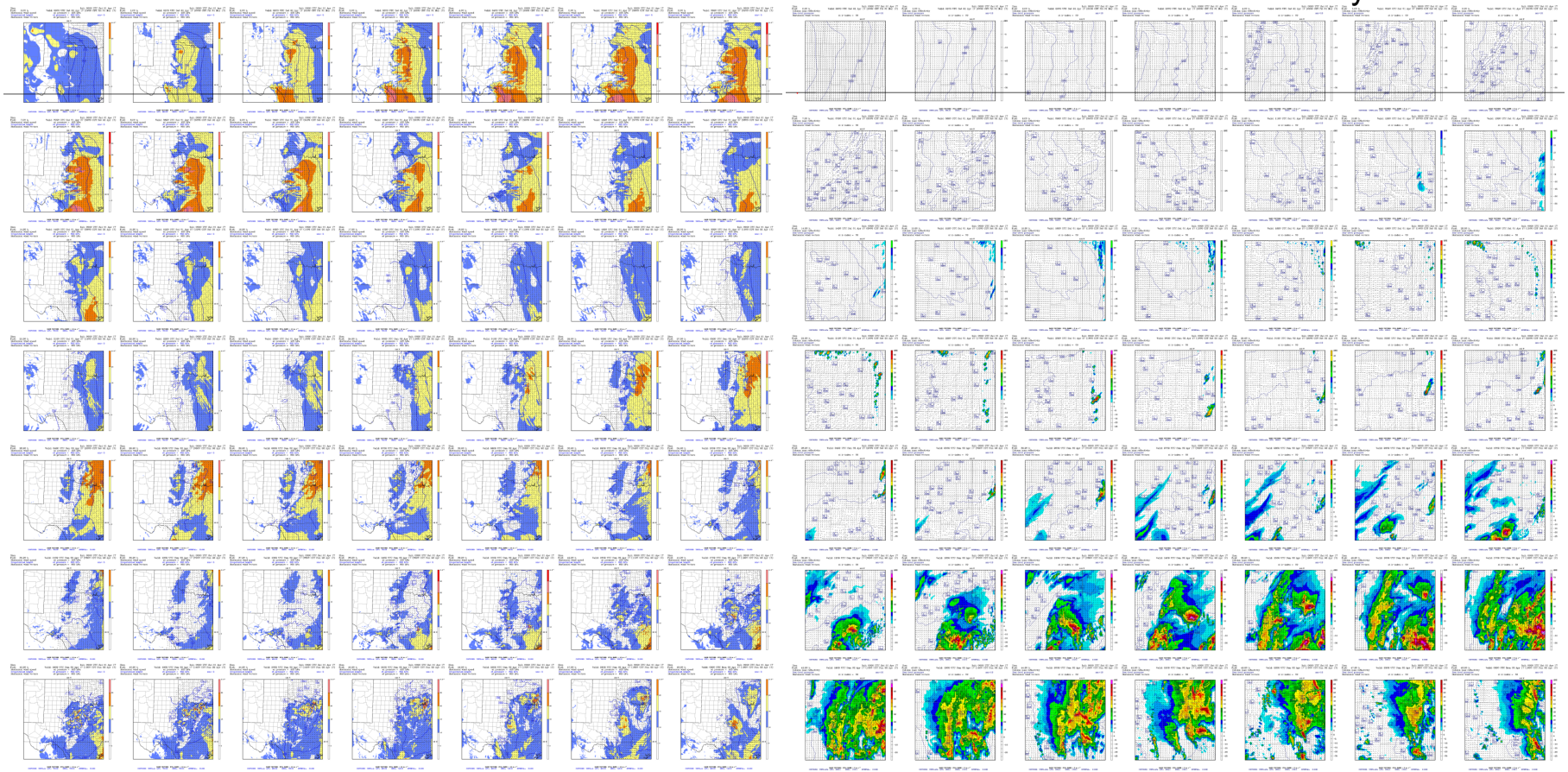


Project Nolan: Nostradamus-predicted 1-km weather for 4/1-2/2017

(convection effect on wind power production)

925-hPa wind

Max. radar reflectivity



Project Nolan: Nostradamus-predicted 1-km weather for 4/1-2/2017

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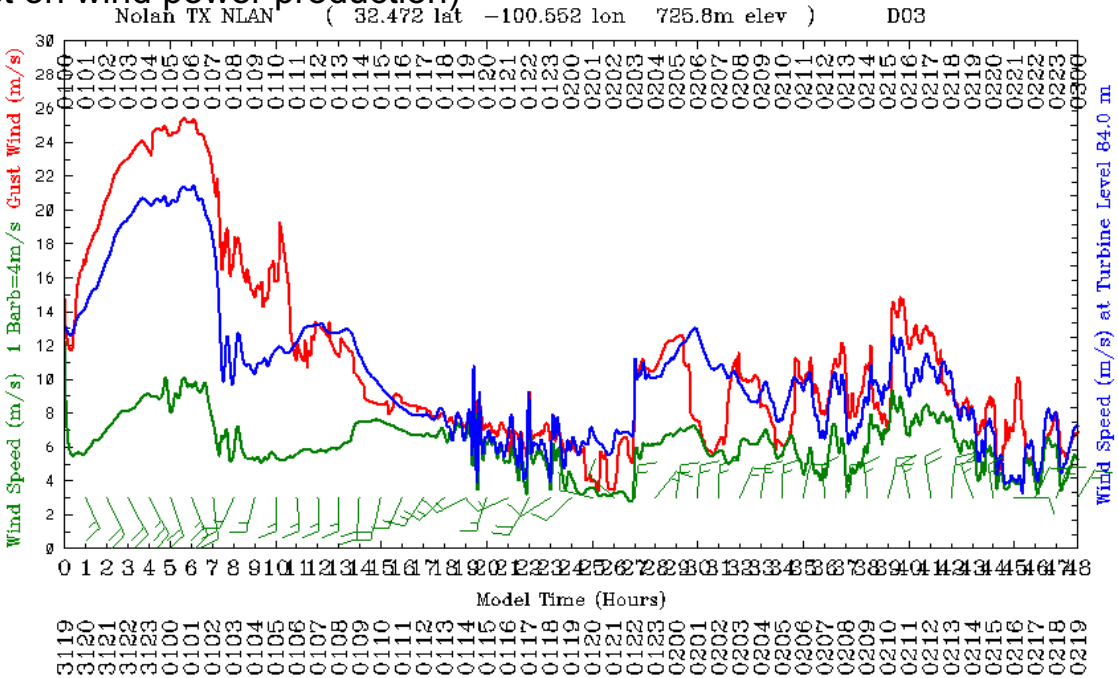


Nostradamus-predicted surface wind speed and gust at Nolan, TX, for 1-2 Apr 2017, showing strong wind gusts (>20m/s) on the early morning of 1th but much weaker on the 2nd due to widespread convection (not predicted by weather services based on client).

