

Forecasts on Demand for Renewable Energy and Agriculture at The Weather Company, an IBM Business

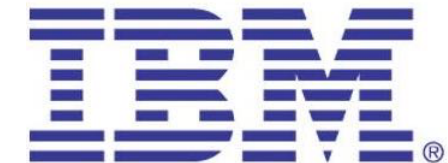
Alexander G. Kalmikov, J. K. Williams, C. S. Guiang, J. I. Belanger, J. P. Koval,
J. Juban, D. Winn, T. Crawford, H. C. Hassenzahl, and P. Neilley

The Weather Company, an IBM Business

29th Conference on Weather Analysis and Forecasting

June 6, 2018

Denver, CO

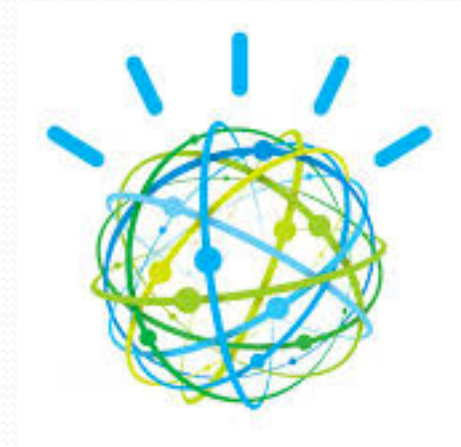


Agriculture and Renewable Energy (AgE)

Forecast Overview

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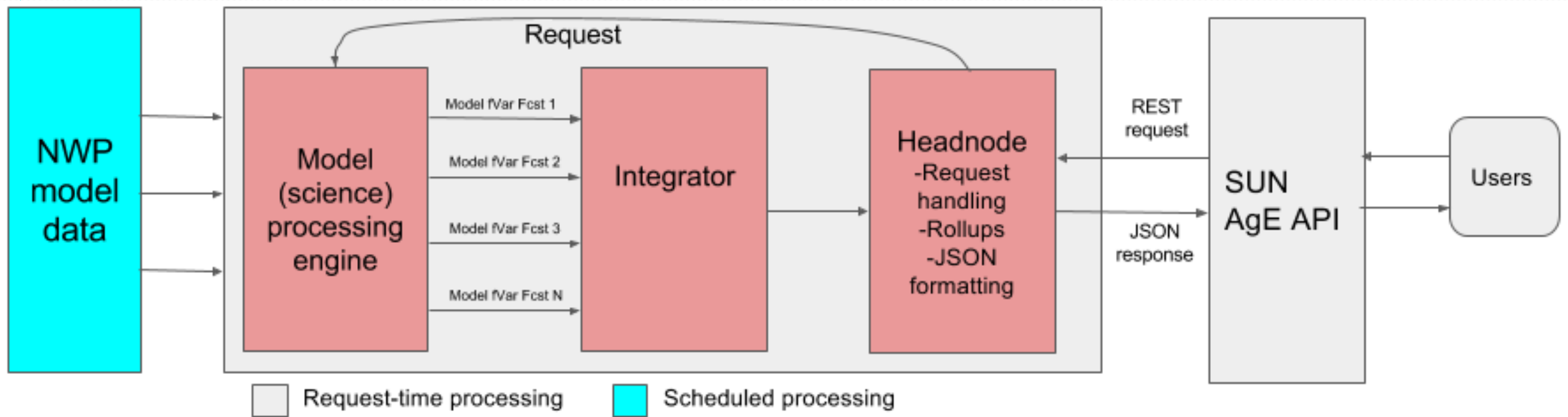
- Forecast on Demand – FOD (*Neilley et al., 2015*)
 - Custom generated at any location on earth (1km spatial resolution)
 - Blending freshest input NWP model data (forecasts not pre-produced)
 - Statistical multi-model weighted consensus and bias correction
- AgE FOD
 - 3 dimensional extension of FOD (underground and above ground profiles)
 - Use consensus weights from FOD
- Enabling:
 - Engineering applications
 - Decision analytics models



AgE Forecast on Demand Architecture

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- Diverse NWP models + proprietary IBM Deep Thunder
- Different spatial and vertical coordinates, projections, boundary conditions and parameterizations
- Heterogeneous input physical variables



- API delivery – scalable, globally distributed, public facing web services
- Cloud-based platform – highly available, robust, extremely low latency
- In-memory fast just-in-time backend science computation engine

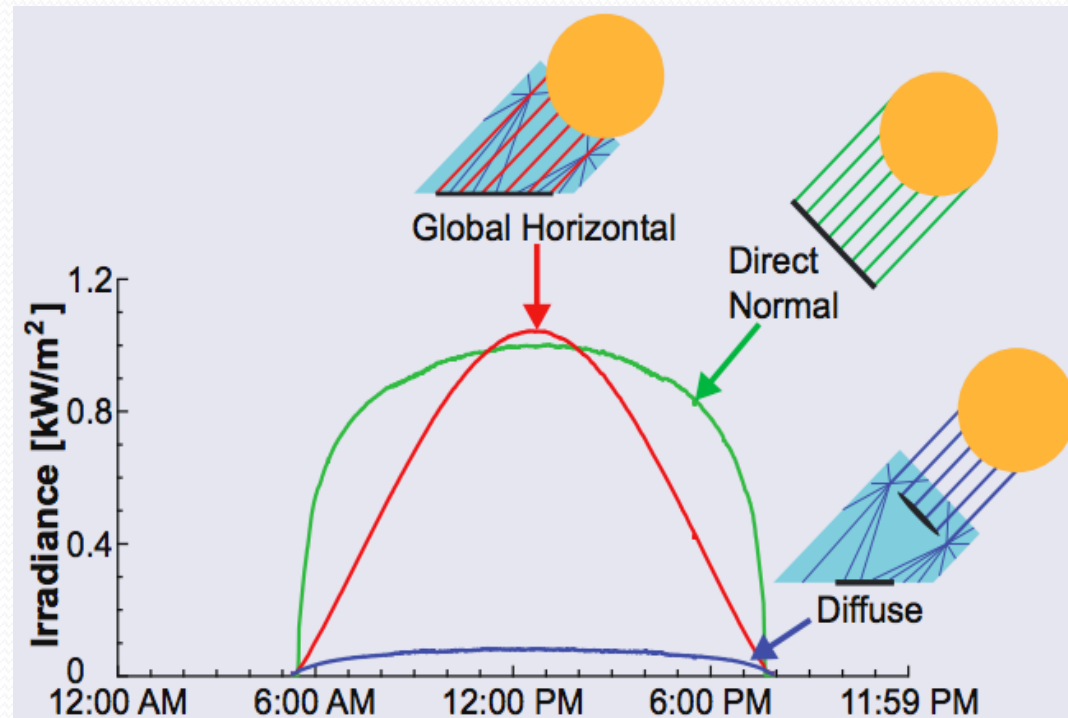
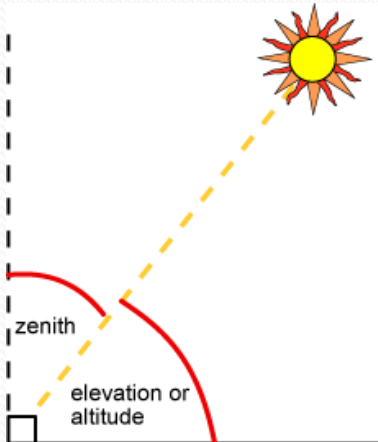
Solar Irradiance Forecast

