DA development and testing for the initial version of the FV3-GFS with comments on hybrid enhancements & JEDI

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NOAA/NWS/NCEP/EMC

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In collaboration with: Rahul Mahajan, Cathy Thomas, Ting Lei, Russ Treadon, Jeff Whitaker, Phil Pegion, Fanglin Yang, Shrinivas Moorthi, John Derber, Andrew Collard, Wan-Shu Wu, Deng-Shun Chen, Xuguang Wang, Bo Huang, Kayo Ide

&

Tom Auligne, Yannick Tremolet, and entire JCSDA JEDI Team

&

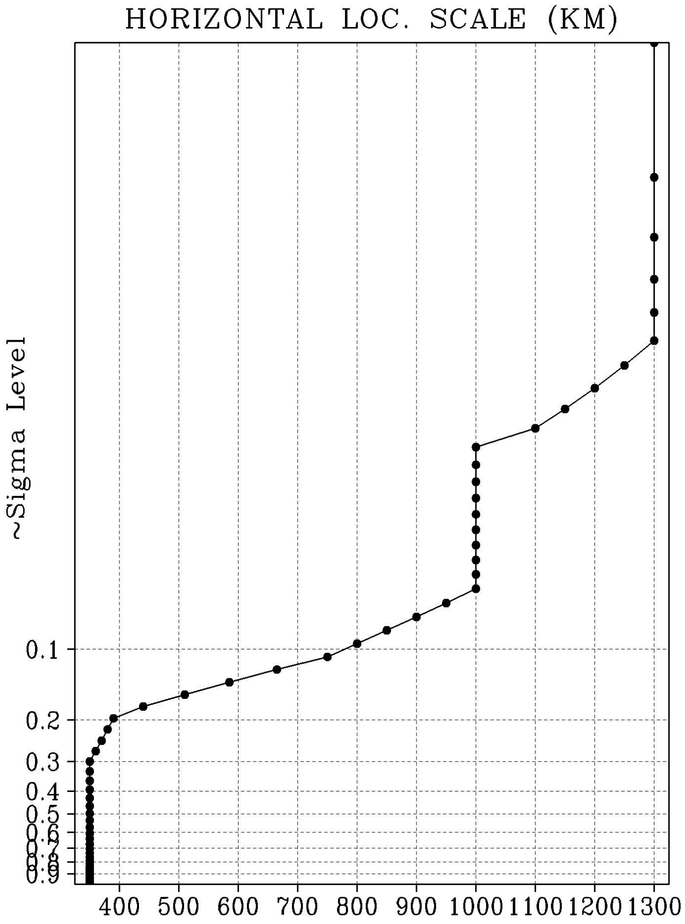
Many, many others from EMC

Current Operational GDAS Configuration
Hybrid 4DEnVar (May 2016)

$$J(\mathbf{x}'_c,\mathbf{a}) = \beta_c \frac{1}{2}(\mathbf{x}'_c)^T \mathbf{B}_c^{-1}(\mathbf{x}'_c) + \beta_e \frac{1}{2}\mathbf{a}^T\mathbf{L}^{-1}\mathbf{a} + \frac{1}{2}\sum_{k=1}^{K}(\mathbf{H}_k\mathbf{x}'_{(t)k} - \mathbf{y}'_k)^T\mathbf{R}_k^{-1}(\mathbf{H}_k\mathbf{x}'_{(t)k} - \mathbf{y}')$$