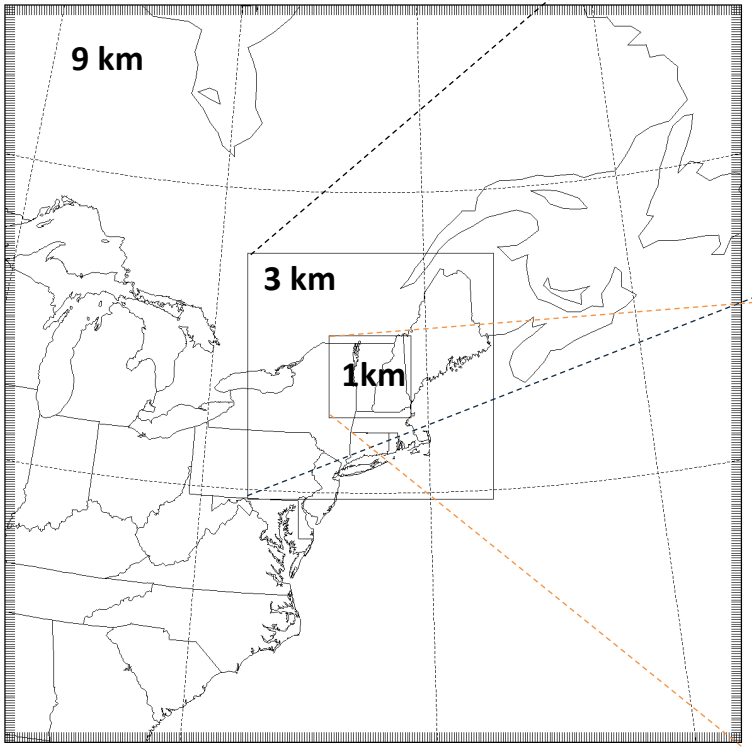
Nostradamus Grids for Vermont

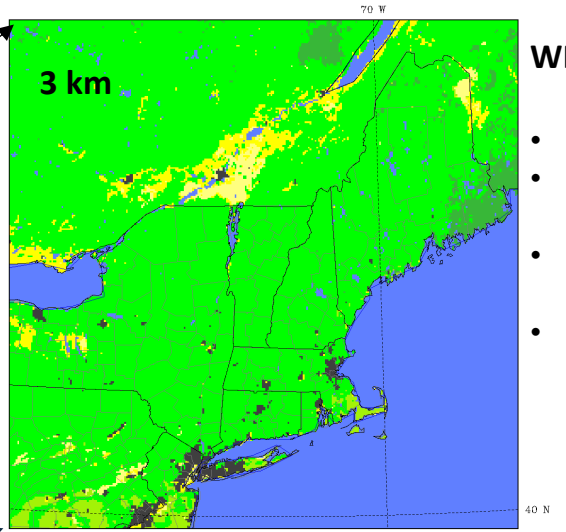
Wind and Solar HyperCast

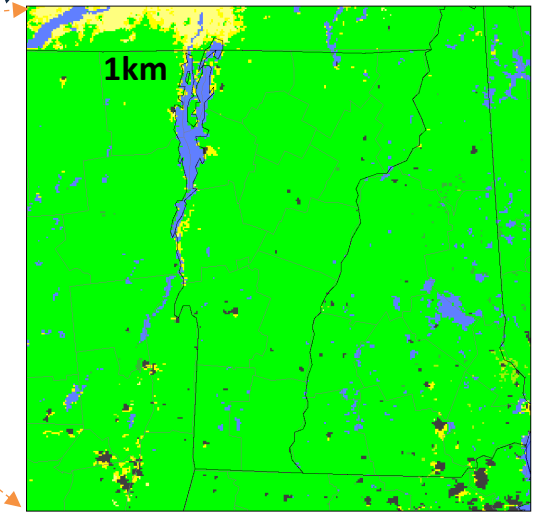
WRF Grids: dx=9/3/1 km

NXxNYxNZ=300x300x50/300x300x50/300x300x50

Z(1)=10 m, with first 20 layers below 2 KM AGL







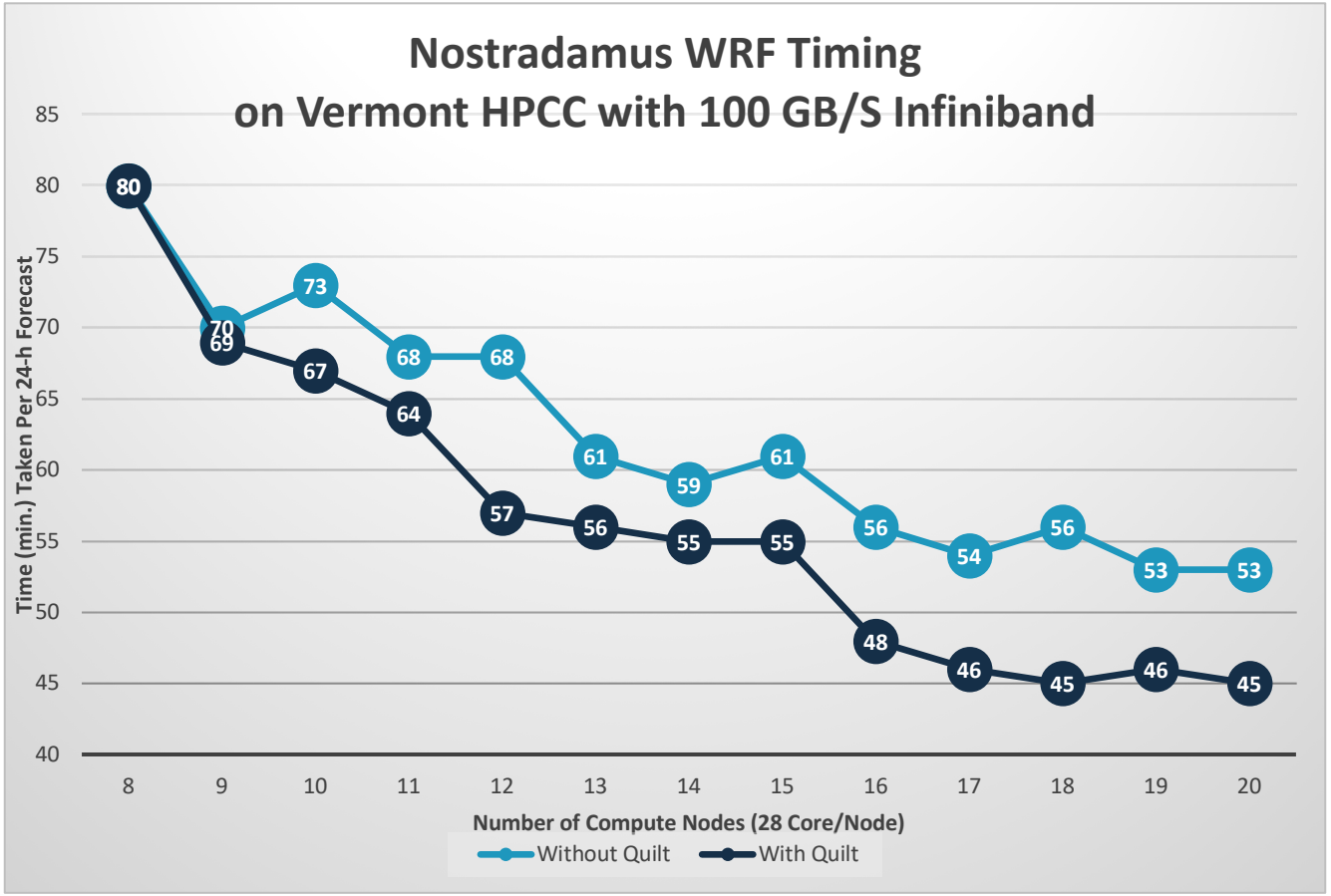
WRF Initialization:

- GFS for IC/BCs
- Currently twice daily at 00/12 UTC,
- 3-day forecast, being extended to 10 days
- 18 computing nodes (504 cores) on HPCC

Model Physics (V3.9.1):

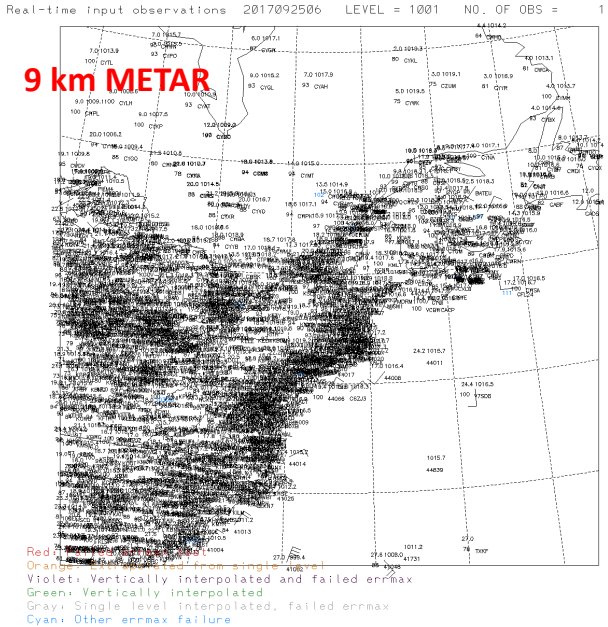
- Identical to those used in NOAA RAP, except:
- KF CPS on the 9-km grid, No shallow convection parameterization
- Noah LSM
- FDDA for dynamic initialization (DI)