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- Global 15-Day Hourly Forecast
- Global 7-Day 15-Minute Forecast
- **Global Horizontal Irradiance (GHI)** – total direct and diffuse (scattered) radiation through a horizontal surface
- **Direct Normal Irradiance (DNI)** – direct radiation through a plane perpendicular to the direction of the sun

$$GHI = DNI \times \cos(z) + \text{Diffuse}$$

- z : solar zenith angle

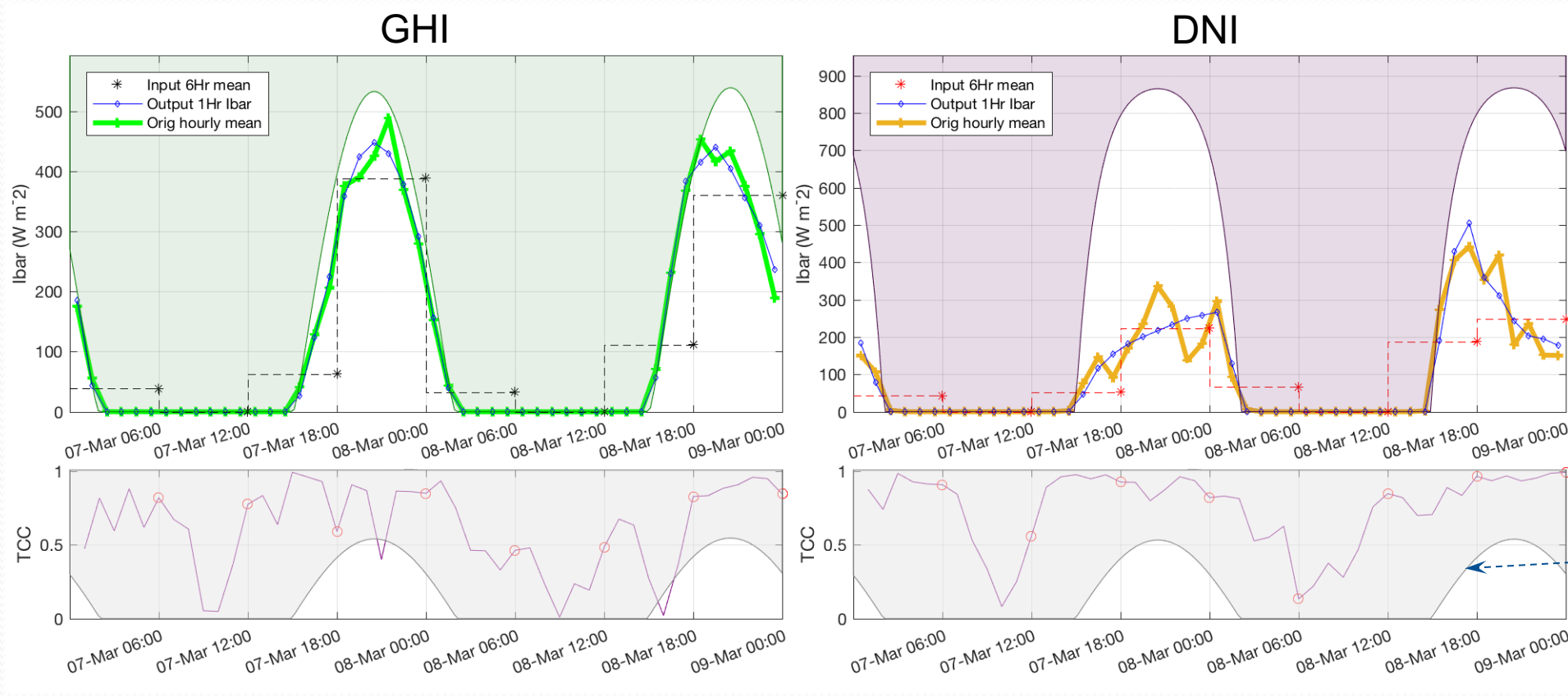


<https://energy.mit.edu/wp-content/uploads/2015/05/MITEI-The-Future-of-Solar-Energy.pdf>

Solar Irradiance Downscaling

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- Cloud cover–based governor function
- Theoretical clear sky irradiance profiles
- Energy conserving nonlinear spline smoother
- Test: aggregating hourly to 6-hourly and disaggregating back to hourly
- Result smooths out subscale variability, preserving the trend

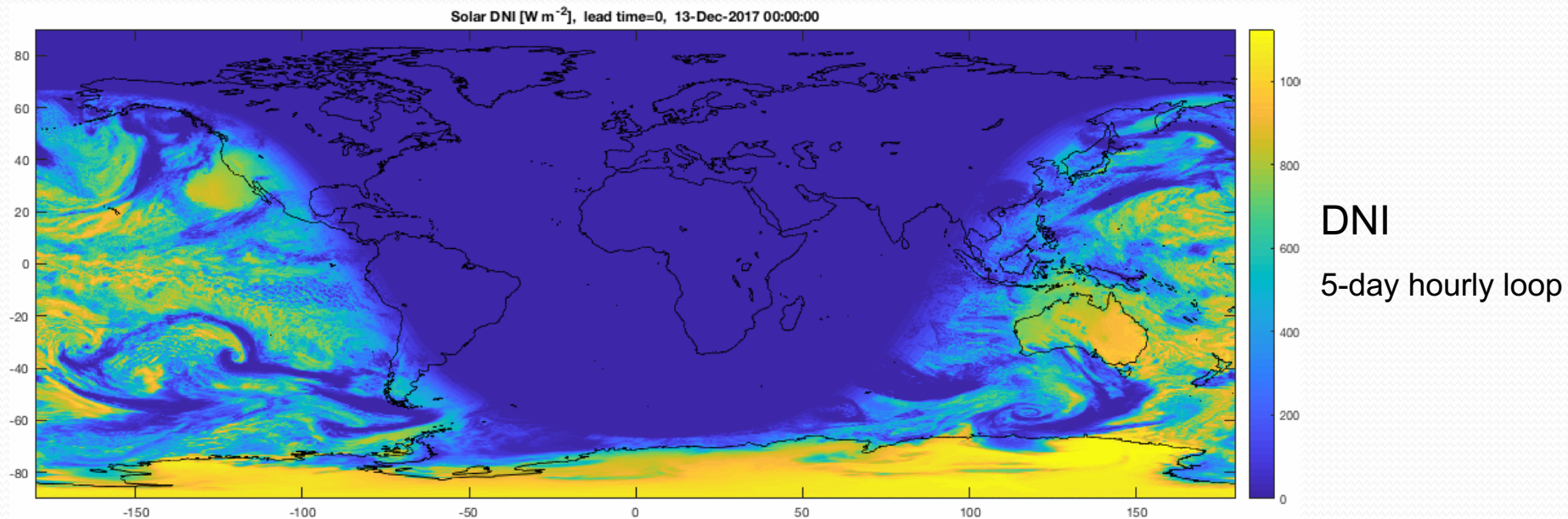
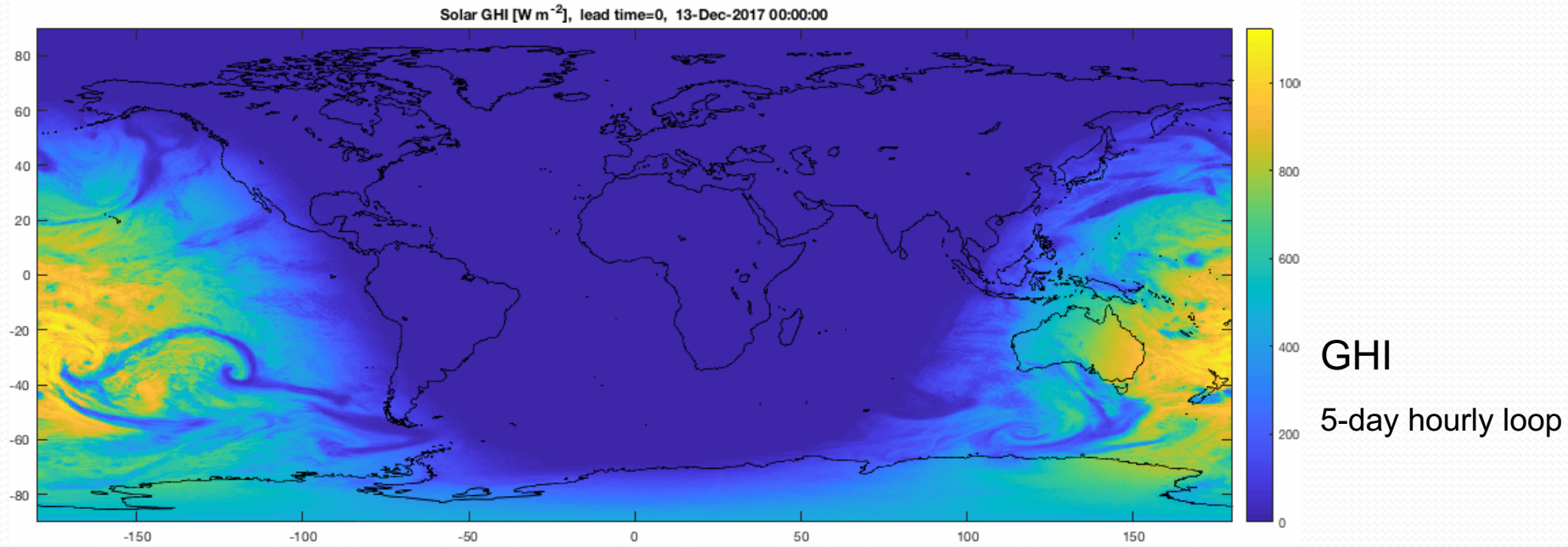


