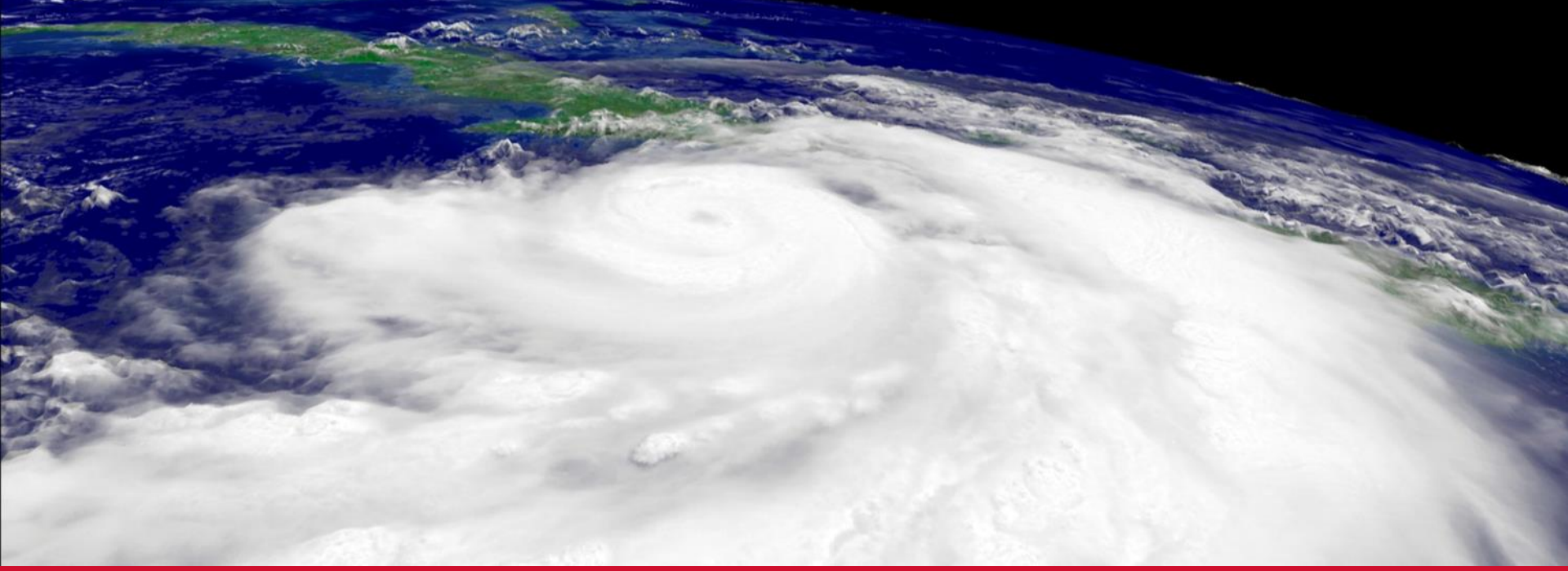


INDUSTRY TRENDS & CAPABILITIES IN NWP

MARIA PIRONE

Sr. Business Development Manager, Environmental Solutions

Space & Intelligence Systems

HARRIS® TECHNOLOGY TO CONNECT, INFORM AND PROTECT™

Acknowledgements

This presentation is a compilation of material from leaders in the modeling, HPC & remote sensing communities as noted below-

Arakawa A., J.-H. Jung and C.-M. Wu, 2010: Toward unification of general circulation and cloud-resolving models. In *Proceedings of ECMWF workshop on non-hydrostatic modelling*, 8-10 November, 2010, 18 pp.

Arakawa, A., J.-H. Jung, and C. M. Wu, 2011: Toward Unification of the Multiscale Modeling of the Atmosphere. *Atmospheric Chemistry and Physics*, **11**,3731-3742.

Arakawa, A., and C.-M. Wu, 2013: A Unified Representation of Deep Moist Convection in Numerical Modeling of the Atmosphere. Part I. *J. Atmos. Sci.*, **70**,1977–1992.

Wu, C.-M., and A. Arakawa, 2014: A Unified Representation of Deep Moist Convection in Numerical Modeling of the Atmosphere. Part II. *J. Atmos. Sci.*, **71**,2089–2103.

Randall, Dave, 2015: Gliding into the Grey Zone, Proceedings of the ICAS2015 Conference in Annecy, France.

Randall, D. A., M. Khairoutdinov, A. Arakawa, and W. Grabowski, 2003: Breaking the cloud-parameterization deadlock. *Bull. Amer. Meteor. Soc.*, **84**, 1547-1564.

Arakawa, A., 2004: The Cumulus Parameterization Problem: Past, Present, and Future. *J. Climate*, **17**, 2493-2525.

Jung, J.-H., and A. Arakawa, 2005. Preliminary Tests of Multiscale Modeling with a Two-Dimensional Framework: Sensitivity to Coupling Methods. *Mon. Wea.Rev.*, **133**, 649-662.

Jung, J.-H., and A. Arakawa, 2010: Development of a Quasi-3D Multiscale Modeling Framework: Motivation, basic algorithm and preliminary results. *J. Adv. Model. Earth Syst.*, Vol. 2, Art. #11, 31 pp.

Arakawa, A., J.-H. Jung, and C. M. Wu, 2011: Toward Unification of the Multiscale Modeling of the Atmosphere. *Atmospheric Chemistry and Physics*, **11**,3731-3742.

Jung, J.-H., and A. Arakawa, 2016: Simulation of Subgrid Orographic Precipitation with a 2-D Cloud-Resolving Model Embedded in a Coarser 3-D Grid. Submitted for publication.

Jung, J.-H. and A. Arakawa, 2014: Modeling the moist-convective atmosphere with a Quasi-3-D Multiscale Modeling Framework (Q3D MMF). *J. Adv. Model. Earth Syst.*, **6**, 185-205.

Arakawa, A., and J.-H. Jung, 2011: Multiscale modeling of the moist-convective atmosphere -- A review. *Atmos. Res.*, **102**, 263-285.

Rothfusz, L, P. Schlatter, et al, 2016: A Future Watch/Warning Concept: Forecasting a Continuum of Environmental Threats (FACETs)

IDC Reports, 2015

Special thanks to the folks at Earthcast Technologies and Penguin Computing for providing sample model data and information about the HPC Cloud market.

prologue

"May you live in interesting times." Confucius

Well, we live in interesting times….

There is a modestly paced paradigm shift underway in our Modeling Community, influenced by unrelated external factors coming together at the same time.

This isn't a bad situation, it isn't a setback for the Weather Enterprise, or the industries that depend on NWP and weather forecasts.

We haven't experienced anything of this magnitude in the past 25 years and will probably not experience it again, quite so dramatically, in another 25 years.

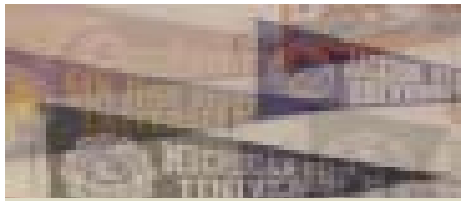
As critical users of forecast products, this presentation is meant to give you insight and guidance in determining how to navigate through this change and, perhaps, how to optimize your access to the weather information you need.

Changing NWP Landscape

Industry offerings now include products and output from their own model runs--

Government

Academia



UCAR, NCAR and the UCAR Universities.