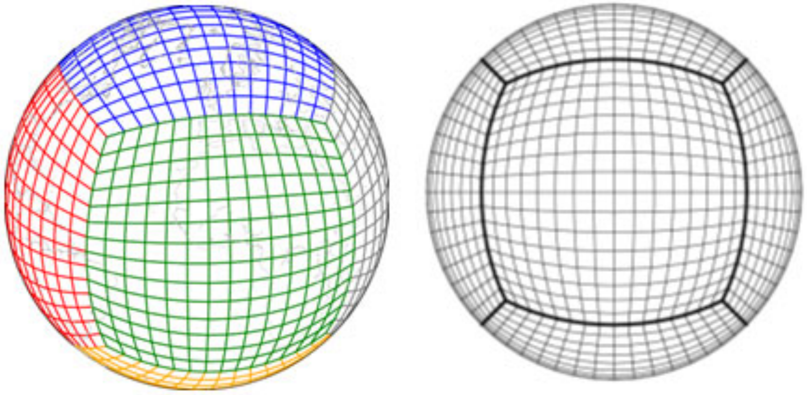
$$\mathbf{z} = \mathbf{B}^{-1}\mathbf{x}'_c \qquad \mathbf{v} = \mathbf{L}^{-1}\mathbf{a}$$

- ***T1534L64*** Semi-Lagrangian GFS (GSM)
  - 80 member ***T574L64*** EnSRF for data assimilation
  - Level-dependent localization
  - Stochastic physics to represent model uncertainty (SPPT, SKEB, SHUM) – Since January 2015
  - Analysis increment at ensemble resolution
  - Ensemble perturbations centered about hybrid analysis
    - Ensemble mean state estimate replaced



NGGPS/FV3-GFS

- NOAA GFDL FV3 selected for dynamic core component of NGGPS
  - Using Non-hydrostatic option
  - Initial prototyping with (mostly) GFS physics (new: GFDL MP)
  - Same vertical levels and model top (~55km)



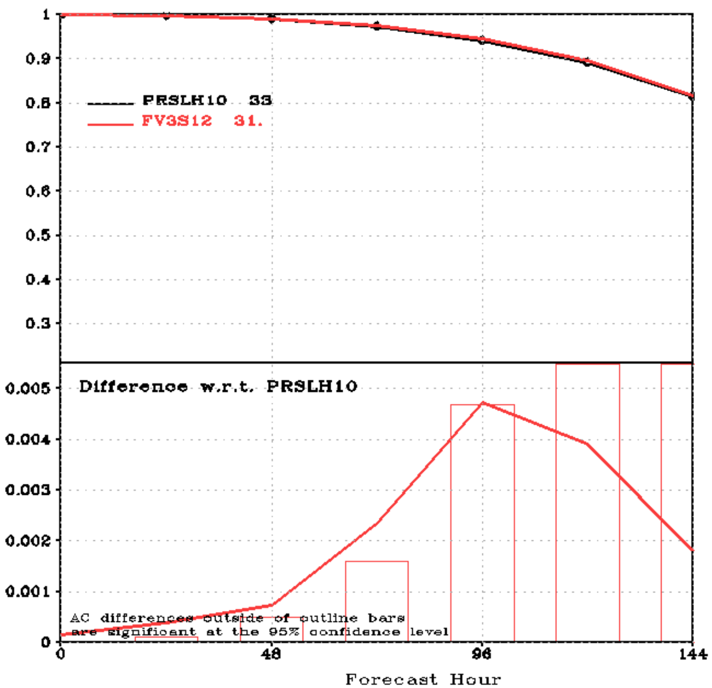
Courtesy: GFDL

- Data Assimilation
  - ***Adaptation of current hybrid 4DEnVar scheme***
  - ***Re-gridding to accommodate current DA infrastructure***