- Theoretical profiles
- 6-hourly mean
- downscaled hourly

- Total Cloud Cover (TCC)
- cos(zenith)

Global Solar Forecast Maps

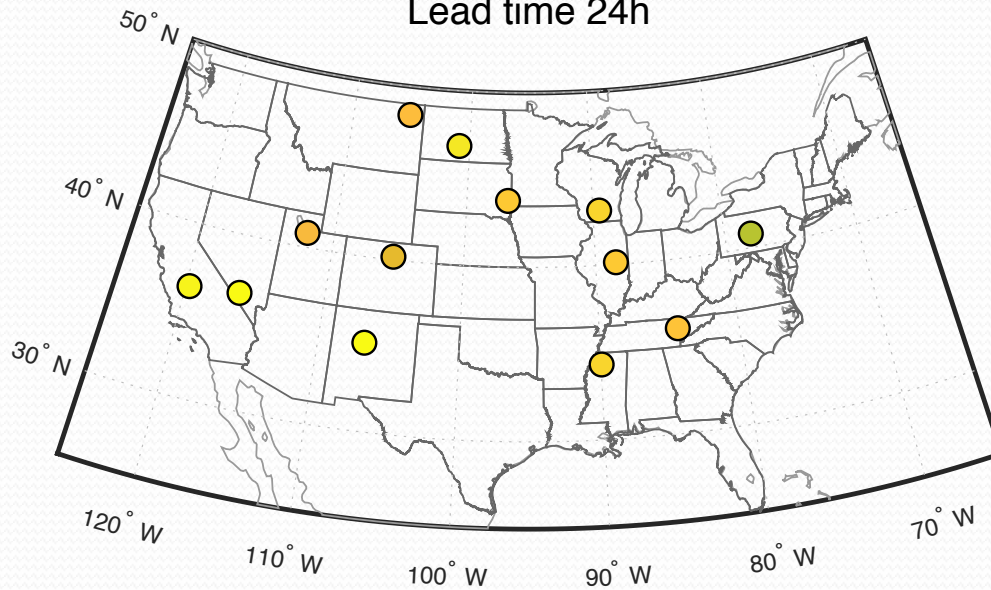
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Verification of Hourly Solar Forecast

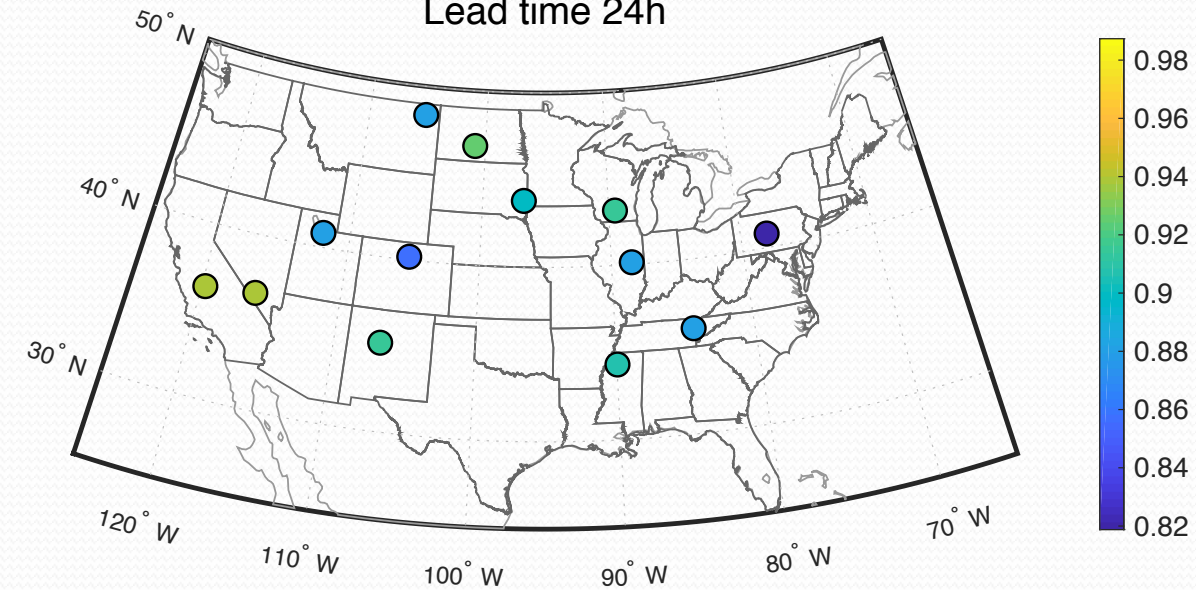
- Correlations with SURFRAD (Surface Radiation Network) observations
- Correlations with SOLRAD (formerly ISIS) observations