Industry

AccuWeather

EARTHCAST TECHNOLOGIES

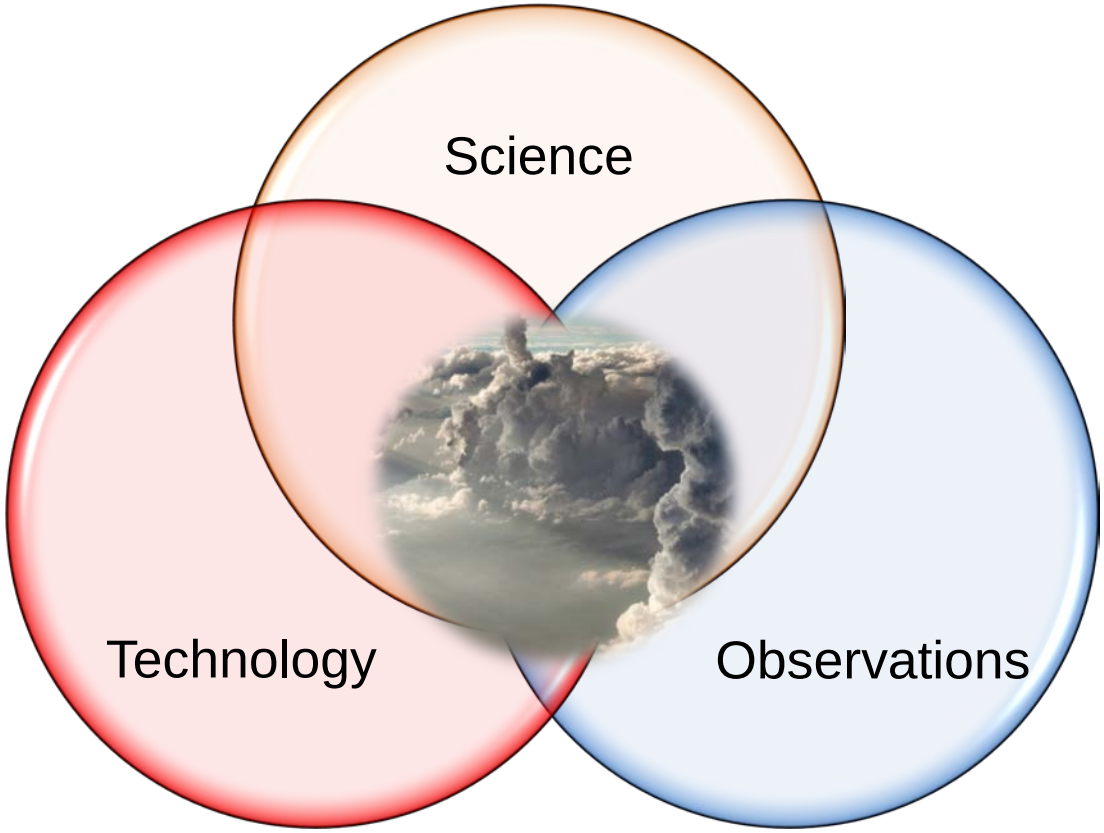
Panasonic

spire

TempoQuest

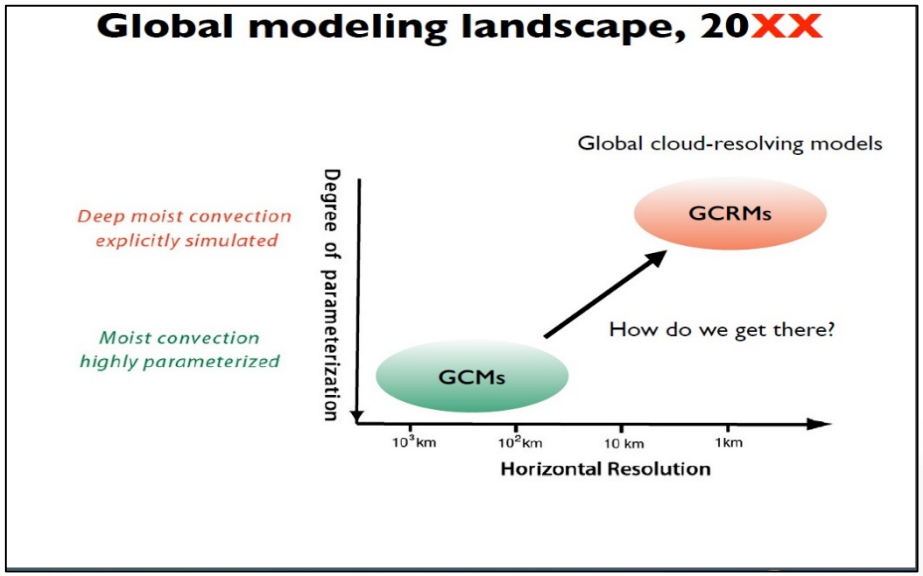
The Weather Company
An IBM Business

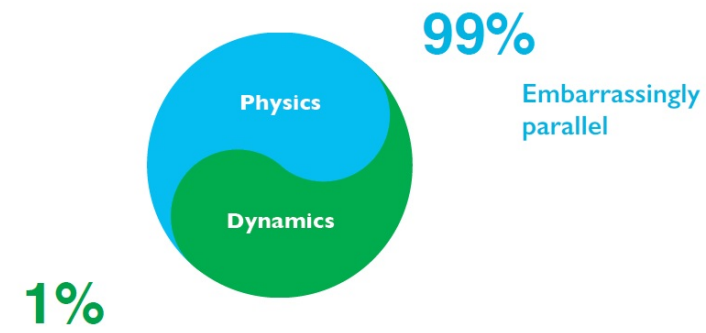
What are the drivers influencing NWP?



NWP or Model Performance is influenced by advances in Atmospheric Science, HPC Technology and Earth Observations in concert with one another.

Science: What's holding us back?





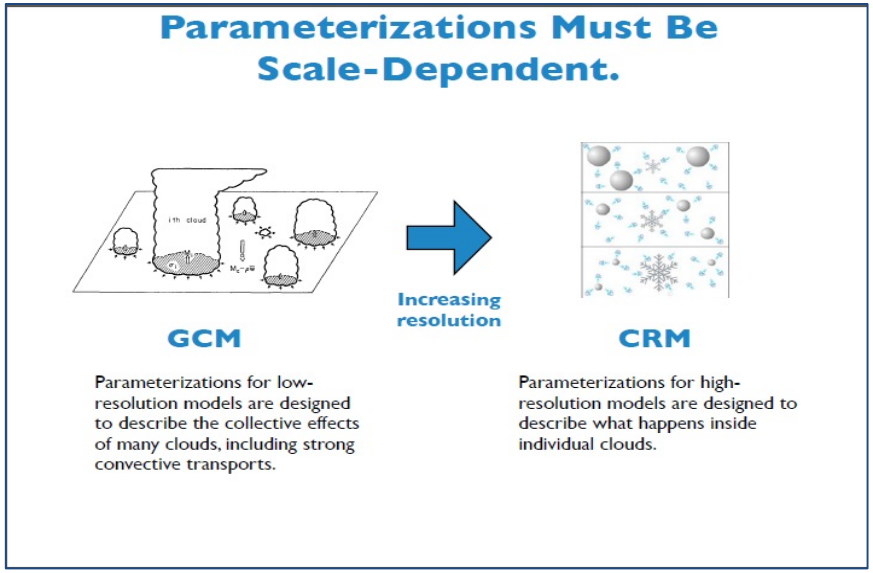
When done within a Multi-scale Model Framework (MMF) it is computationally expensive

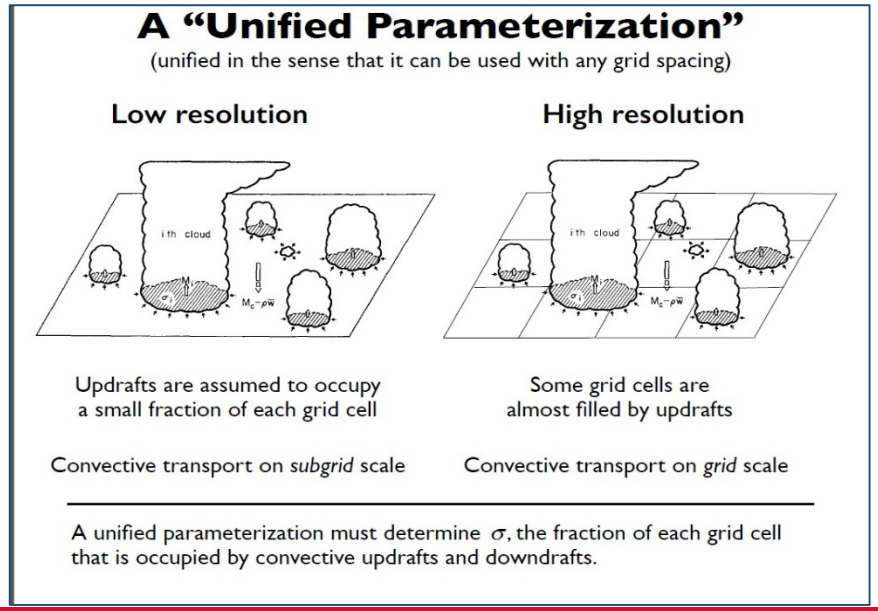
Science: Arriving at a Scalable Framework

Today's MMF parameterizes clouds differently in low vs high resolution and we don't completely understand the processes inside individual clouds.

Scientists' goal is to produce a consistent representation of cloud processes at coarse and fine scales-

For a unified global-to-local-scale modeling Framework.