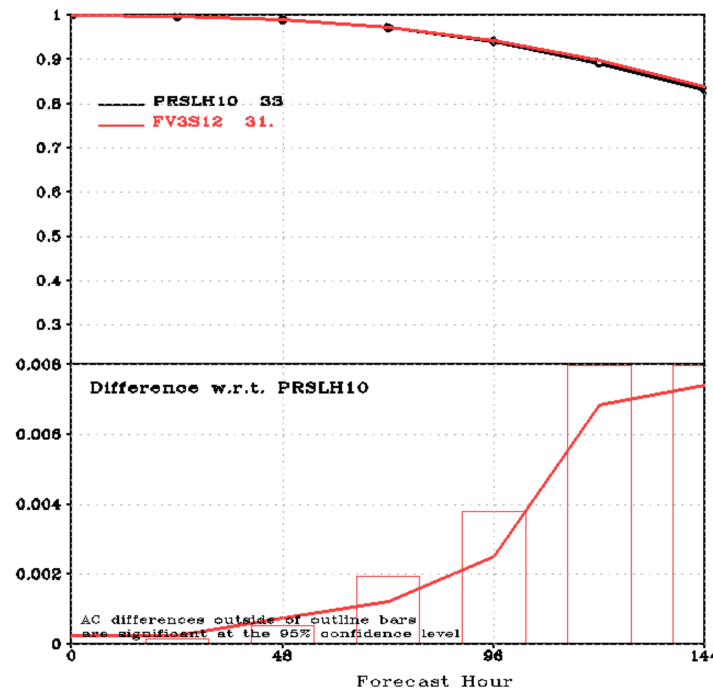
Low Resolution Prototyping

- Experimental FV3GFS [**FV3S12**] DA experiments:
  - 2015112500-2015122700 (10 days ignored for spin-up)
  - 25km (50km ensemble)
  - Non-hydro, some parameters tuned, SPPT/SHUM, hybrid 4DEnVar
  - Compare with T670L64 (80 member EnSRF) GFS/GSM [**PRSLH10**]