SURFRAD, SOLRAD GHI forecast vs. obs correlation
Lead time 24h



GHI

SURFRAD, SOLRAD DNI forecast vs. obs correlation
Lead time 24h



DNI

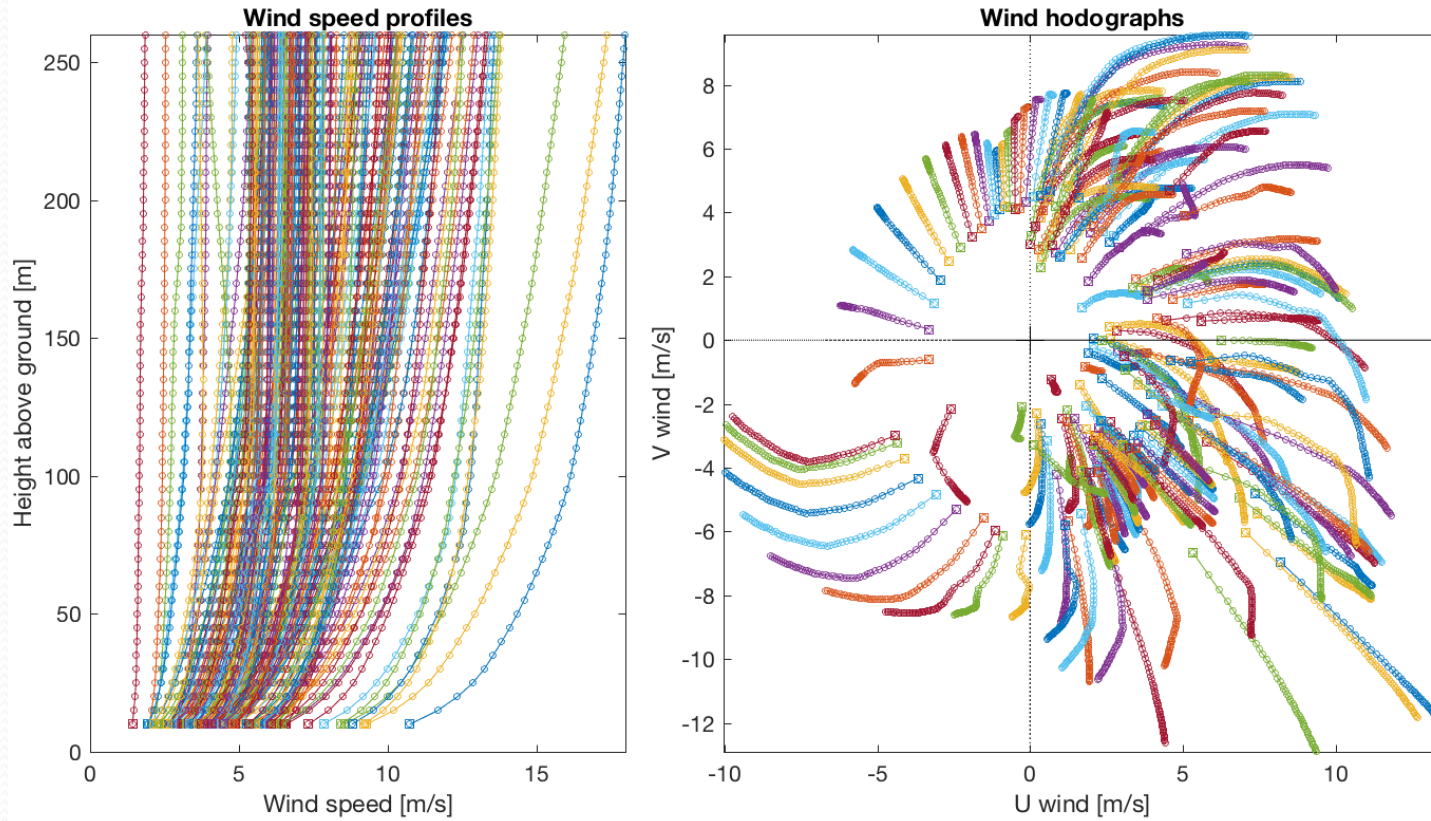
Analysis period: April 2018

Wind Forecast

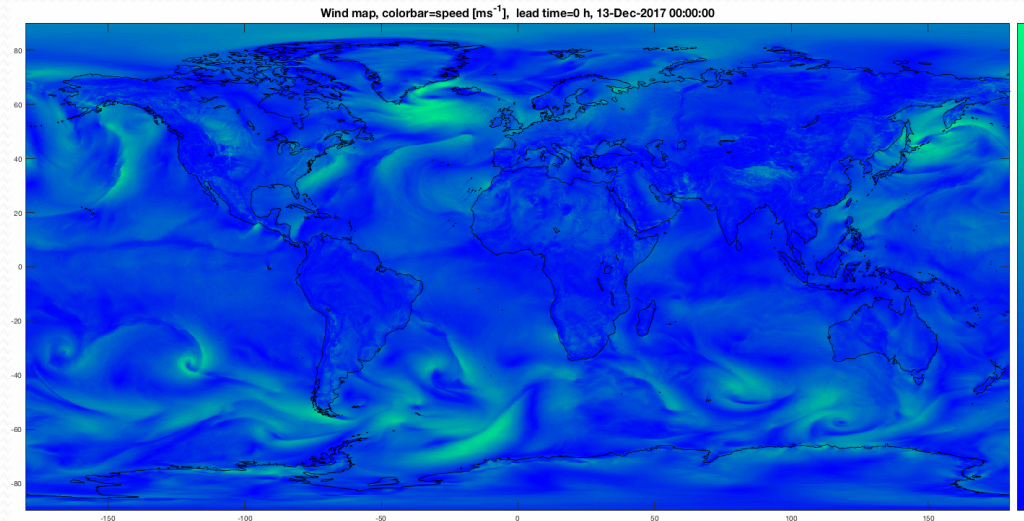
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- Global 15-Day Hourly Forecast, at any height from 10m–260m above ground
 - **Wind Speed, Wind Direction, Moist Air Density**
 - User can specify ground elevation

Wind vector profile evolution (over 15 days at single site)



Wind speed map (50m agl)



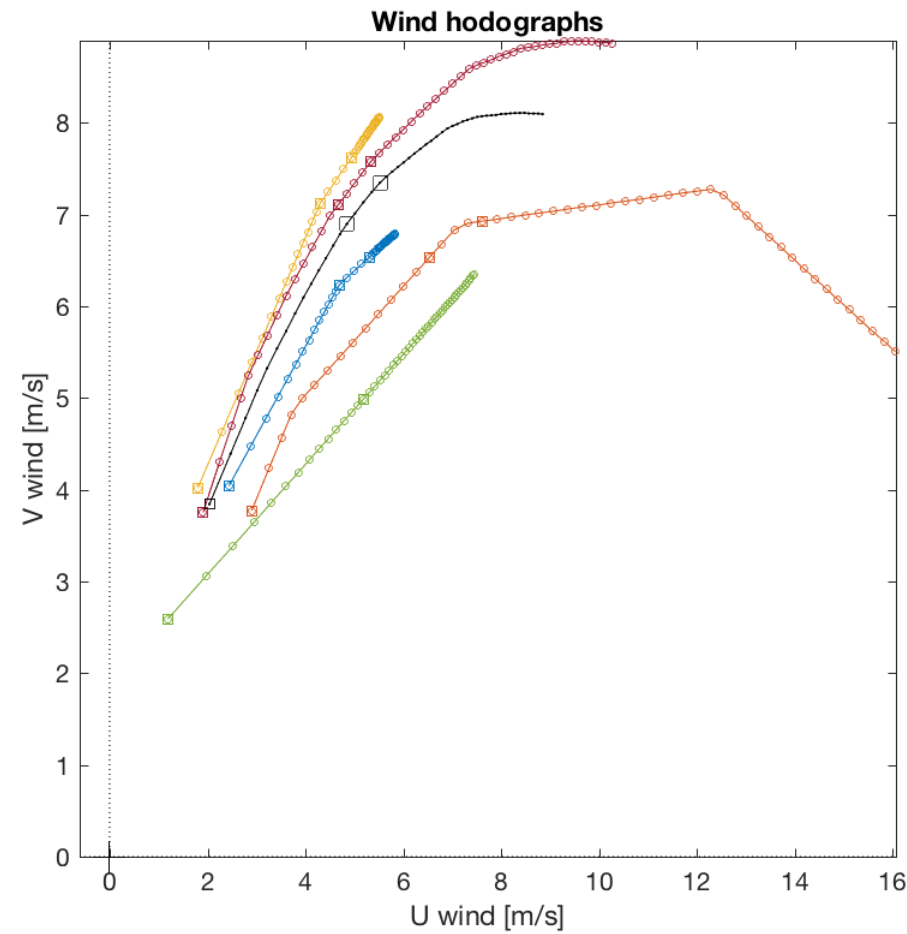
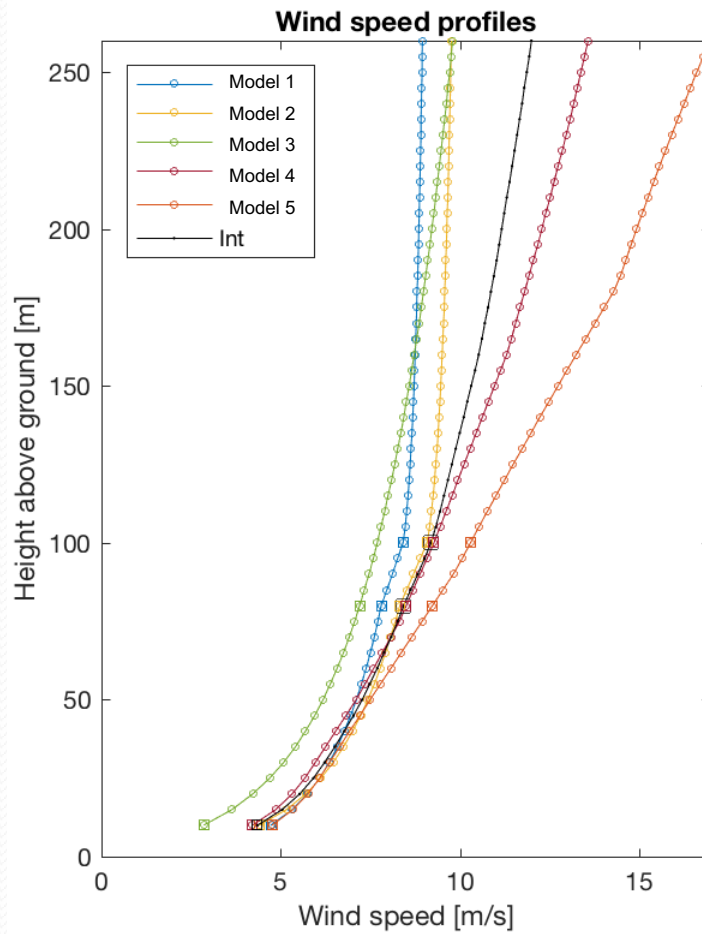
Wind vector profile downscaling