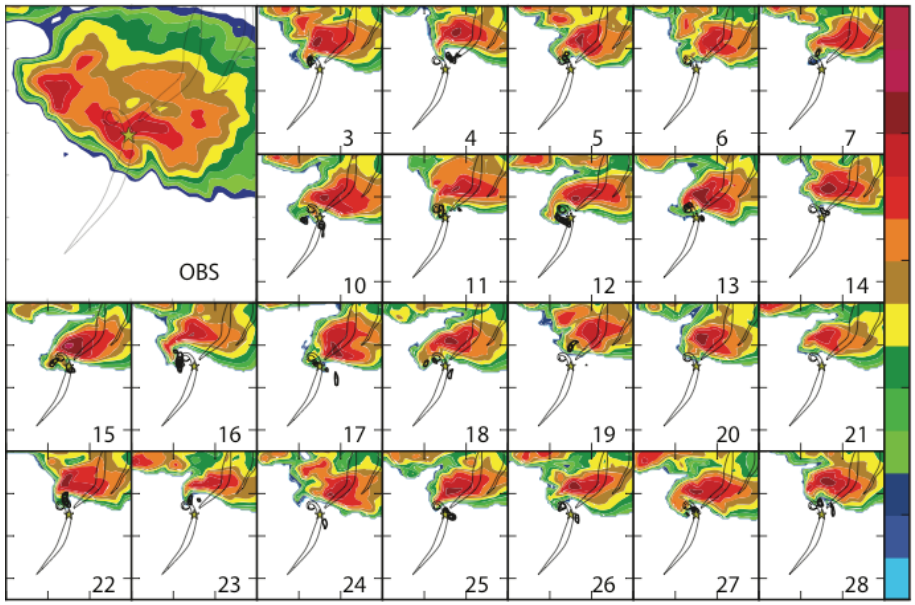


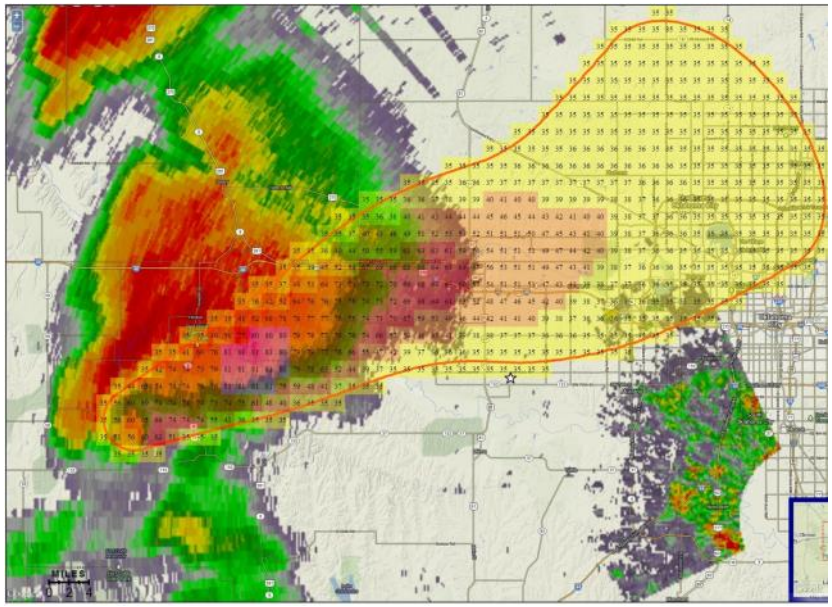
Science Requirements & Potential Results

CRM (including Unified Parameterization) science development requires key resources-

- More frequent, evenly dispersed, hyperlocal ***observations*** of moisture & temperature for the Planetary Boundary Layer
- Additional ***computational resources*** to run the improved cloud physics
- And even ***more computational resources*** to generate ensembles with post-processed statistically derived probabilities.

With those needs met—storm scale ”WOF” may eventually become a reality-





Technology: HPC Industry Trends

The Broader HPC Market

The Broader HPC Market Growth to 2019
Worldwide HPC Compute, Storage, Middleware, Application and Service Revenues ($M)

	2014	2015	2016	2017	2018	2019	CAGR (14-19)
Server	10,222	10,718	11,467	12,958	14,073	15,165	8.2%
Storage	4,229	4,504	4,865	5,546	6,123	6,796	9.9%
Middleware	1,163	1,217	1,294	1,426	1,534	1,645	7.2%
Applications	3,598	3,769	4,028	4,479	4,824	5,167	7.5%
Service	1,819	1,895	2,006	2,223	2,356	2,497	6.5%
Total	21,032	22,103	23,660	26,632	28,910	31,270	8.3%

Source: IDC 2015

But what about the computational resources needed to pull this off?

Affordability? Scalability? Accessibility?

HPC Forecasts

- Forecasting a 8.2% yearly growth from 2014 to 2019
- 2019 should reach $15.2 billion

Worldwide Total Technical Computer Market Shipments Forecast

	2013	2014	2019	CAGR (14-19)
Supercomputer	3,995	3,150	5,034	9.8%
Divisional	1,355	1,524	2,156	7.2%
Departmental	3,363	3,831	5,406	7.1%
Workgroup	1,586	1,718	2,569	8.4%
Total	10,299	10,222	15,165	8.2%

Source: IDC 2015

IDC

While large private HPC data centers continue to thrive—what about HPC Cloud or POD- Cloud on Demand?

Has it peaked? Is it capable to support the modeling community?

HPC Usage

HPC Server Market: By Industry/Applications ($000)

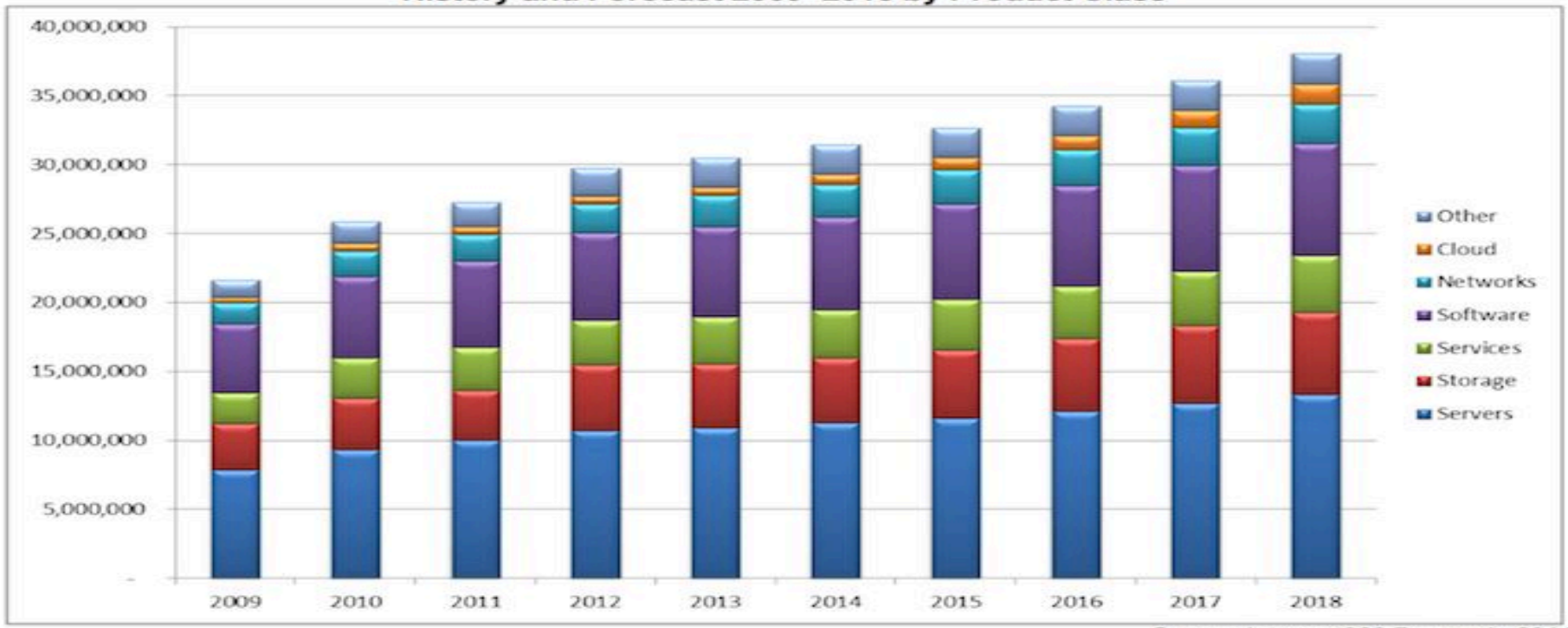
WW HPC Revenue by Applications	
	2015
Bio-Sciences	1,090,722
CAE	1,299,380
Chemical Engineering	187,851
DCC & Distribution	704,950
Economics/Financial	614,503
EDA / IT / ISV	807,199
Geosciences	838,157
Mechanical Design	61,079
Defense	1,140,544
Government Lab	1,986,865
University/Academic	2,043,357
Weather	493,773
Other	94,903
Total Revenue	11,363,283

Technology: Demand for Cloud

Cloud HPC market size is estimated to grow from $4.37 billion in 2015 to $10.83 billion by 2020, at an estimated compound annual growth rate of 19.9%. **The main factors driving the growth of cloud HPC are:**

- Complex applications management
- Emergence of big data market
- Adoption of the pay-as-you-go model

Figure 1: Total HPC Market (Combined HPTC and HPBC) Revenue History and Forecast 2009–2018 by Product Class



Source: Intersect360 Research, 2014

Data Intensive Uses of HPC & HPC Cloud

HPDA = Data-Intensive Computing Using HPC

Drivers:
- Competition
- Complexity
- Time

Modeling & Simulation

- Existing HPC users
  - Larger problem sizes
  - Higher resolution
  - Iterative methods
  - EP jobs to the cloud (Novartis)
- New commercial users
  - E.g., SMEs

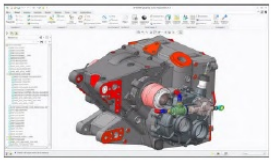
Advanced Analytics

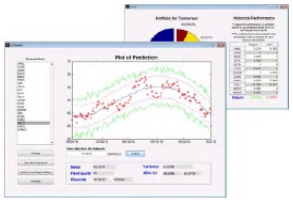
- Existing HPC users
  - Intelligence community, FSI
  - Data-driven science/ engineering (e.g., biology)
  - Knowledge discovery
  - ML/DL, cognitive, AI
- New commercial users
  - Fraud/anomaly detection
  - Business intelligence
  - Affinity marketing
  - Personalized medicine

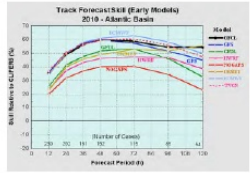
IDC Analyze the Future

HPDA Includes Cumulative Results of Iterative Methods

- Parametric modeling (product design)
- Stochastic modeling (financial)
- Ensemble modeling (weather/climate)







IDC Analyze the Future

HPC Cloud without the Capital Investment

"…..no monthly fee, no long term commitment..pay as you go."