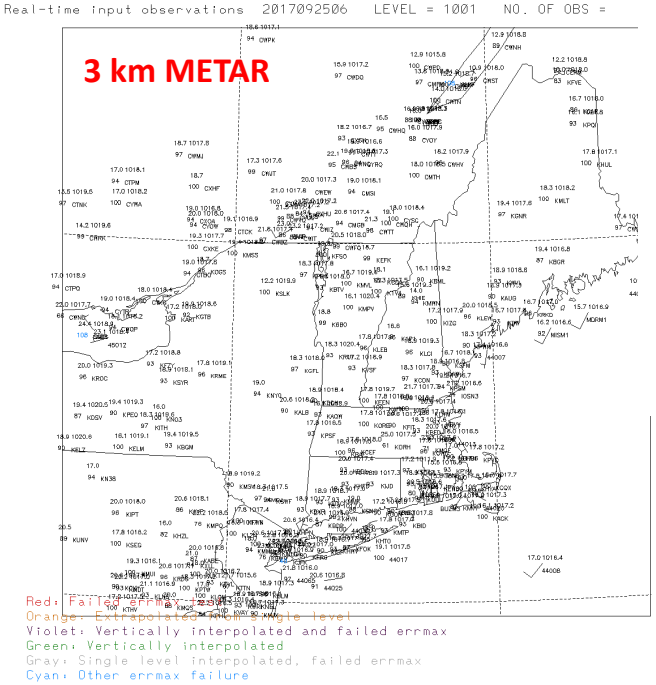
WRF Timing on Vermont HPCC Using up to 560 CPU Cores

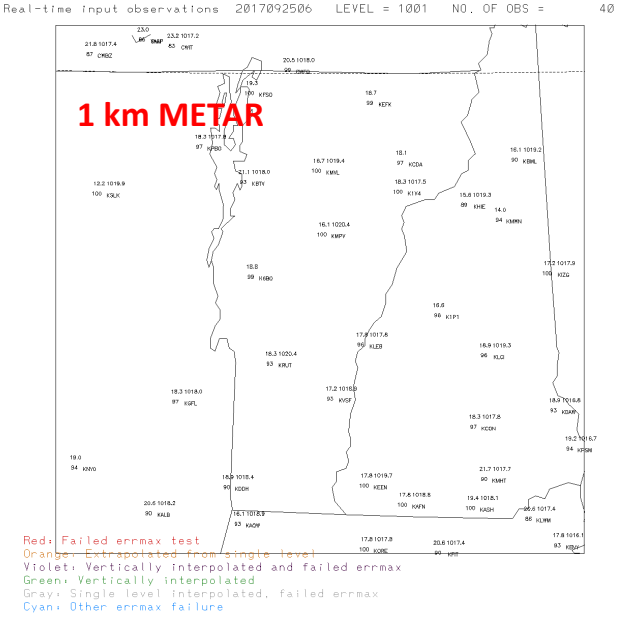


Observation Currently Being Processed in Vermont Nostradamus:

- NOAA ACARS
- NOAA satellite winds
- NOAA buoy stations
- NOAA METAR (currently assimilated)
- NOAA profilers
- NOAA Radio sondes
- Non-NOAA Mesonet
- Non-NOAA profilers







Previous Runs: 2017 09 25 00

9-km 3-km 1-km

landuse/ SST/ Snow/ Assimilation/

Nostradamus Forecasting System

Model Grids Observations

UTOPUS INSIGHTS

Model Error Select:

Horizontal Charts:

- 300hPa S
- 500hPa S
- 700hPa S
- 850hPa S
- 850hPa Jet S
- 925hPa S
- 925hPa Jet S
- Sfc Temperature S
- Sfc Wind Speed S
- Sfc Streamlines S
- Int. Cloud Water S
- Max CAPE S
- K-Index S
- PBL Depth S
- Cloud Ceiling S
- Sfc SWDOWN S
- Sfc Cloud Water S
- Sfc Relative Humidity S
- Visibility S
- Sea-Level Pressure S
- 3-h Pressure Change S
- 3-h Total Precip. S
- 3-h Cumulus Precip. S
- 3-h Resolved Precip. S
- 6-h Precip. S
- 12-h Precip. S
- 24-h Precip. S
- Total Precip. Since 0 h S

Cross Sections:

- SWNE S
- NWSE S
- WE S
- SN S

Time Series: Select:

Station Skewt: Select:

Wind Profiles: Select:

Last update: 201709251251 UTC

Play | Ⅱ | << | >> | Close | Normal

9km Init: 0000 UTC Mon 25 Sep 17

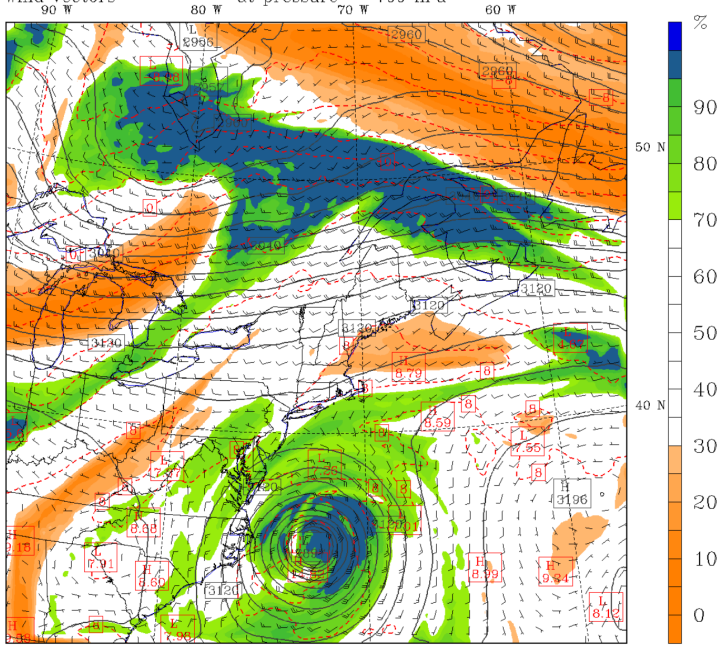
Fcst: 66.00 h Valid: 1800 UTC Wed 27 Sep 17 (1400 EDT Wed 27 Sep 17)