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- Logarithmic profile of wind speed and vector components
- Displacement height tuning via nonlinear regression
- Shear and veer conserving piecewise log-linear vertical interpolation
- Ensemble averaging: wind vector averaging (linear) and wind speed averaging (nonlinear)

$$u_z = \frac{u_*}{\kappa} \left[\ln \left(\frac{z - d}{z_0} \right) \right]$$

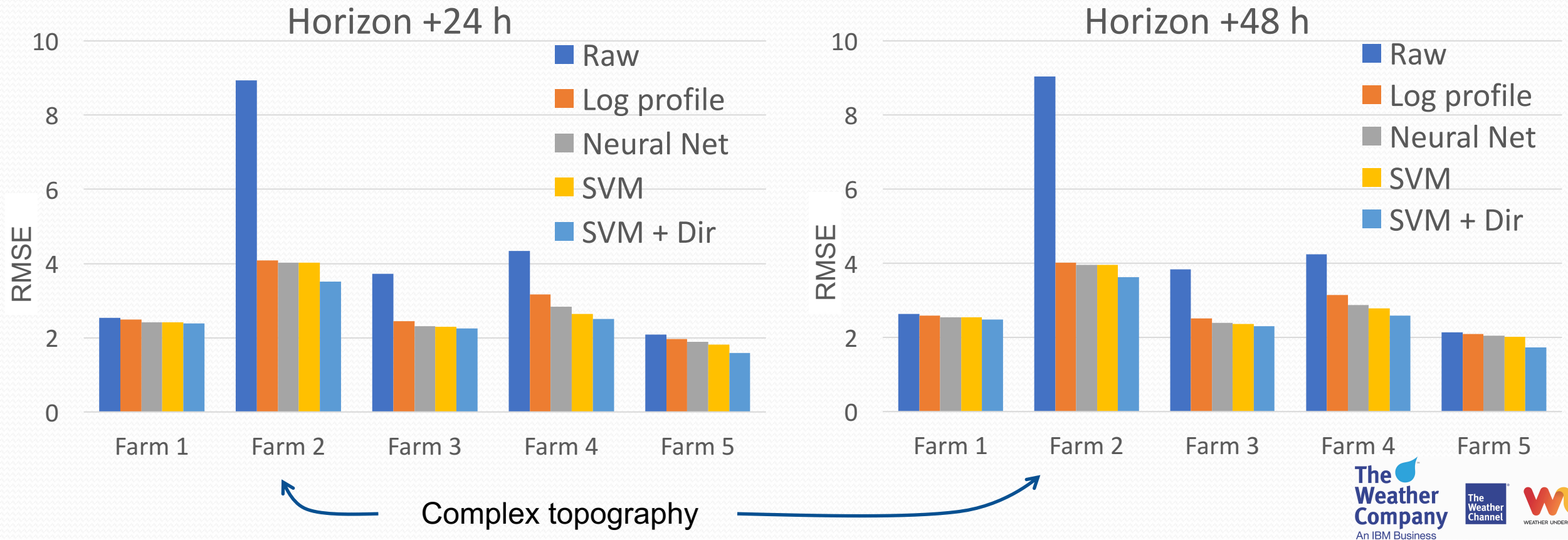
- Integration of lagged modules
- Ekman spiral veer preserved in the integrated profile



Hub-Height Wind Speed Statistical Correction

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- Logarithmic profile correction (multiplicative factor)
- Non-parametric MOS (Machine Learning) correction:
 - Neural Net: feedforward with one hidden layer
 - Support Vector Machine (SVM) regression: speed only
 - Support Vector Machine (SVM) regression: speed+direction



Moist Air Density Forecast

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- Moist air is lighter than dry air