It's the mantra of HPC Cloud on Demand services.

1000's of CPU Cores at your fingertips.

No managing of applications.

No data center costs – power, communications, A/C or storage.

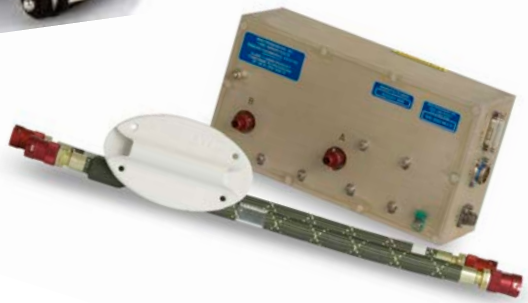
Pay for what you use not what is in the room.

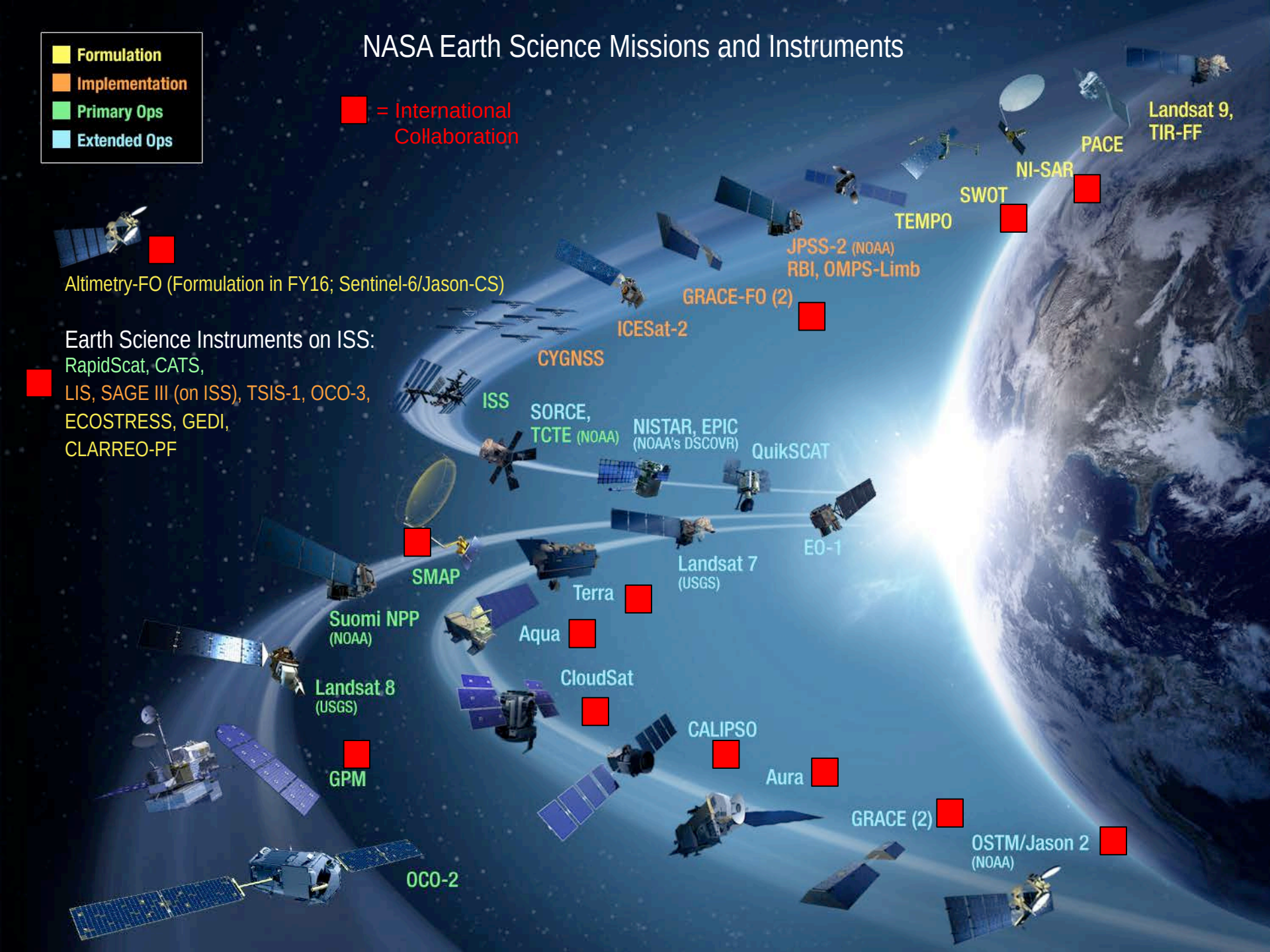
Use as little or as much as you need—flexible Compute power for your variable needs.

Who wouldn't want this exciting accessibility to resources that were previously out of reach?

Observations: Next Generation

- Mesonets of surface observations multiplying daily—implemented by Academia, Private Sector, State & Local Government.
- Lidar, Aircraft data (MDCRS, TAMDAR, WVSS II), Total Lightning data, Webcams, mPing -- reporting PBL conditions for model input and/or V&V of NWP output.
- Technology has once again had a positive impact on advances in this area.




Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science Missions and Instruments
= International Collaboration
Landsat 9, TIR-FF
PACE
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
Altimetry-FO (Formulation in FY16; Sentinel-6/Jason-CS)
Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS, GEDI,
CLARREO-PF
ISS
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(NOAA's DSCOVR)
QuikSCAT
EO-1
SMAP
Landsat 7
(USGS)
Terra
Suomi NPP
(NOAA)
Aqua
CloudSat
Landsat 8
(USGS)
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

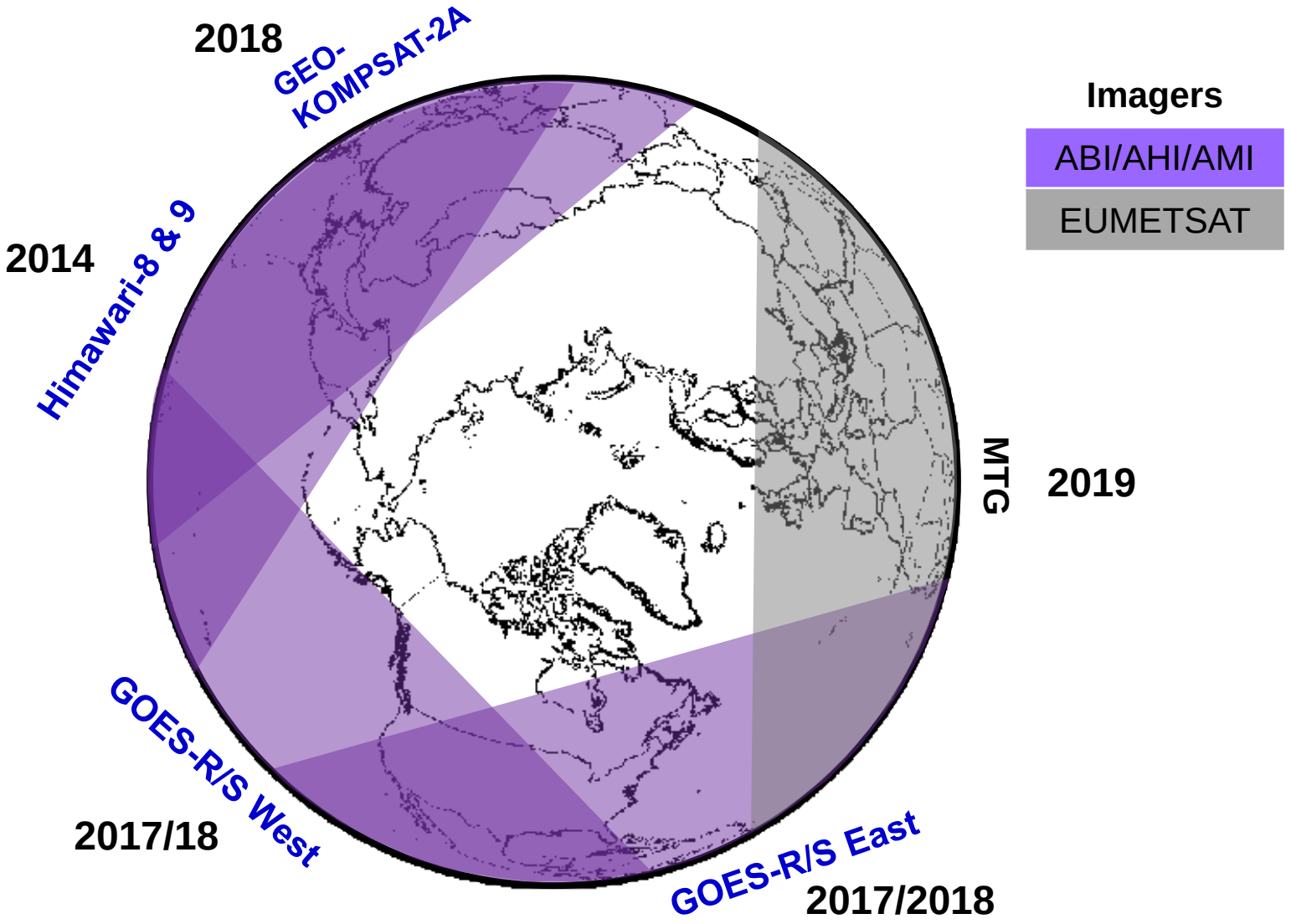
Next Generation Satellite Missions & Instruments