500 hPa AC, Northern Hemisphere

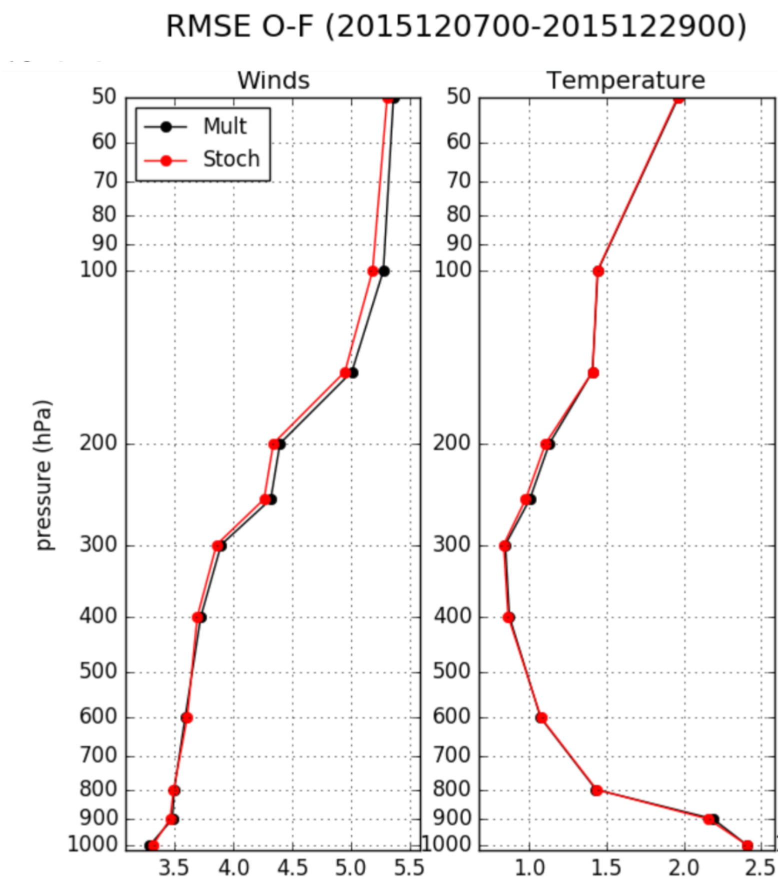


500 hPa AC, Southern Hemisphere

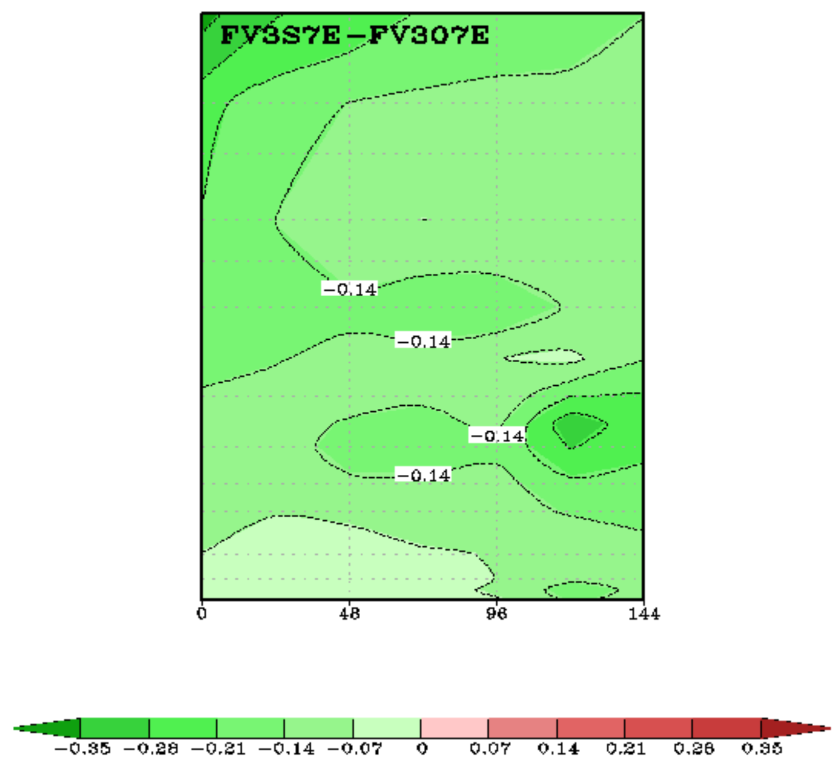


Impact of Stochastic Physics
C384 L64 cycled DA tests (3DHybrid)

- Similar to tests from GFS/GSM, use of stochastic physics (SPPT/SHUM) show modest improvement in data assimilation experiments
  - GFS/GSM also uses SKEB, work ongoing within FV3



Wind RMSE Difference, Global (EXP-SP minus Control)



NGGPS: FV3 Timeline (proposed)

Implementation Plan for FV3-GFS (FY2017-2019)

FV3GFS	FY17				FY18				FY19			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
FV3 Documentation	Evaluate, prepare and document FV3 dycore for GFS											
FV3 Dycore in NEMS		Implement FV3 dycore in NEMS[@]										
FV3 Dycore with GFS Physics			Couple FV3 to GFS physics (NUOPC physics driver) perform forecast-only experiments, tuning and testing									
Preliminary GSI/EnKF DA for FV3			**Develop DA techniques** and use new data									
Cycled FV3GFS* experiments (real-time parallels)				Cycled experiments, benchmarking, efficiency and optimization								
							Real-time parallel FV3GFS forecasts to the field					
Post Processing					Adapt post-processing							
Pre-implementation T&E for FV3GFS[@&%]							3-year retrospective + real-time parallels, EMC and Community Evaluation					
Transition to operations							◆		NCO 30 DAY IT TEST ◆	NEMS/FV3GFS in OPS		

NOW

Proposed Implementation 24 Jan. 2019

Key Differences from Current Operations

- Ensemble and analysis increment resolution
  - ***While control remains ~13km, ensemble and increment resolution have been increased to ~25 km (currently ~39km)***
- Initialization
  - Current GFS uses digital filter, ***NEMS-FV3GFS not yet using initialization***
    - Both use Tangent Linear Normal Mode Constraint
- Treatment of system error
  - GFS uses SKEB+SPPT+SHUM, FV3GFS utilizes SPPT+SHUM only
- Modifications to upper levels (largely model, impacts DA)
  - ***Reset stratospheric humidity to HALOE climatology (cold start only at beginning of experiment).***
  - ***New ozone and methane chemistry***