Relative humidity (w.r.t. water) at pressure = 700 hPa

Temperature at pressure = 700 hPa sm= 5

Geopotential height at pressure = 700 hPa sm= 5

Horizontal wind vectors at pressure = 700 hPa



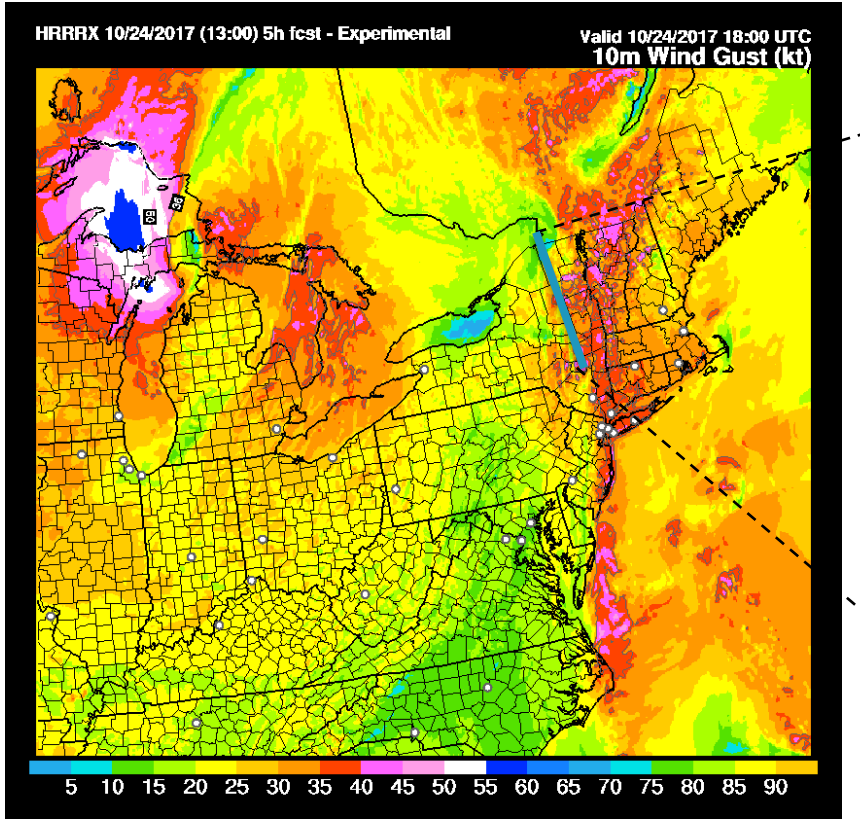
BARB VECTORS: FULL BARB = 10 m s^{-1}

CONTOURS: UNITS=m LOW= 2880.0 HIGH= 3180.0 INTERVAL= 20.000

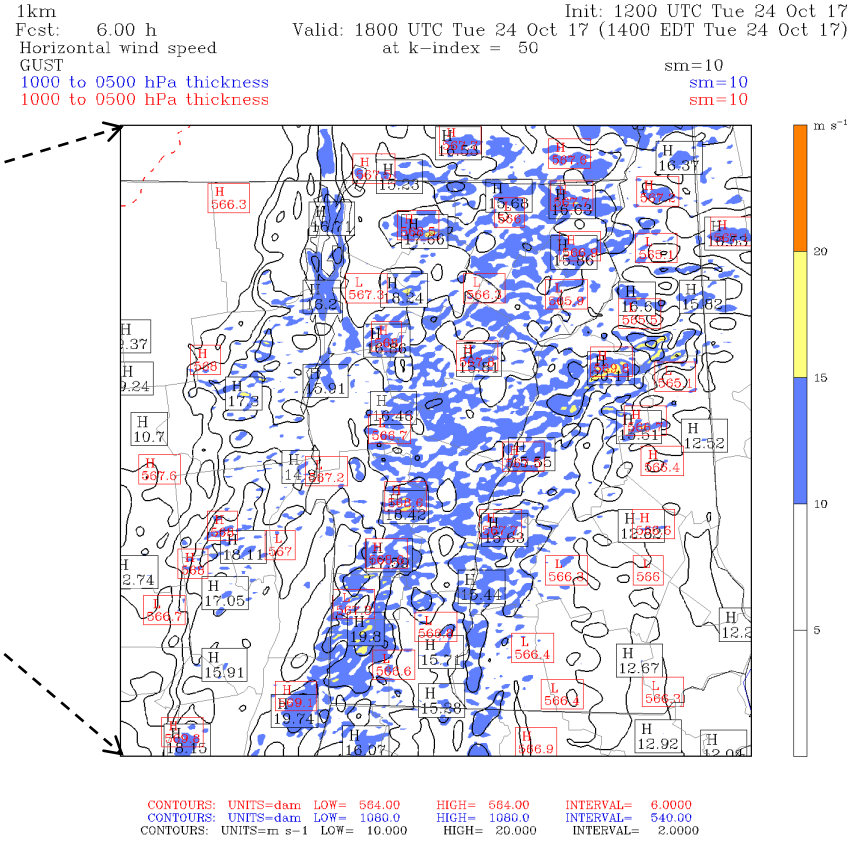
CONTOURS: UNITS=°C LOW= -10.000 HIGH= 14.000 INTERVAL= 2.0000