Satellite / Sensor	Legacy	MSA	Improved Capability	Initial Operations Date
GOES-R / ABI	GOES-NOP	1 - 8	16 vs 5 imagery channels 2X spatial resolution > 4X temporal resolution ~21 vs 5 derived products	Spring 2017
GOES-R / GLM	none	1 – 7	Total lightning, hemispheric, every 20 s	Fall 2017
SNPP-JPSS / VIIRS	POES & MeTOP /AVHRR	1 – 8	21 vs 5 channels 2X spatial resolution ~41 vs 5 derived products	2015 > Summer 2017
GCOM-W / AMSR2	none	2,4,5, 6,7,8	4 (Microwave) imagery channels 10 derived products	2016 > Summer 2017
JASON 2 & 3 / Altimeter	none	4, 5	4 derived products	Fall 2016
Himawari / AHI	MTSAT Imager	1 – 8	Nearly identical to GOES-R > 4 vs 0 derived products	Dec 2015 – Jul 2016
GPM / GMI	none	4,5,7,8	4 (Microwave) imagery channels > 3 derived products	2016 > Summer 2017
Sentinel & RadarSAT / SAR	none	4, 5	1 derived product	Summer 2016

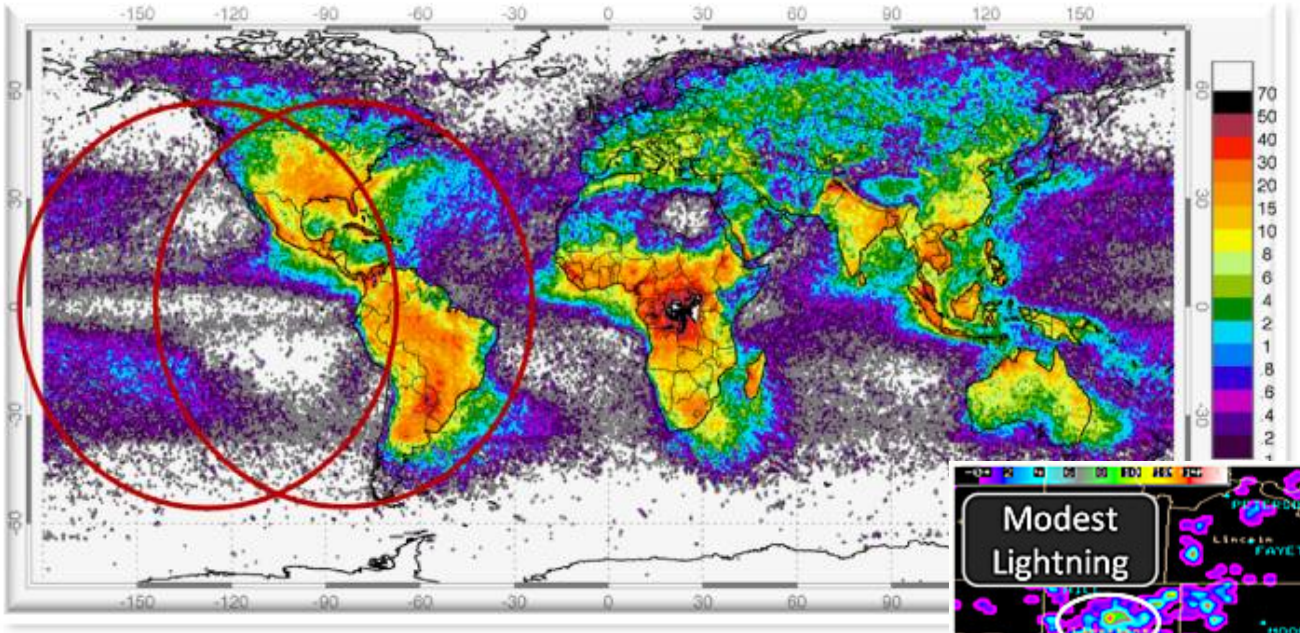
MSA = Mission Service Areas for Weather

1. Severe
2. Routine
3. Aviation
4. Tropical
5. Marine
6. Fire
7. Precip / Hydrology
8. Winter Weather

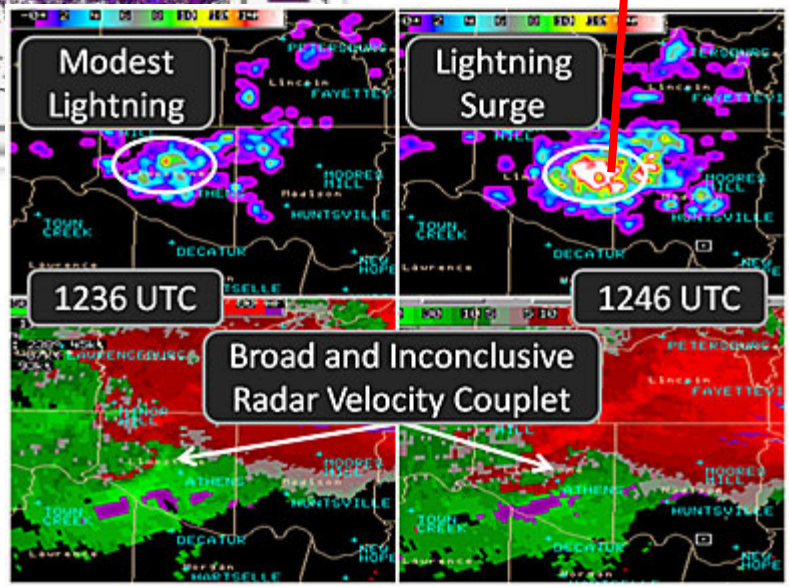
World-Wide Coverage with ABI-class Imagers



Geostationary Lightning Mapper (GLM)

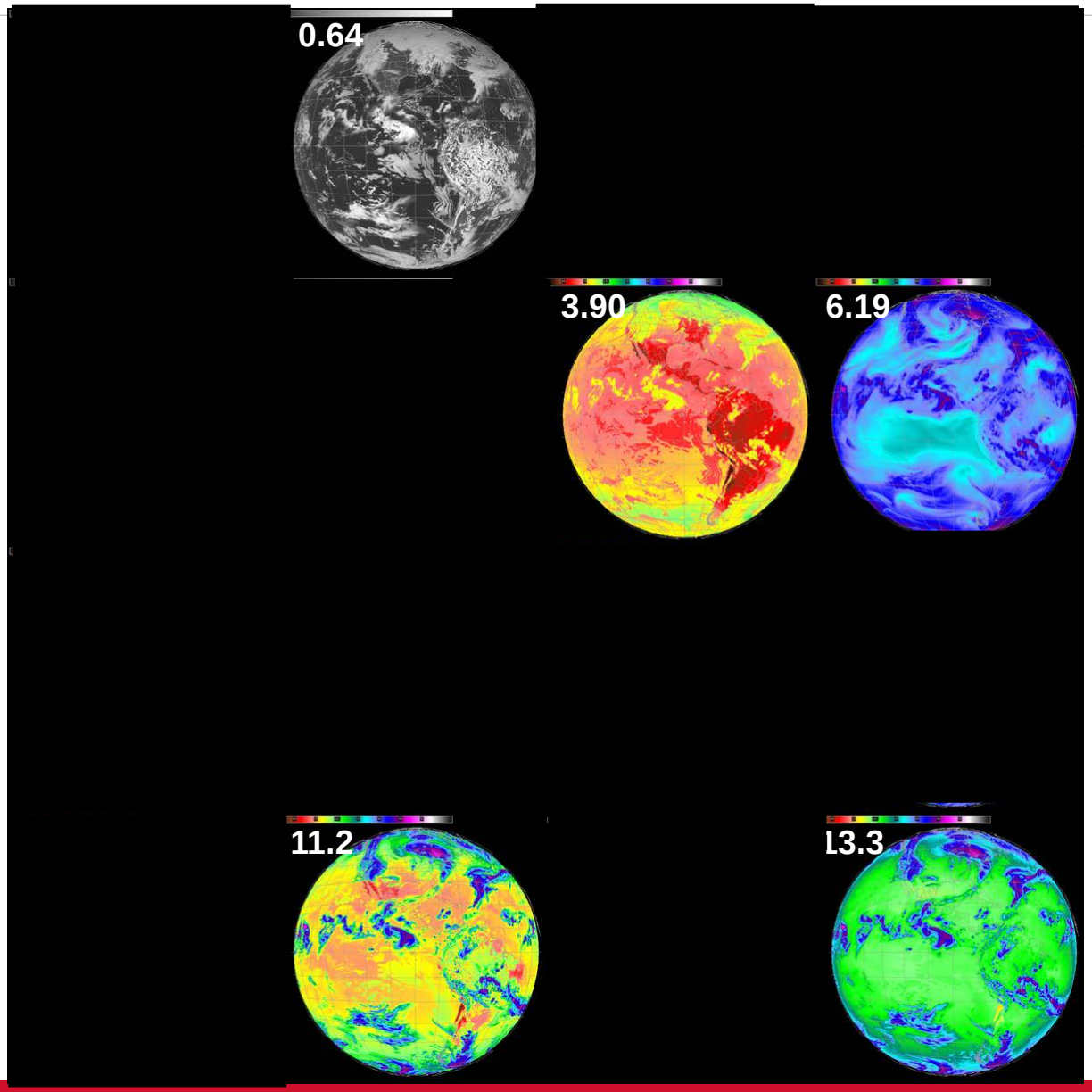


Lightning surge of over 200% occurred 14 minutes prior to a confirmed tornado touchdown