$$\rho_{moist} = \frac{P}{R_d \cdot T_v}$$

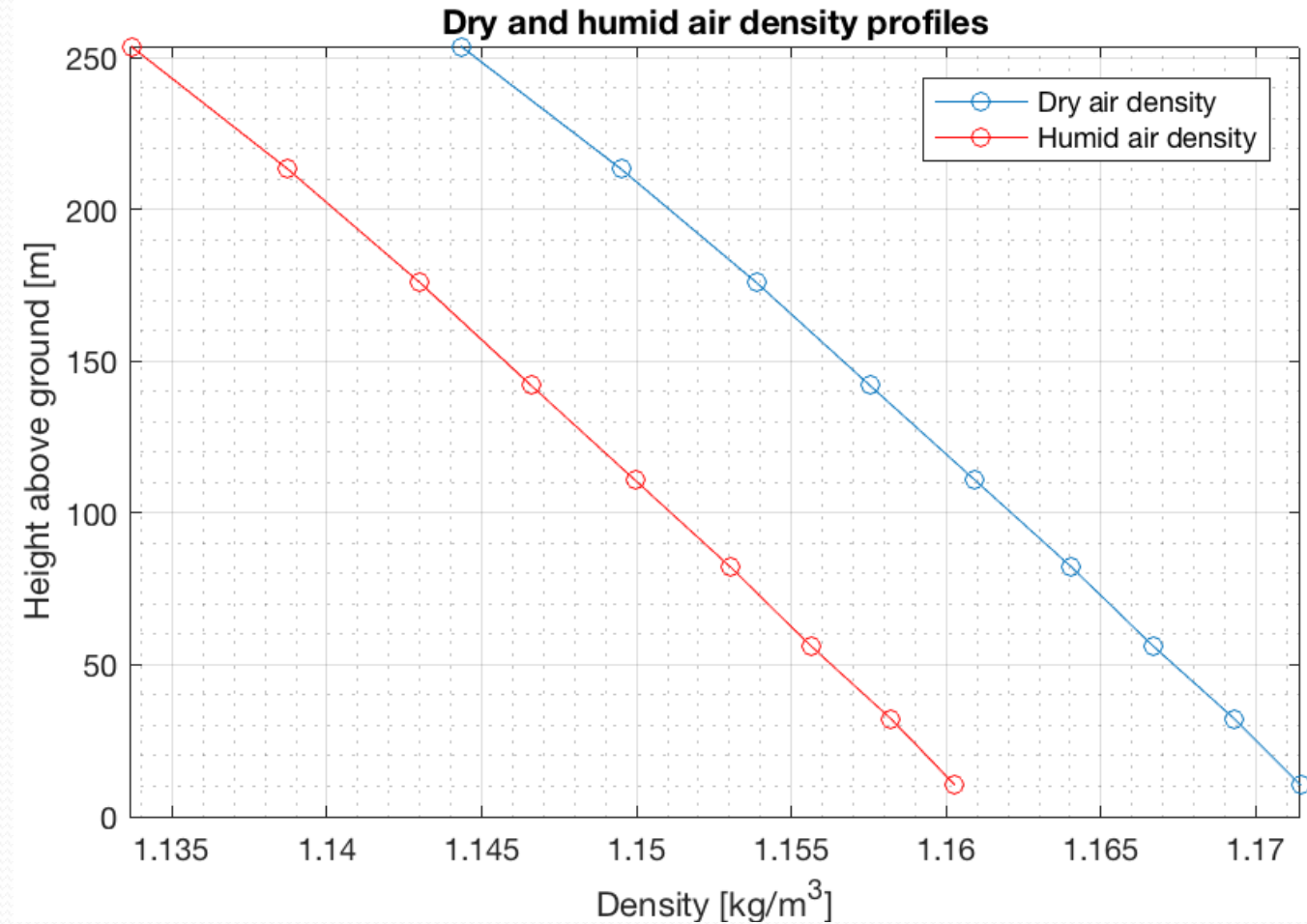
- Virtual temperature, linearized

$$T_v = T(1 + 0.608 \cdot Q)$$

- Density profile governor function:

$$\rho = \rho_0 \left[\frac{T_0 - \Gamma z}{T_0} \right]^{\left(\frac{g}{R_d \Gamma} - 1 \right)}$$

- Piecewise fixed lapse rate density profile
- Reconstructing density profile
- Correcting for model vs. actual surface elevation mismatch