WRF-Predicted Surface Wind Gust Valid at 18 UTC, 10/24/2017

HRRR

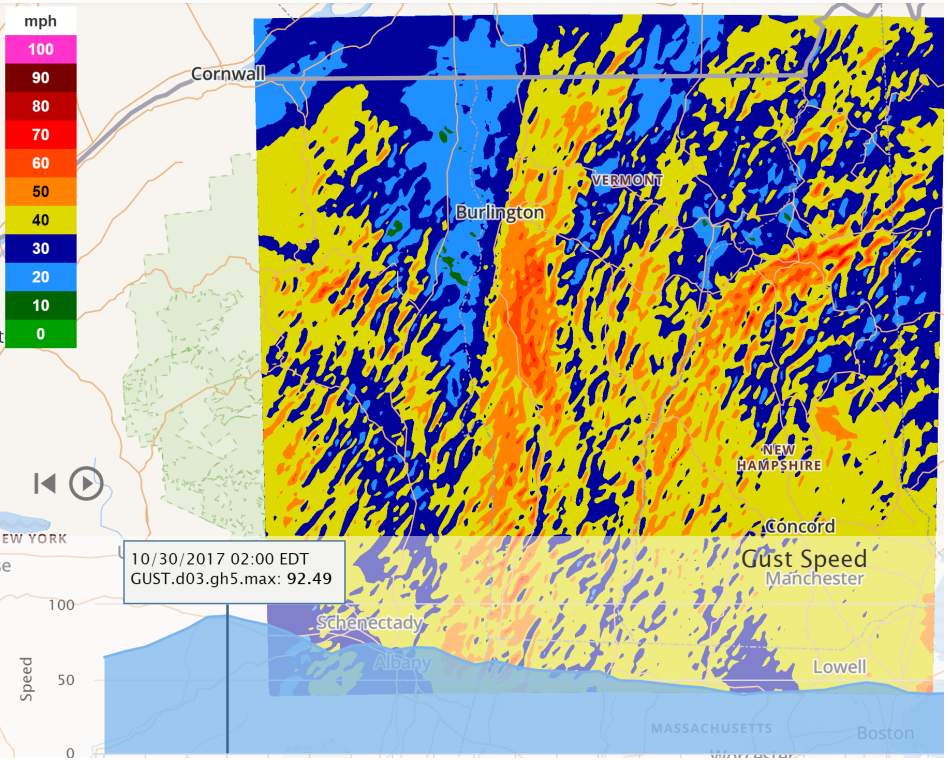


Nostradamus

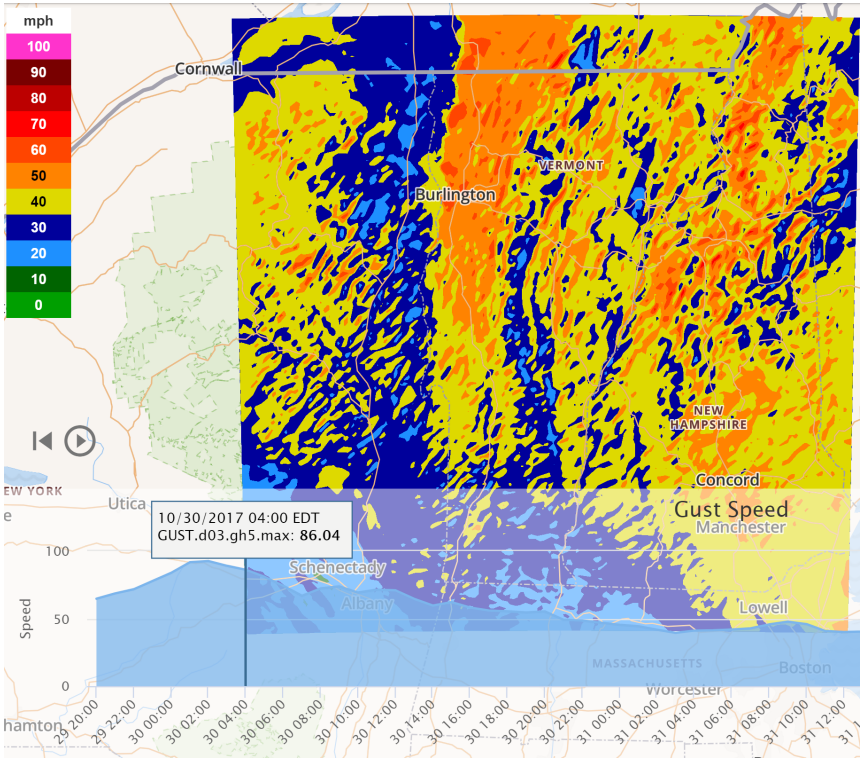


Weather Insights: Nostradamus-Predicted Wind Gust for 10/30/2017

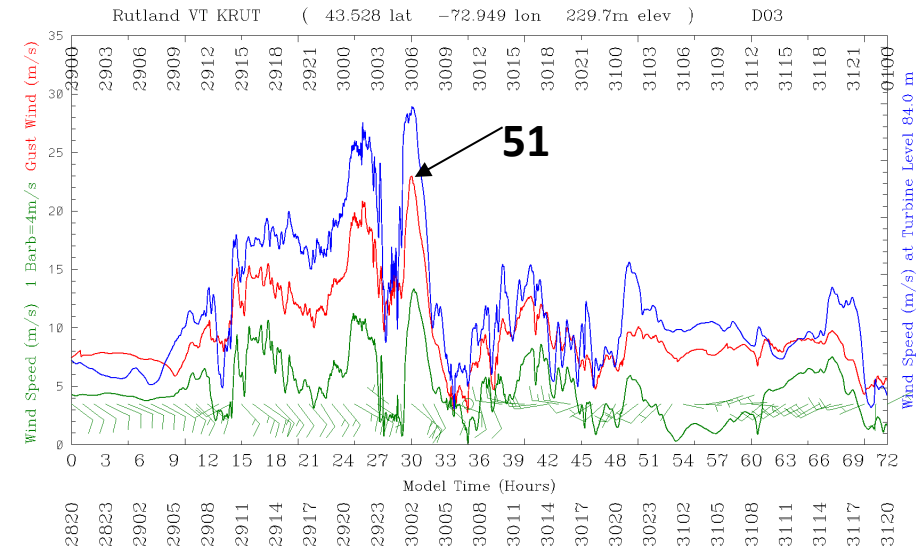
2 AM EDT

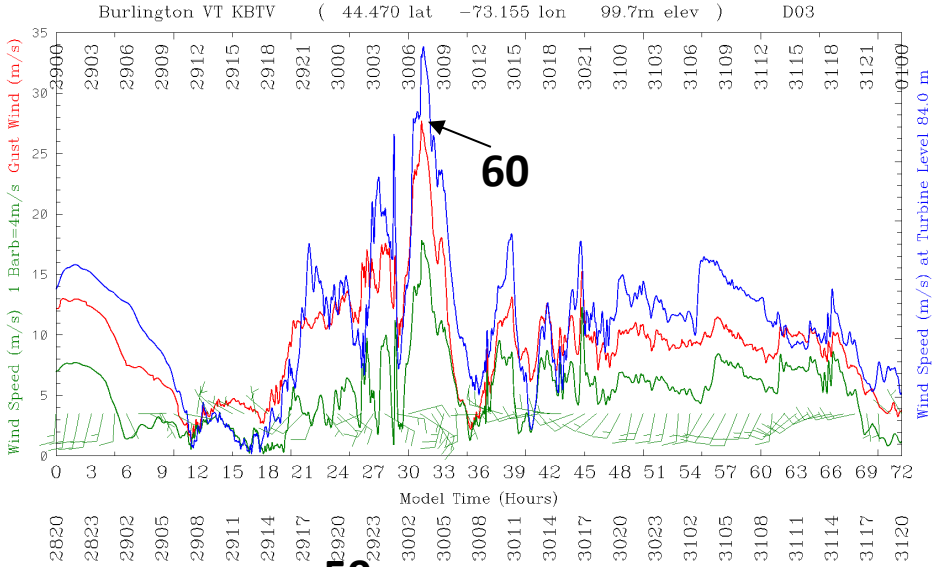


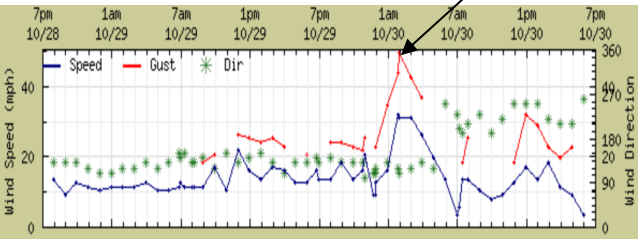
4 AM EDT

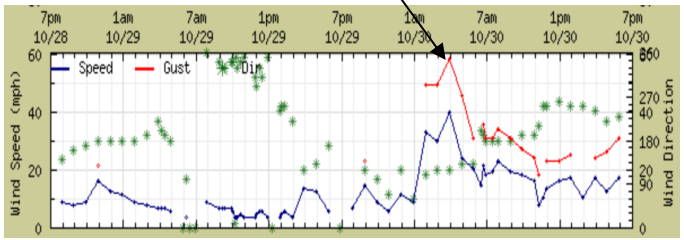


00 UTC 10/29 Nostradamus-predicted (top) Wind Gusts at Rutland and Burlington Compared with Observations (bottom):
Observed: Rutland 49 mph at 1:56AM 10/30 and Burlington 59 mph at 3:54 AM 10/30
Model: Rutland 51 mph at 2:00AM 10/30 and Burlington 60 mph at 3:10 AM 10/30







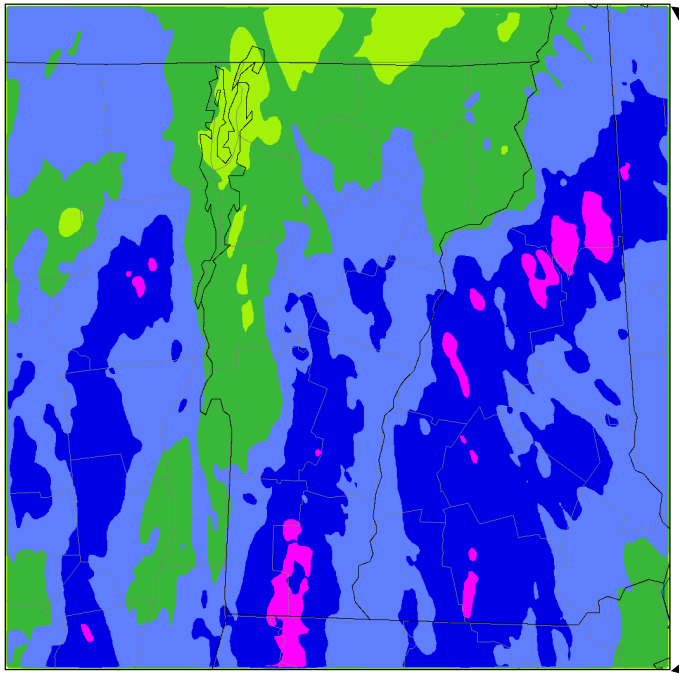


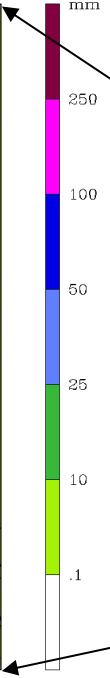
Nostradamus Prediction at 1-km Resolution

Observation

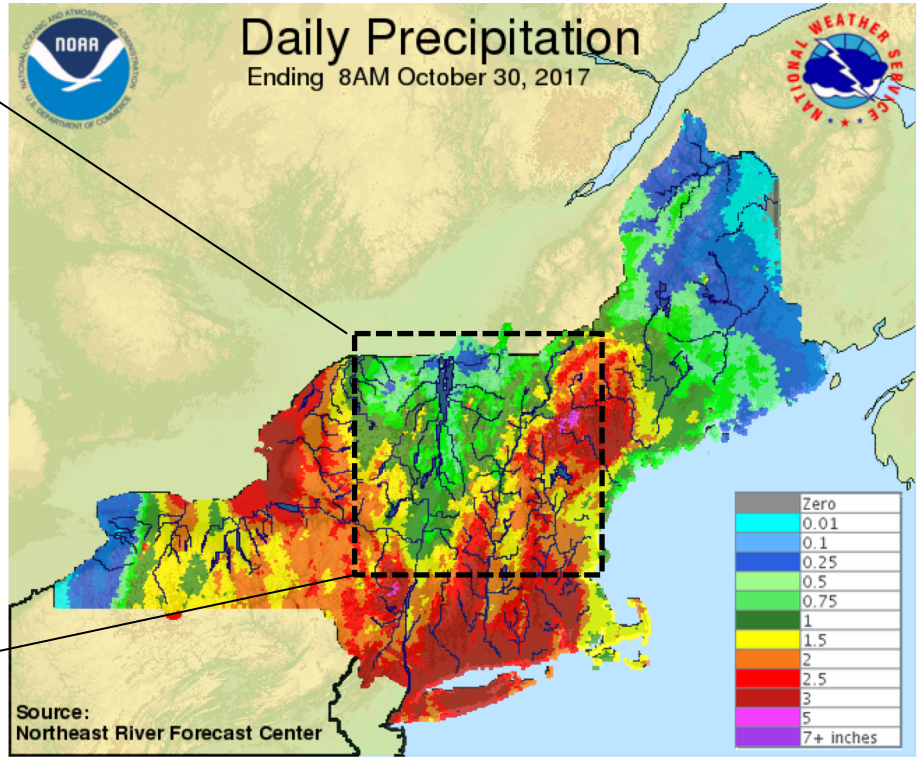
1km
Fcst: 24.00 h
Total precip. since h 6