- GLM provides hemispheric displays of lightning events
- Provides earlier indication of extreme weather development

Current GOES Imager

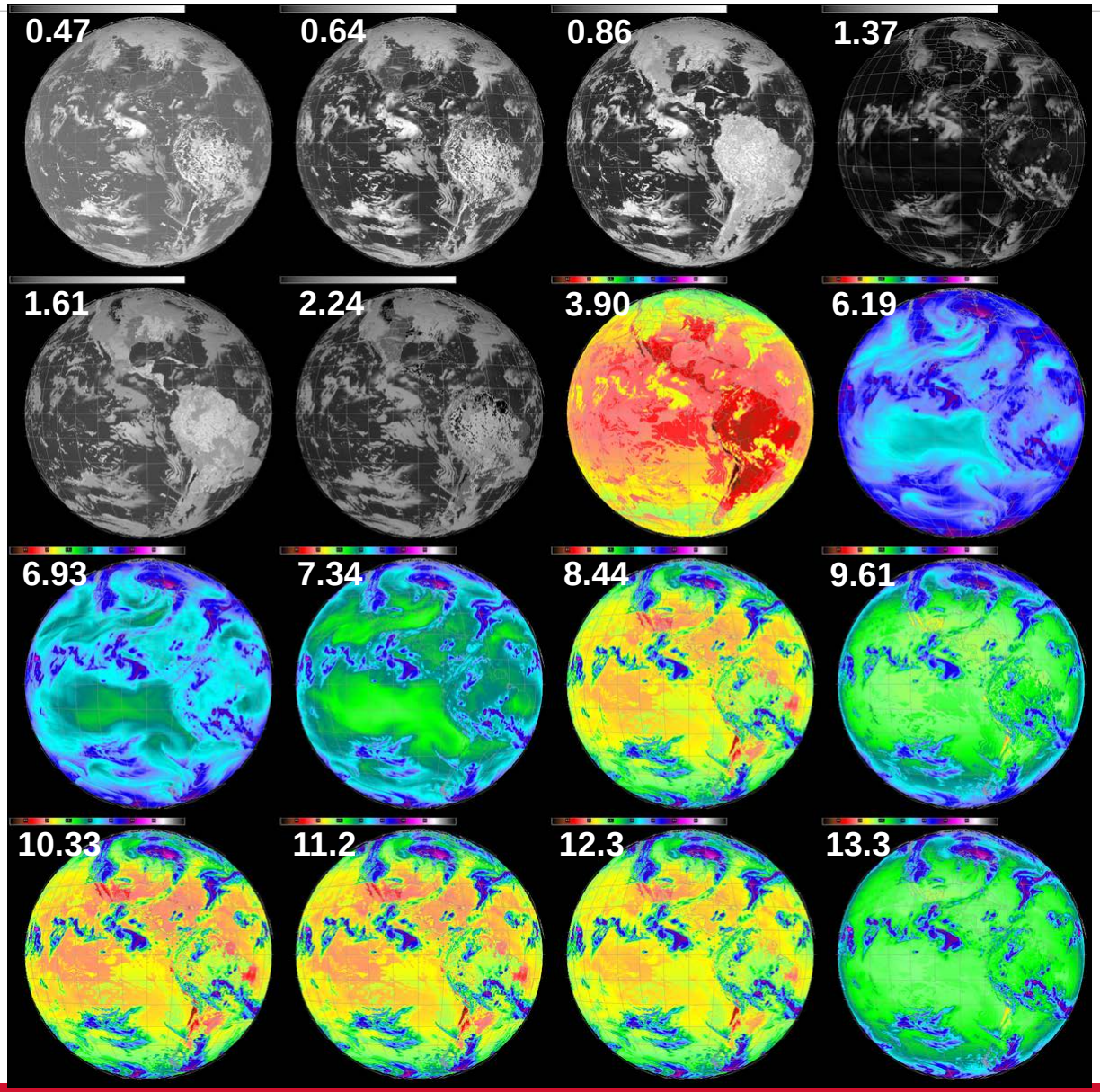


Current GOES Imager Channels (Wavelength) Used for Observation

1:
2: 0.64 µm (Red; 2 km)
3:
4:
5:
6:
7: 3.9 µm (Shortwave Window)
8: 6.2 µm (Upper Level Water Vapor)
9:
10:
11:
12:
13:
14: 11.2 µm (IR Longwave)
15:
16: 13.3 µm (CO2)

Image courtesy of Tim Schmit

GOES-R Advanced Baseline Instrument (ABI)



Earth Image Depends Upon ABI Channel (Wavelength) Used for Observation

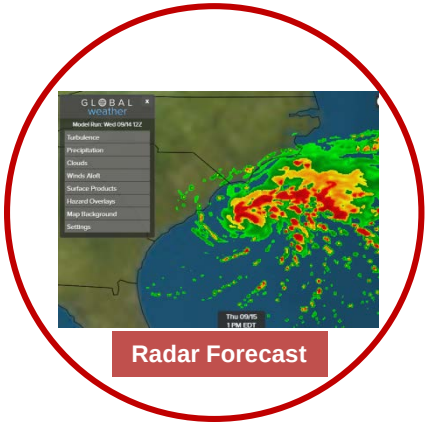
1: 0.47 µm (Blue; 1 km)
2: 0.64 µm (Red**; 0.5 km**)
3: 0.86 µm (Veggie; 1 km)
4: 1.37 µm (Cirrus; 1 km)
5: 1.61 µm (Snow/Ice)
6: 2.3 µm (Cloud Particle Size)
7: 3.9 µm (Shortwave Window)
8: 6.2 µm (Upper Level Water Vapor)
9: 6.9 µm (Mid-Level Water Vapor)
10: 7.3 µm (Low-Level Water Vapor)
11: 8.4 µm (Cloud Top Phase)
12: 9.6 µm (Ozone)
13: 10.3 µm (Clean IR Longwave)
14: 11.2 µm (IR Longwave)
15: 12.3 µm (Dirty IR Longwave)
16: 13.3 µm (CO2)

3x Spectral Bands
4x Spatial Resolution
6x Temporal Resolution

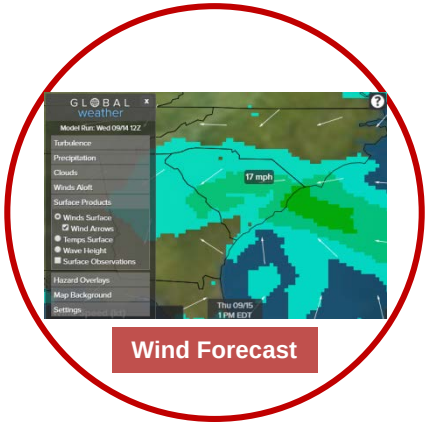
Image courtesy of Tim Schmit

Observations: Summary

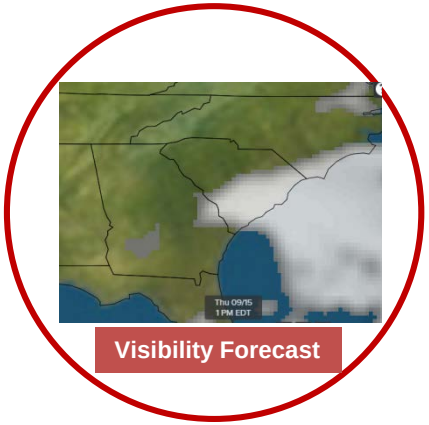
- The planet will be observed from space with three distinct high resolution moisture channels, at the very least, to assimilate into global models.
- Mesonet observations will continue to flourish and provide substantive information where previously there was none.
- The next few years will provide new observations that will be tailored for cloud processes in the boundary layer.
- And perhaps additional ground networks to better observe the lower 5km of the atmosphere “from the ground up” will be deployed.