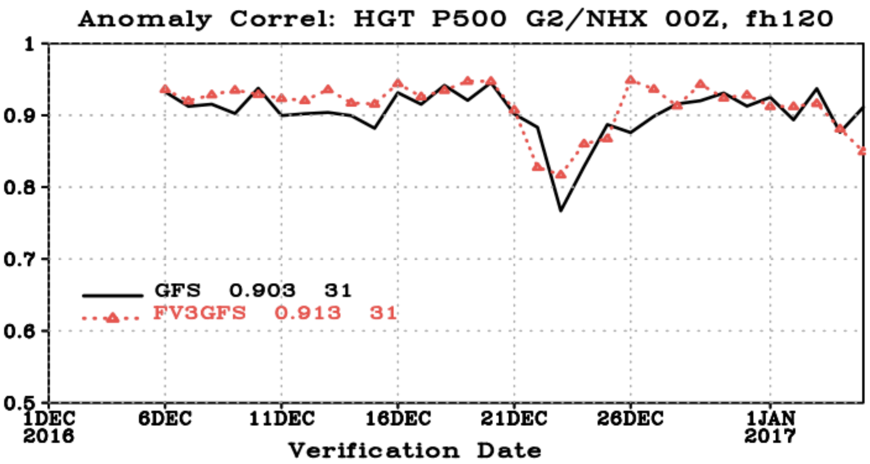
Key Differences from Current Operations

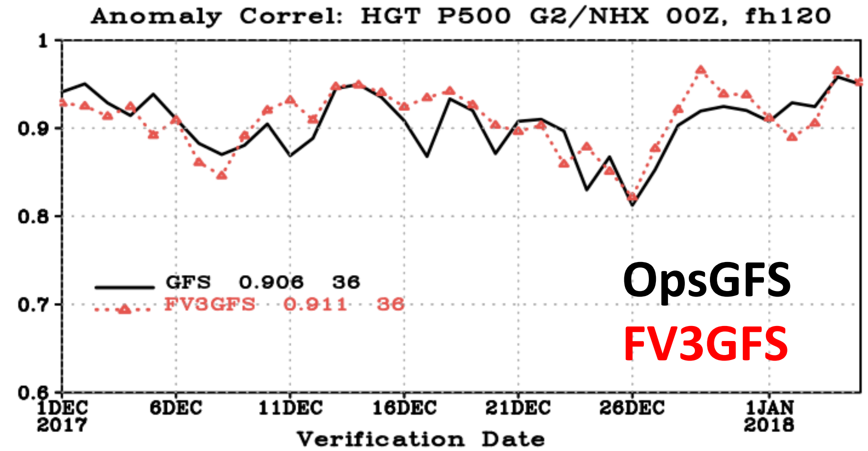
- New microphysics
  - GFS analysis total cloud increment and passes back to model
  - FV3GFS engineered to make this work with new MP scheme (5 species), but does not pass cloud increment back to model

- Observations
  - Operational GFS and to-be operational FV3GFS evolving with new observing system (GOES16 AMVs, NOAA 20 CrIS and ATMS)
  - ***FV3GFS will implement all-sky radiance assimilation for ATMS and additional water vapor channels from IASI***

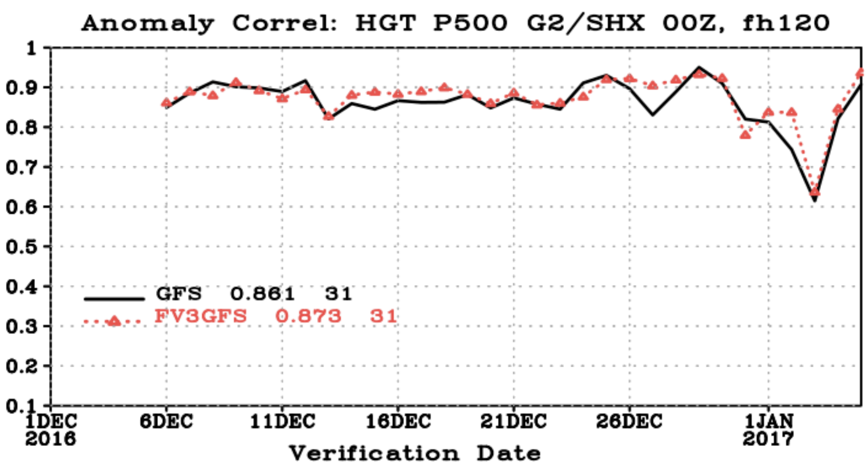
- NSST
  - Background error has been recalibrated