Init: 1200 UTC Sun 29 Oct 17
Valid: 1200 UTC Mon 30 Oct 17 (0800 EDT Mon 30 Oct 17)

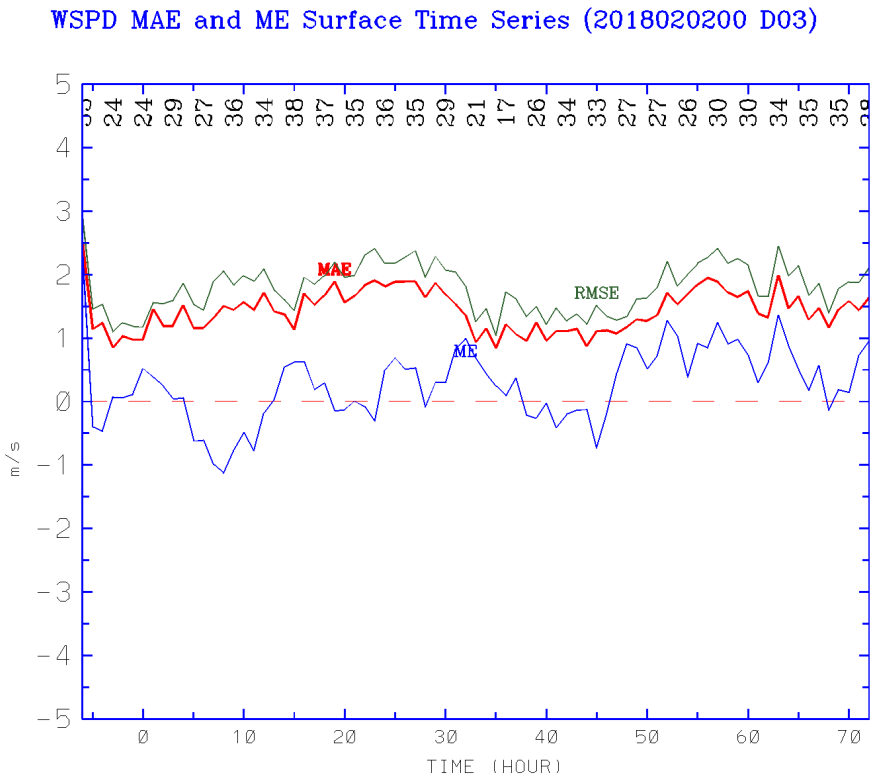


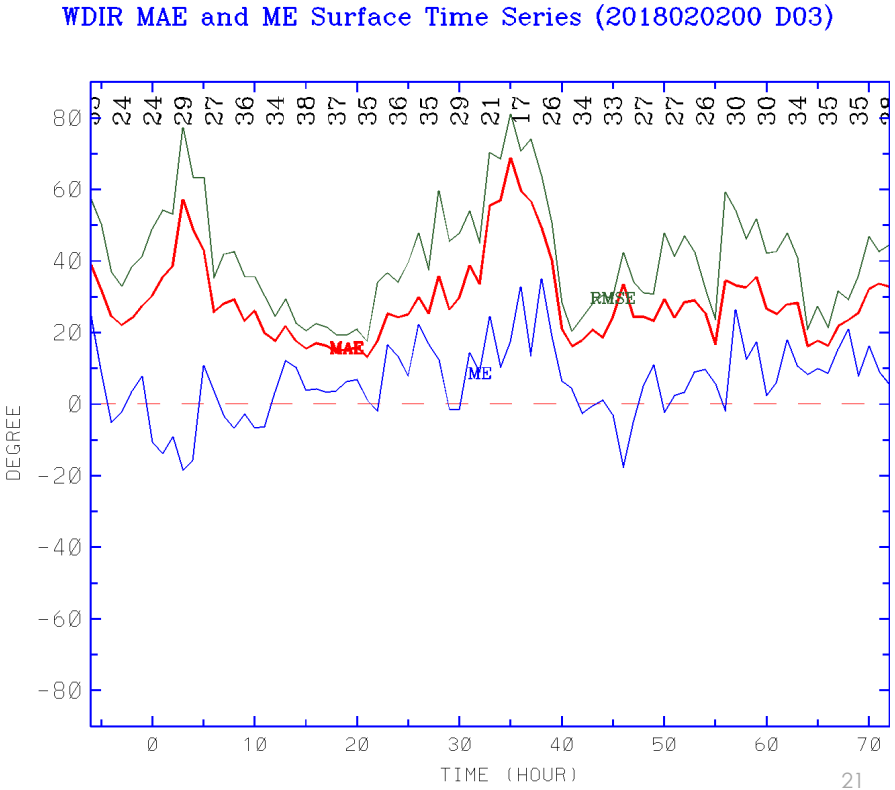


Model Info: V3.8.1 No Cu MYNN2 PB Thompson Noah LSM 1.0 km, 50 levels, 5 sec
LW: RRTM SW: RRTMG DIFF: simple KM: 2D Smagor