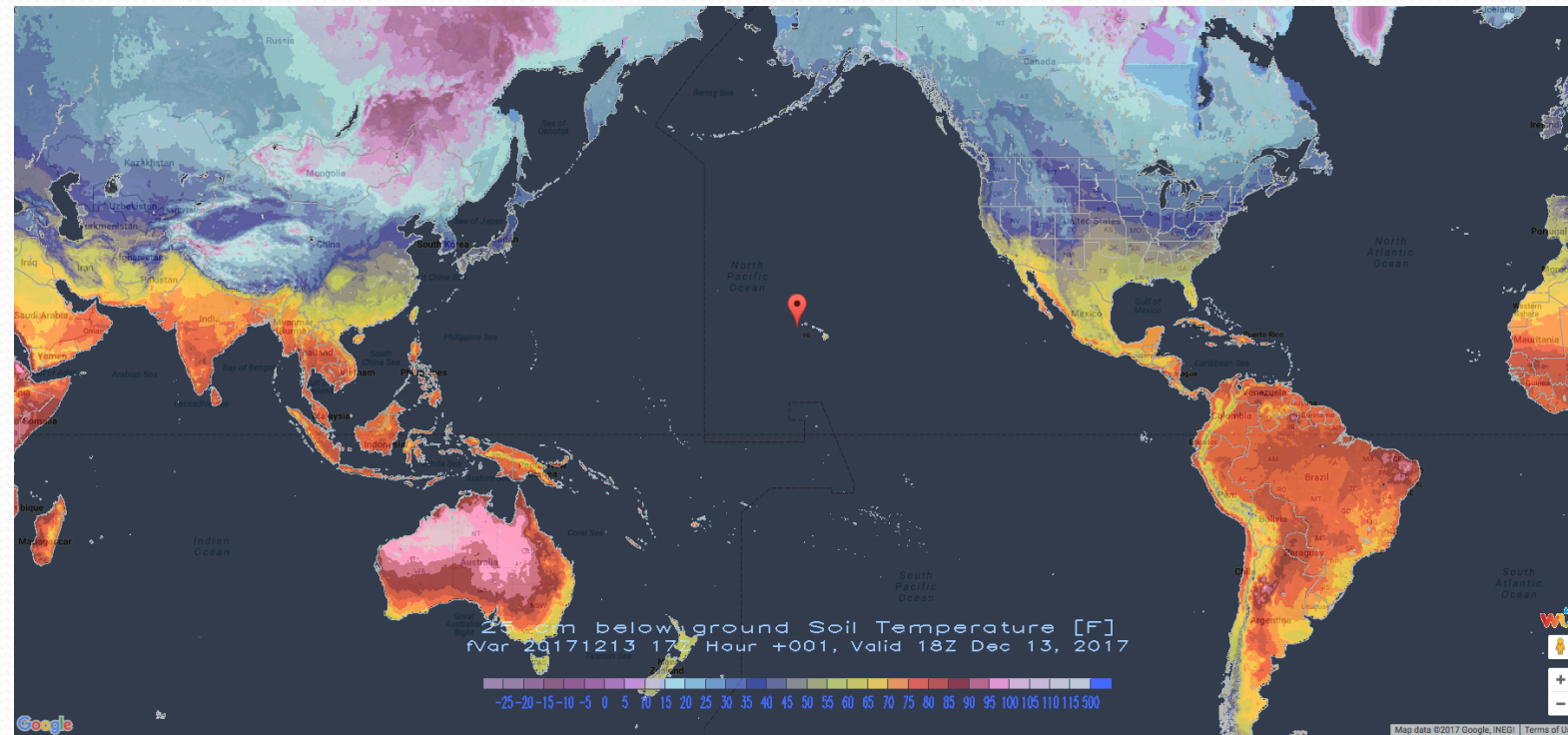


Agriculture Forecast

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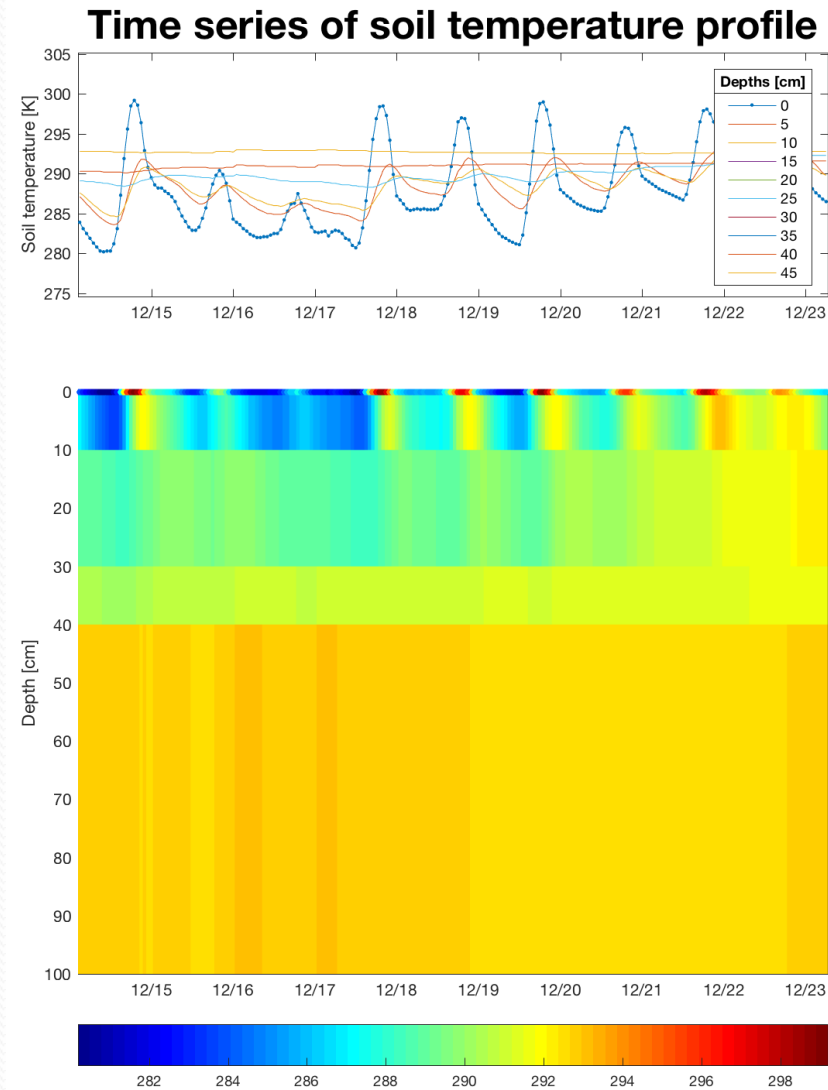
- Global 15-Day Hourly Forecast
- **Evapotranspiration**
 - Reference evapotranspiration (ET_0)
 - Crop-specific reference evapotranspiration (ET_c)
 - Model evapotranspiration (ET_m)
- **Soil Moisture**
- **Soil Temperature**
 - at any depth up to 200 cm below the surface

Soil Temperature at 25 cm depth

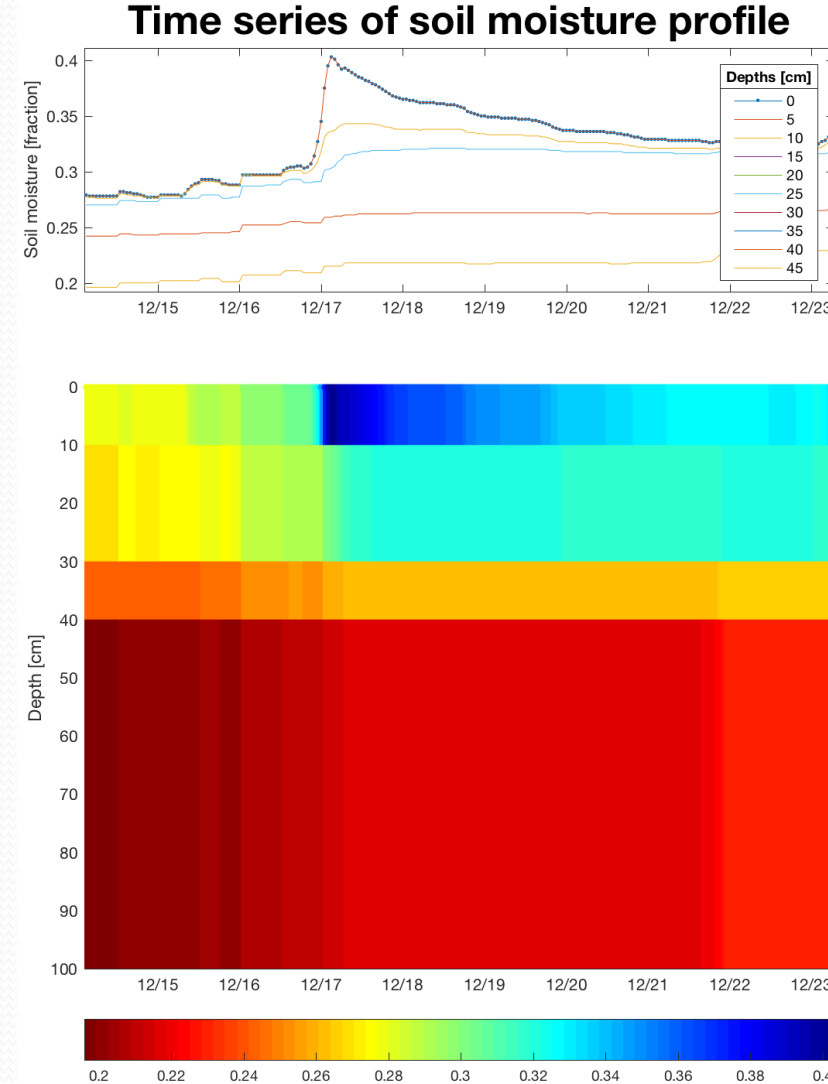


Soil Temperature and Moisture Profiles Evolution

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- Stronger diurnal cycle near the surface
- Downward diffusion of surface signal



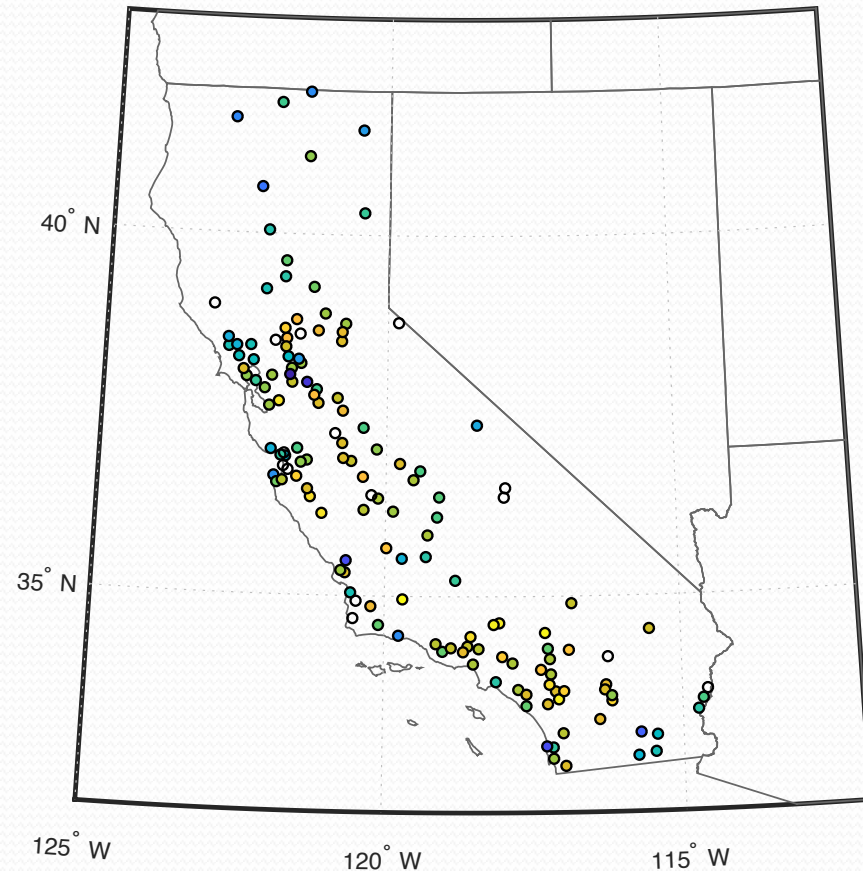
- Singular rain event near the surface
- Downward diffusion of surface signal