Radar Forecast



Wind Forecast

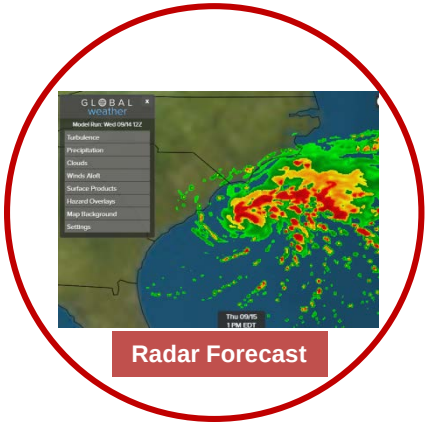


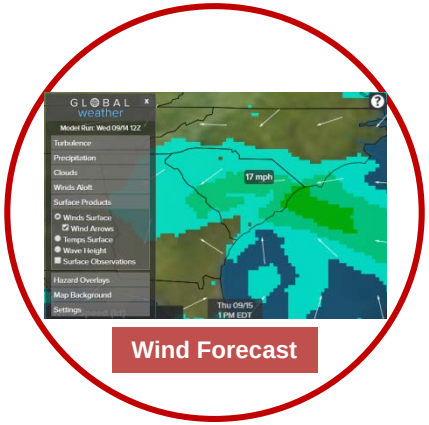
Visibility Forecast

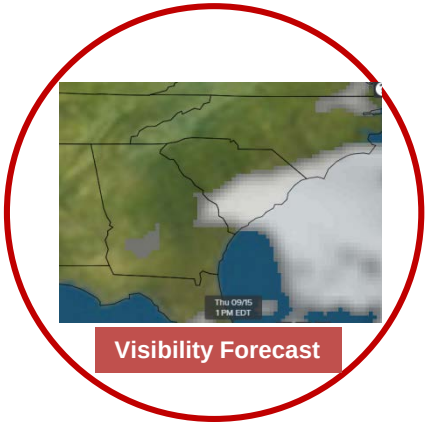
Forecast Example: EarthCast®

- Why? Because the models, the computational resources and the observations are accessible to scientists with modeling credentials…
- Hosted on a POD Cloud, providing 10km global and 3 km nested grids in a NASA spectral model that uses satellite data, mesonets, global obs, and other observations hourly out to 36 hours.
- 3km nest has Cloud Resolving Model to depict local convection.
- Accessible on mobile or web interface—

Science - Technology – Observations are here and will provide the back drop for a new WOF process and, model guidance that when coupled with new observations depicts the certainty in the hyperlocal future conditions.



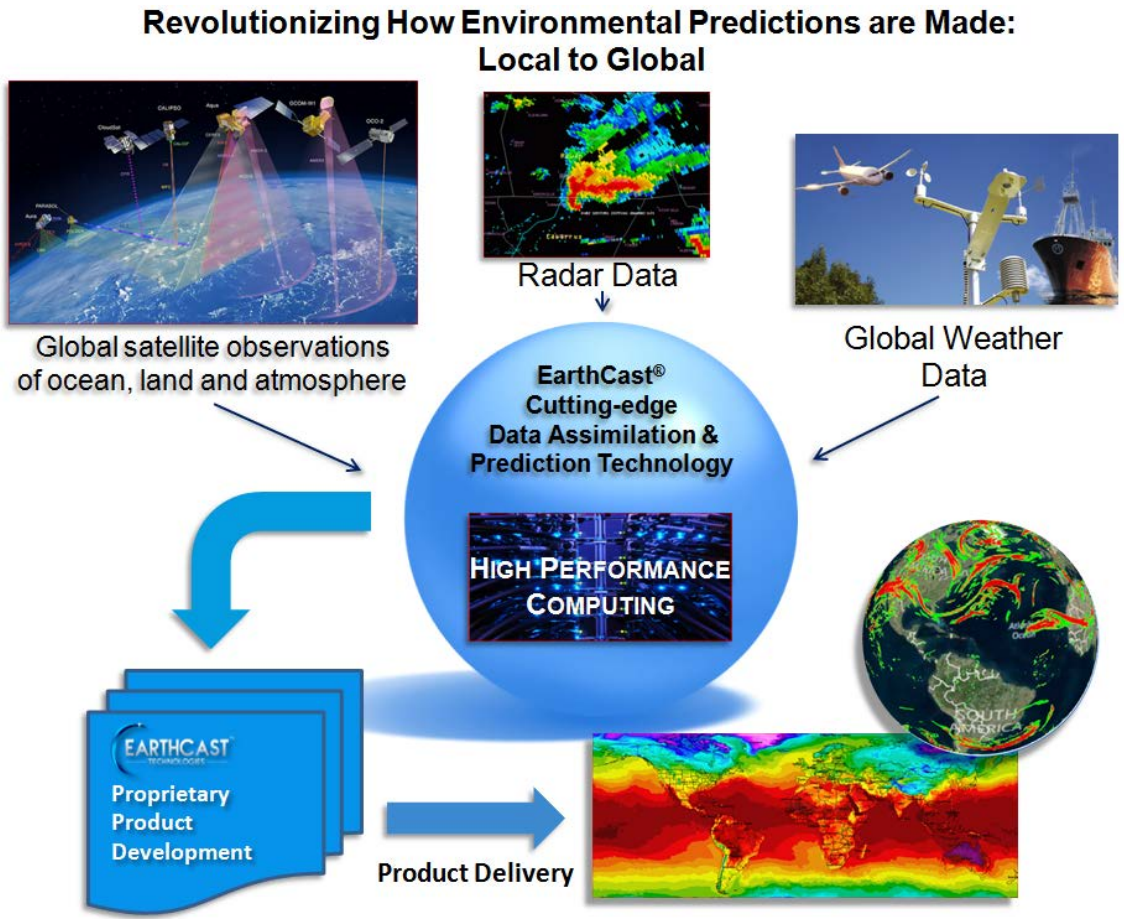




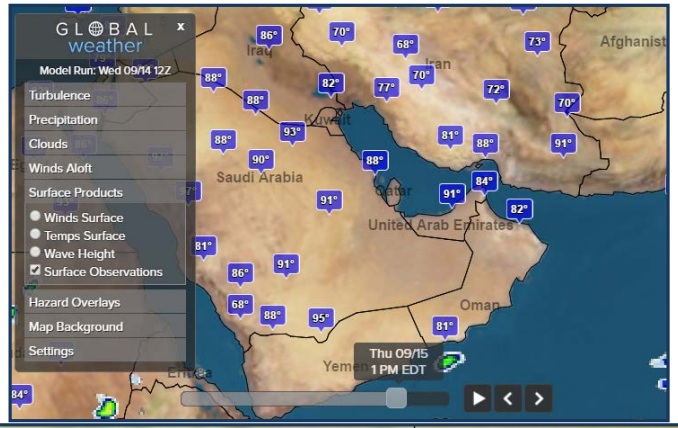
EarthCast® Solution

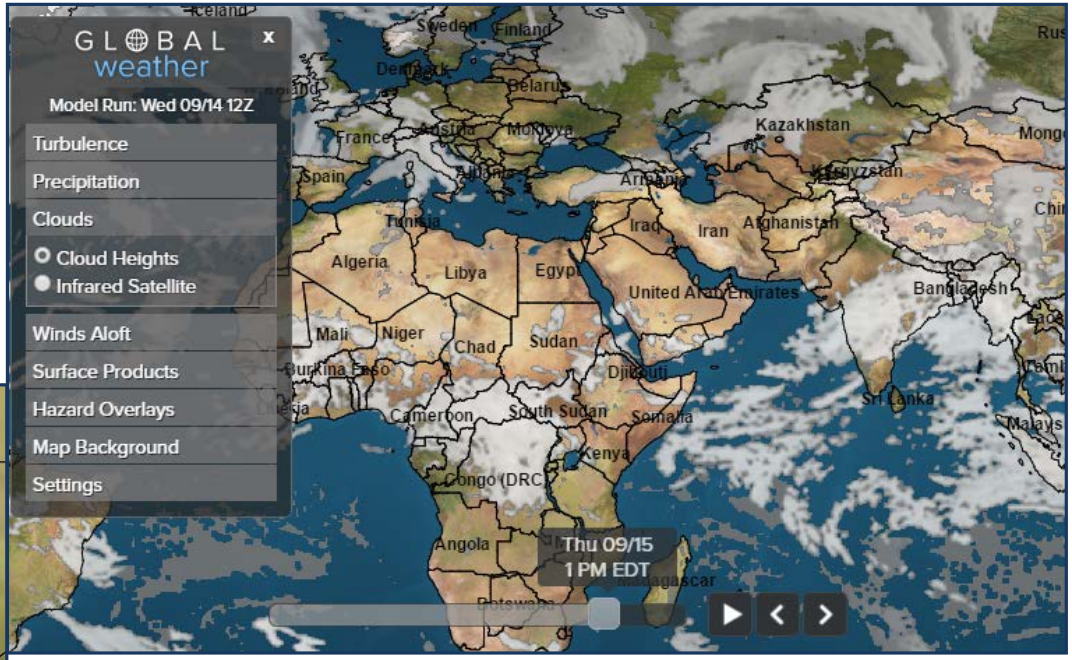
EarthCast is an advanced global to local prediction system that delivers:

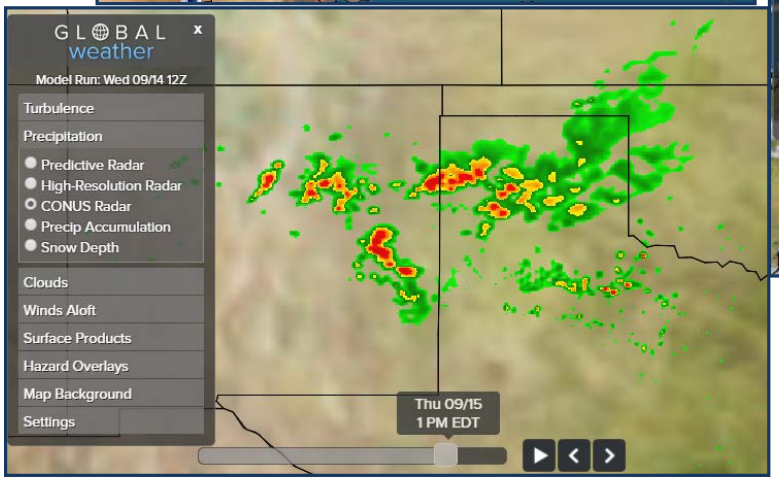
- Truly local to global capability with accurate and detailed information about hazardous environmental conditions before they occur.
- Highly detailed HyperResolution forecasts over cities and airports, along transportation routes; and over remote territories.