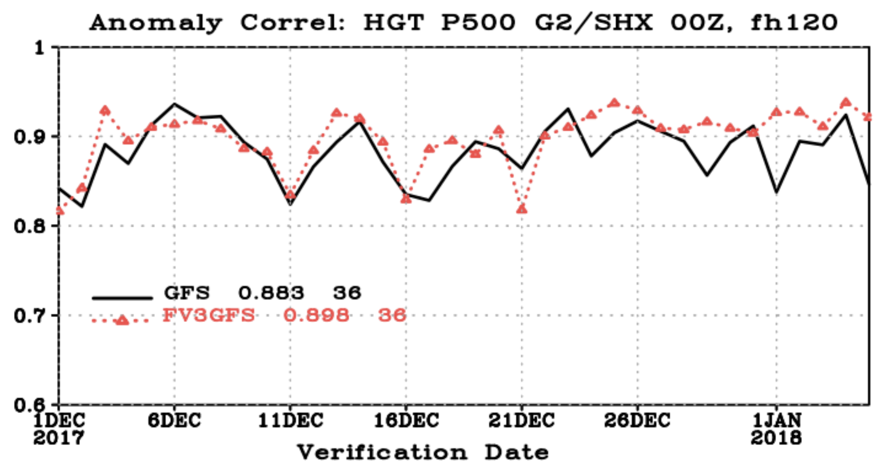
Retrospective Testing (Courtesy Fanglin)
500 hPa AC