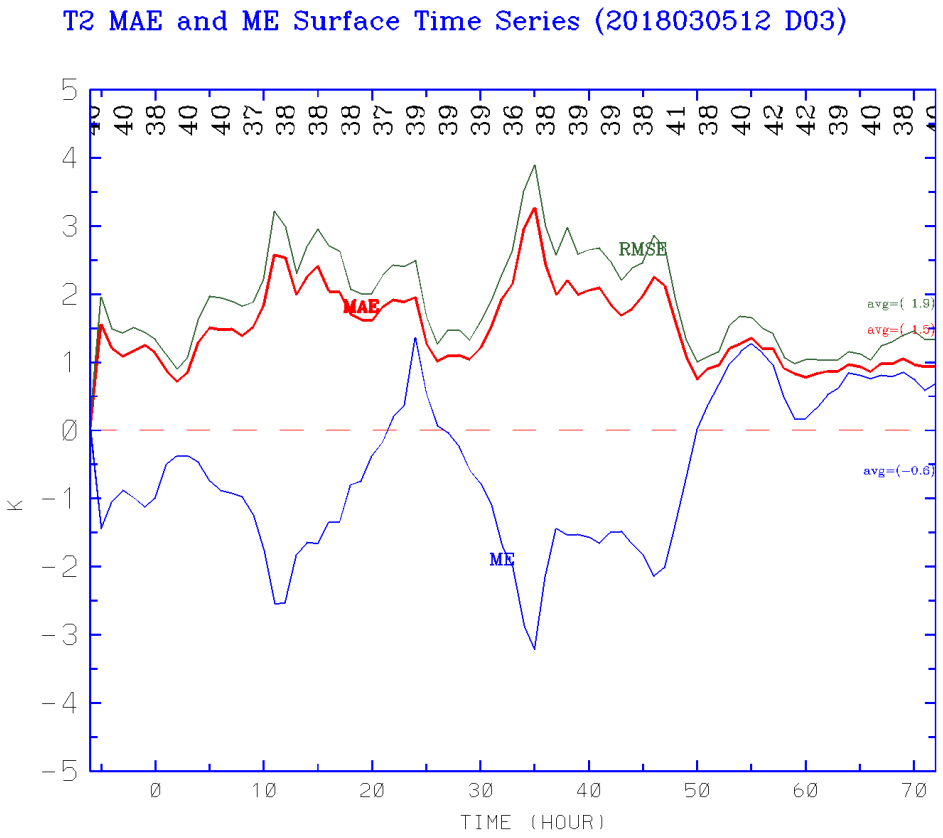


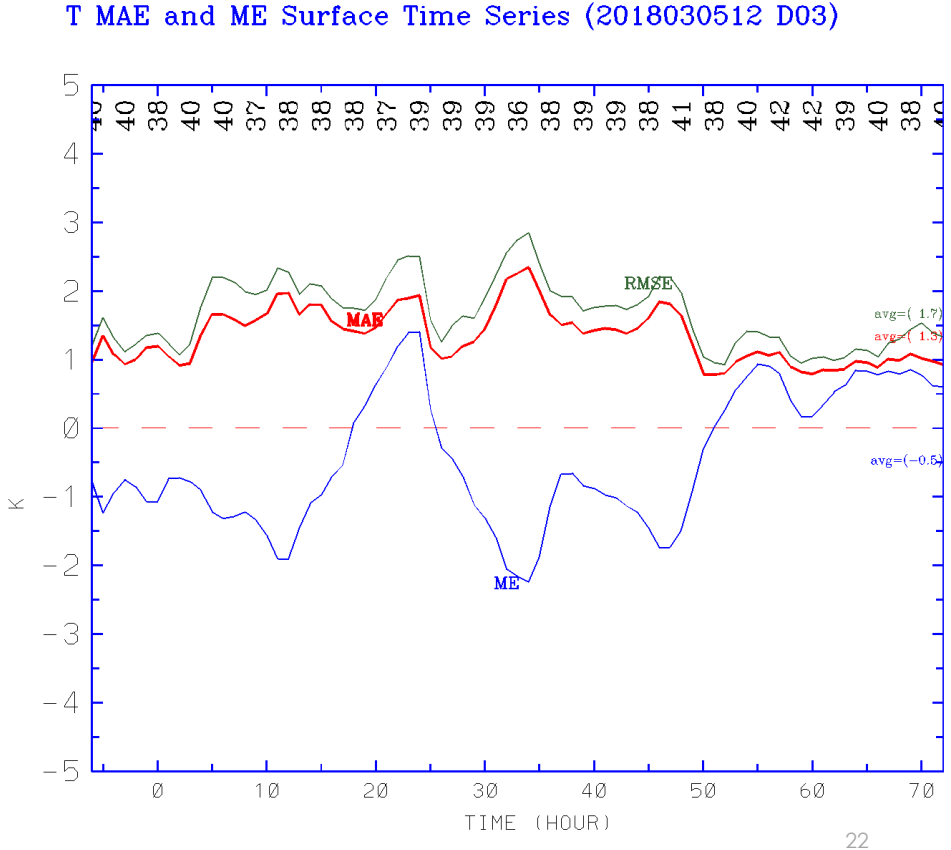
Sample Error Stats for Wind Speed and Direction on the Vermont 1-km Grid

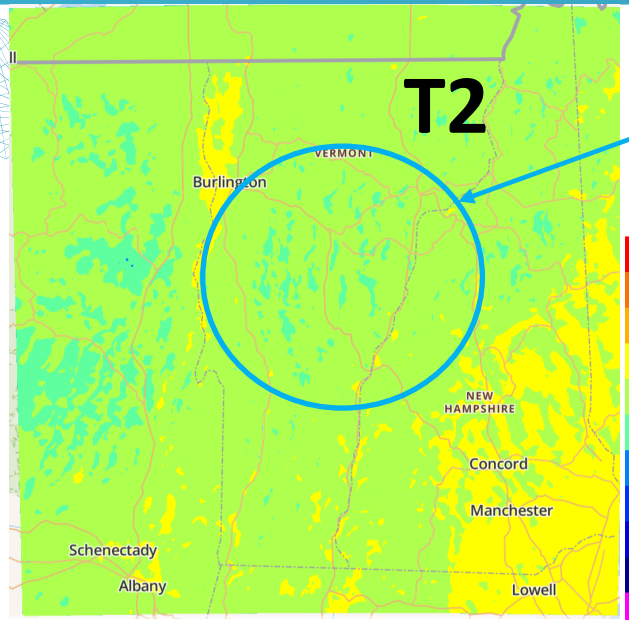




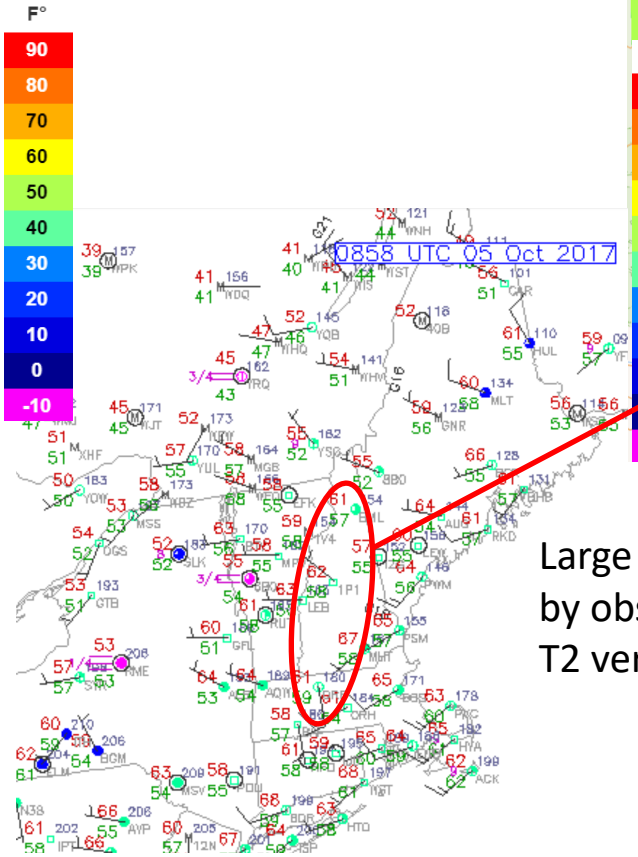
Sample Error Stats for T2 and T(1) on the Vermont 1-km Grid

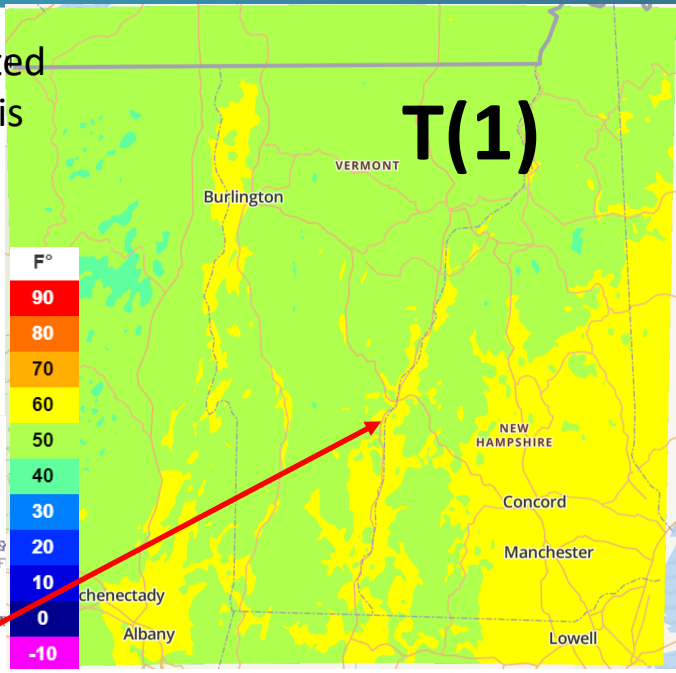






Cold patches of 40s are not supported by observations, while T(1) version is more reasonable





Large patch of 60s are well supported by observations, while not much in T2 version

Wind HyperCast

Forecasting wind power

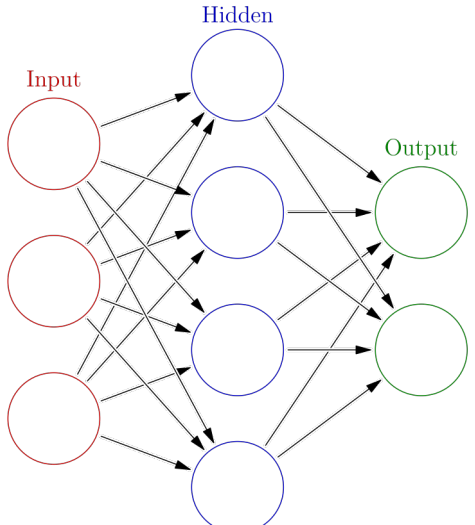
- Of each wind turbine separately or entire farm at once (depending on data)…
- 5 min. up to 10 days ahead (practically as far ahead as Nostradamus forecasts)
- Up to 5min resolution

Using deep learning (neural networks)