EarthCast Web Application

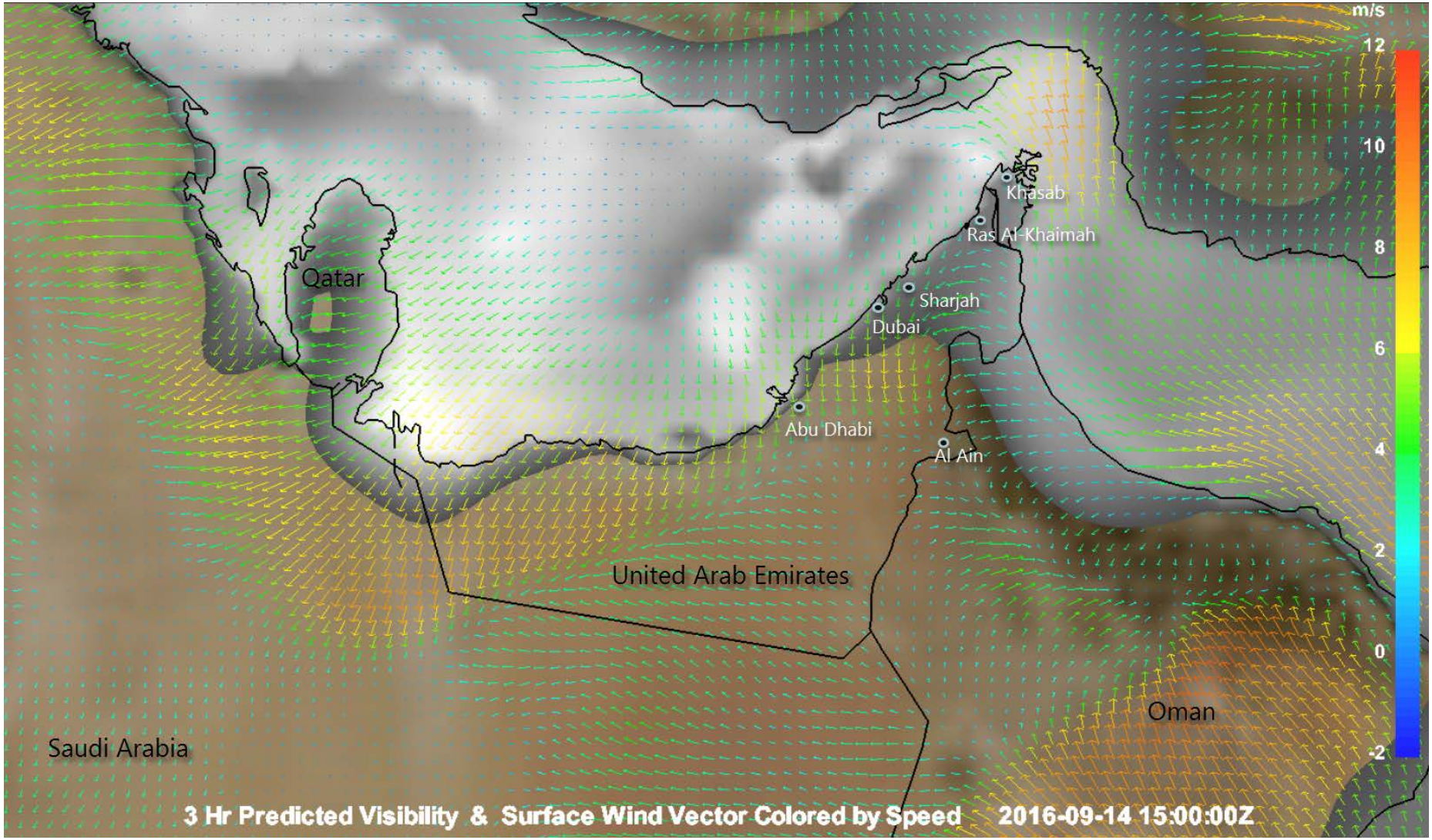




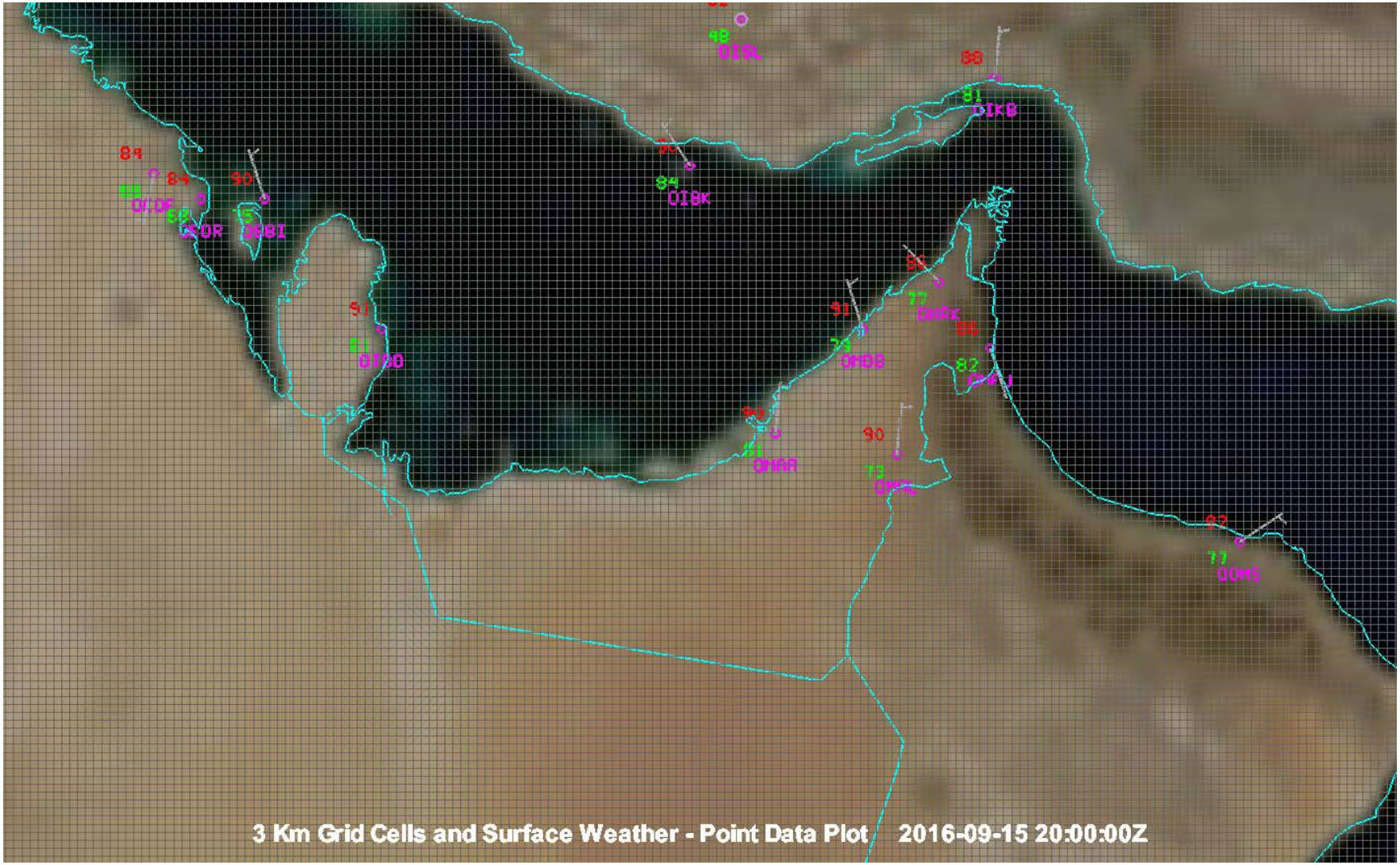


Local to Global Display of Hazardous Conditions and Forecasts

Forecast Solutions at High Temporal & Spatial Resolutions for Unique Requirements



Providing Value Where Surface Observations are Sparse



Thank you.

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