Verification of Agriculture Forecast

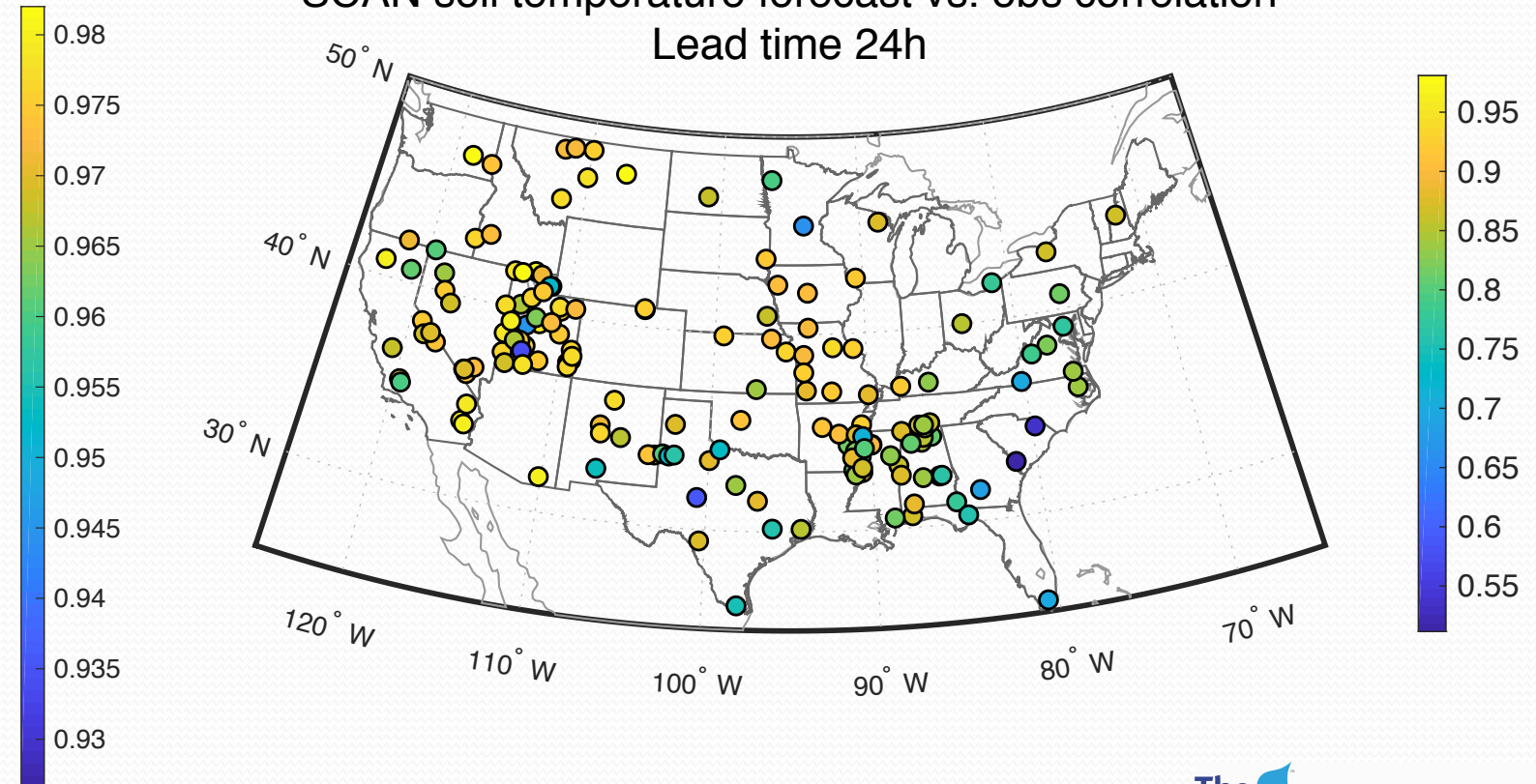
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- Reference evapotranspiration (ET_0) at CIMIS (California Irrigation Management Information Systems)
- Soil temperature (2 inch deep) at SCAN (Soil Climate Analysis Network)

CIMIS ET_0 forecast vs. obs correlation
Lead time 24h



SCAN soil temperature forecast vs. obs correlation
Lead time 24h



Analysis period: April 2018

Summary: Agriculture and Renewable Energy FOD

- Operationally available since July 2017
- Solar Energy, Global 15-Day Hourly, 7-Day 15-Minute Forecast
 - **Global Horizontal Irradiance (GHI)**
 - **Direct Normal Irradiance (DNI)**, only 10-Days
- Wind Energy, Global 15-Day Hourly Forecast
 - **Wind Speed, Wind Direction**, and **Air Density** at any height [10m–260m] above ground
- Agriculture, Global 15-Day Hourly Forecast
 - **Soil Moisture, Soil Temperature** at any depth up to 200cm below the surface
 - **Reference evapotranspiration (ET₀)**
 - **Crop-specific reference evapotranspiration (ET_c)**
 - **Model evapotranspiration (ET_m)**

Target applications

- Wind and solar renewable energy: grid integration, power trading, congestion management
- Precision agriculture: site specific crop management, smart agronomics

Questions



Crop Types

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Utility API

<https://api.weather.com/v3/wx/forecast/agriculture/croptype?apiKey=yourApiKey>

Cacao	BananaYear1	Canola	EggPlant	Oats	Radish	Sweetmelon
Coffee	BananaYear2	Cantaloupe	Fababean	Olives	Rapeseed	SweetPeppers
Corn	Barley	Carrots	Flax	OnionDry	Rice	SweetPotato
Cotton	BeanDry	CassavaYear1	Garbanzo	OnionGreen	RubberTrees	Tea
Soybeans	BeanGreen	CassavaYear2	Garlic	OnionSeed	Safflower	TeaShaded
Sugarcane	Beets	CastorBeans	GrainsSmall	PalmTrees	Sesame	Tomato
Wheat	BellPeppers	Cattails	Grapes	Parsnip	Sisal	TurfGrassCool
AlfalfaHay1stCut	BermudaHay	Cauliflower	GreenGram	Peaches	SorghumGrain	TurfGrassWarm
AlfalfaHayOtherCut	BermudaSeed	Celery	Groundnut	Pears	Spinach	Turnip
Almonds	Berries	Cherries	Hops	Peas	Squash	Walnuts
Apples	Broadbean	Chickpea	Kiwi	Pecans	Sudan1stCut	Watermelon
Apricots	BroadbeanDry	Citrus	Lentil	Pineapple	SudanOtherCut	Wetlands
ArtichokeYear1	Broccoli	CornSweet	Lettuce	Pistachios	Sugarbeet	WetlandsShort
ArtichokeYear2	BrusselSprouts	Cowpeas	MaizeGrain	Plums	SugarcaneRatoon	WinterSquash
Asparagus	Bulrush	Cucumber	MaizeSweet	Potato	SugarcaneVirgin	WinterWheat
Avocado	Cabbage	DatePalms	Millet	Pumpkin	Sunflower	Zucchini

Solar API

<https://api.weather.com/v3/wx/forecast/hourly/energysolar/15day?geocode=33.74,-84.39&format=json&units=m&apiKey=yourApiKey>

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}
```

Wind API

<https://api.weather.com/v3/wx/forecast/hourly/energywind/15day?geocode=33.74,-84.39&format=json&units=m&height=260.0&elevation=7777.0&apiKey=yourApiKey>

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