Nostradamus meteorological forecasts →

Recent power measurements →

Recent speed measurements →



→ power forecasts

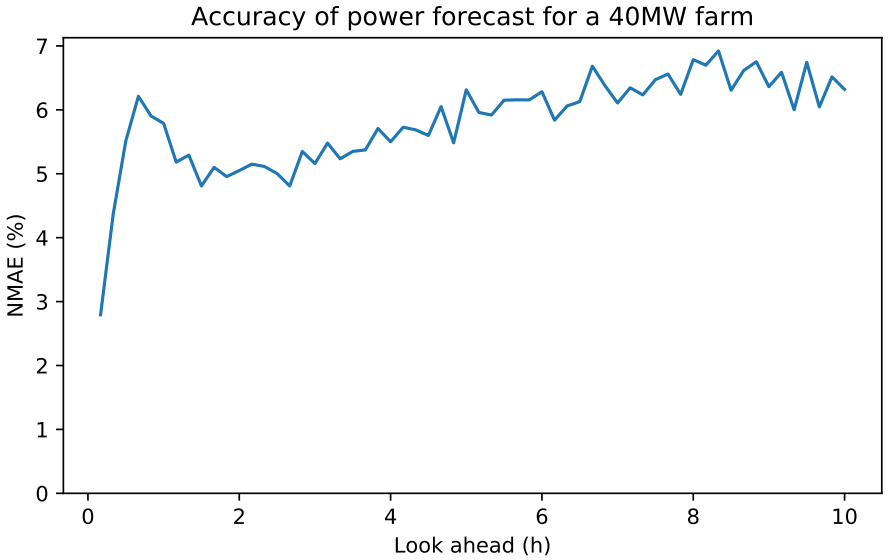
Wind HyperCast

Using recent measurements and Nostradamus-predicted weather for shorter-term forecasting

$$\text{NMAE} = \frac{100\%}{\text{capacity}} \frac{1}{m} \sum_{i=1}^{m} |f^*(X_i) - y_i|$$

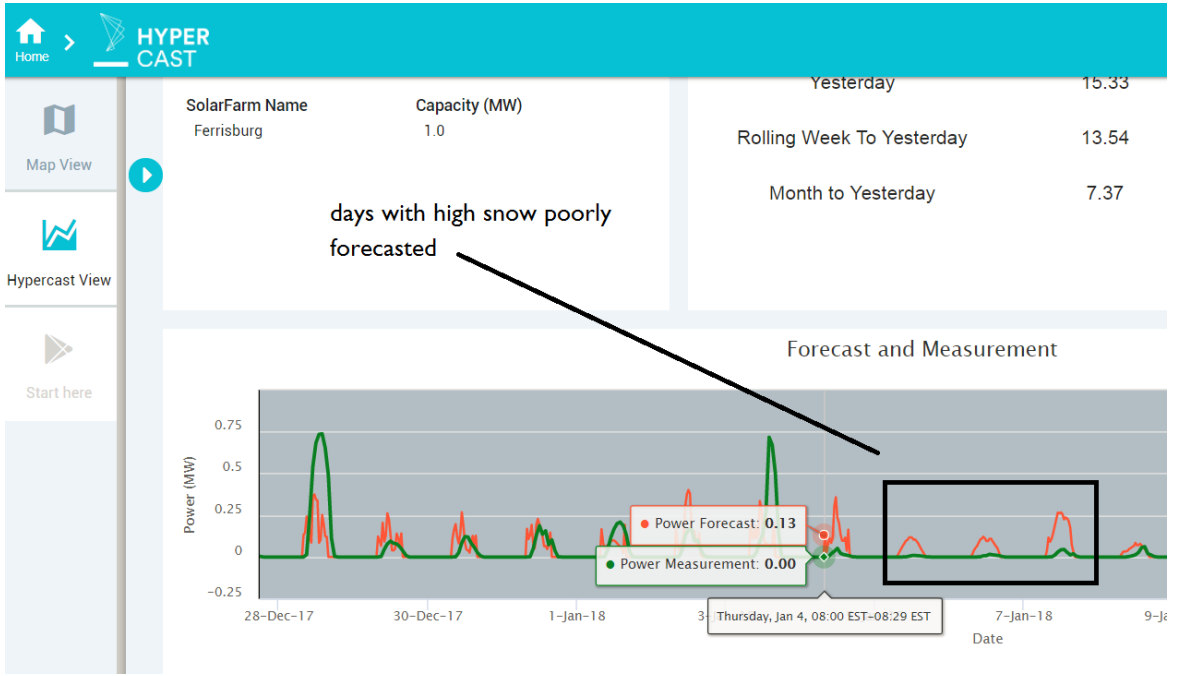
40MW farm example

NMAE < 10% up till 24h ahead



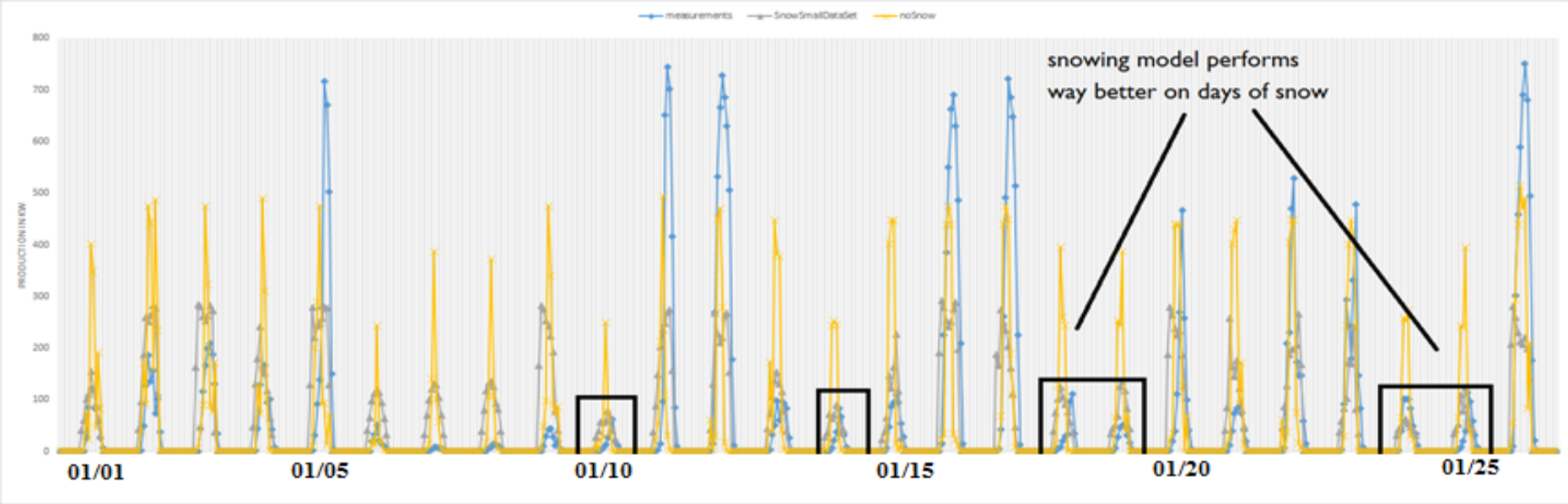
Solar HyperCast : Snow accumulation on panels lowers production

- The day of snow, and subsequent days (*before snow melts off*) usually have lesser production than what is forecasted



Solar HyperCast: Improved solutions

- Now accounts for Nostradamus-predicted snow fall amount.
- These features are in addition to the currently used solar irradiances.
- By training the models to include the mentioned features, the overall average *error in* forecasted power production has **reduced by ~ 0.5%-1% (10%+ for snow days)** for most of the farms (validation period: first 20 days of Jan 2018)
- The forecasts on the day of snow have shown significant improvements, but with degradation (under prediction) for clear-sky days.



Summary and Conclusions

- Nostradamus overall has good forecasting skills, especially for the special events for utilities
- Issues with cold bias, and with anomaly T2 at high resolution
- Wind HyperCast driven by Nostradamus accurately predicts power generation (NMAE<10% up to 24 h).
- For Solar HyperCast, including snow features improves Solar HyperCast, with degradation (under prediction) for clear sky days, needing further development.
- IO quilt is important to improved WRF timing
- Future-turbine drag effect on mesoscale winds is to be explored
- Future-possible assimilation of METMASS from wind farms
- Interested in running a global model due to our global-scale applications. Is MPAS ready?