NH 500 hPa AC

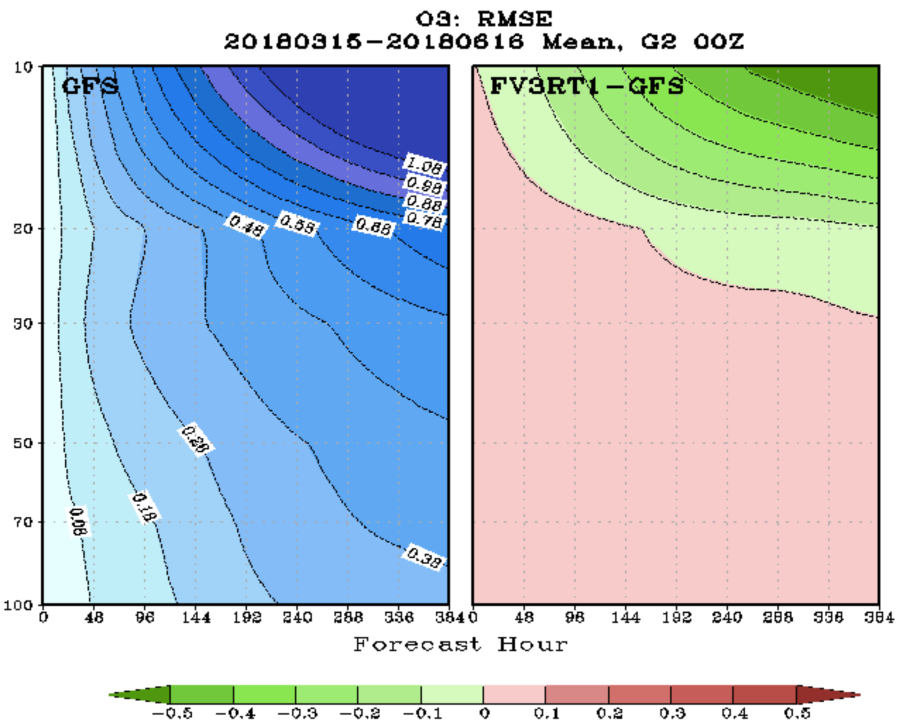




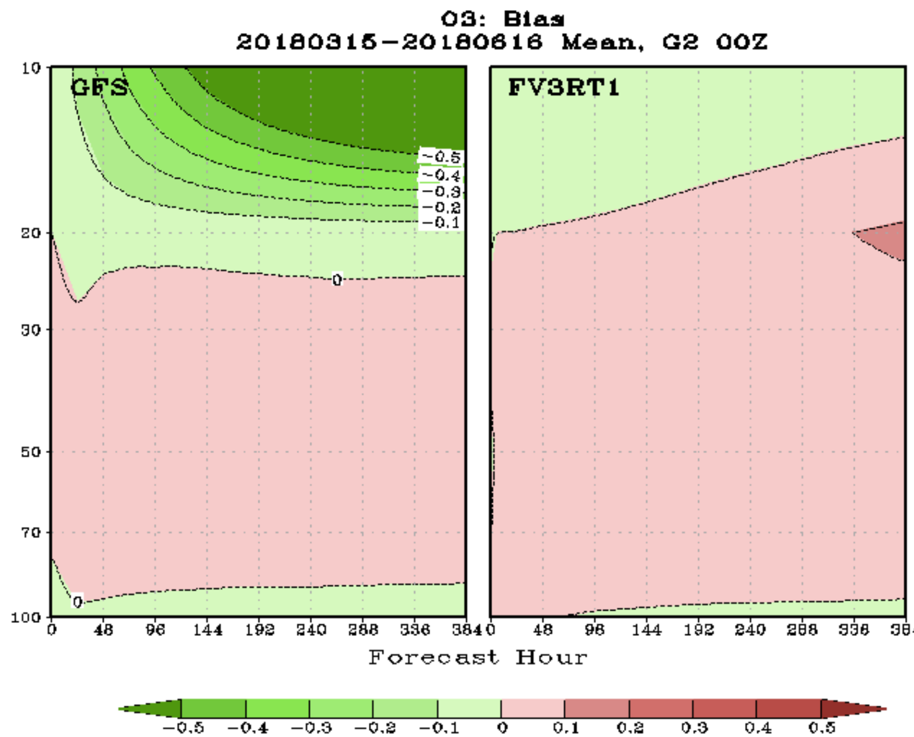
SH 500 hPa AC

Full Resolution Cycling
Ozone

Global Mean Ozone RMSE



Global Mean Ozone Bias



Time Shifting and Lagging

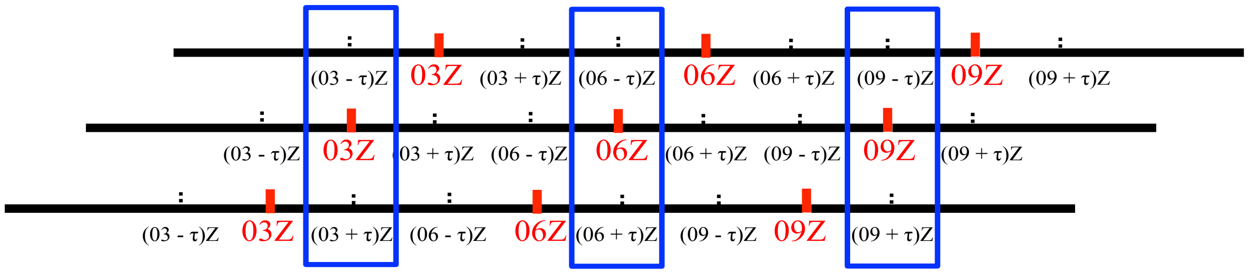
- Experiments have shown improvement in hybrid DA with increased membership
  - 320 member ensemble of Whitaker and Lei (2017)
- Ensemble forecast becoming most expensive component of DA cycling
- ***Personally, I was inspired to explore this from initial collaboration with Taiwan CWB***
  - Their initial hybrid efforts included time lagged ensemble membership!
  - Collaborating with University of Oklahoma on time shifting/lagging
- UK Met Office implementing as part of their operational hybrid DA

VTL method

- Shifting the ensembles valid around the analysis time (**the lagged ensembles**) to the analysis time.

(a) Ensemble background in ENS80

(b) Ensemble background after applying VTL to ENS80 with time lagging interval τ



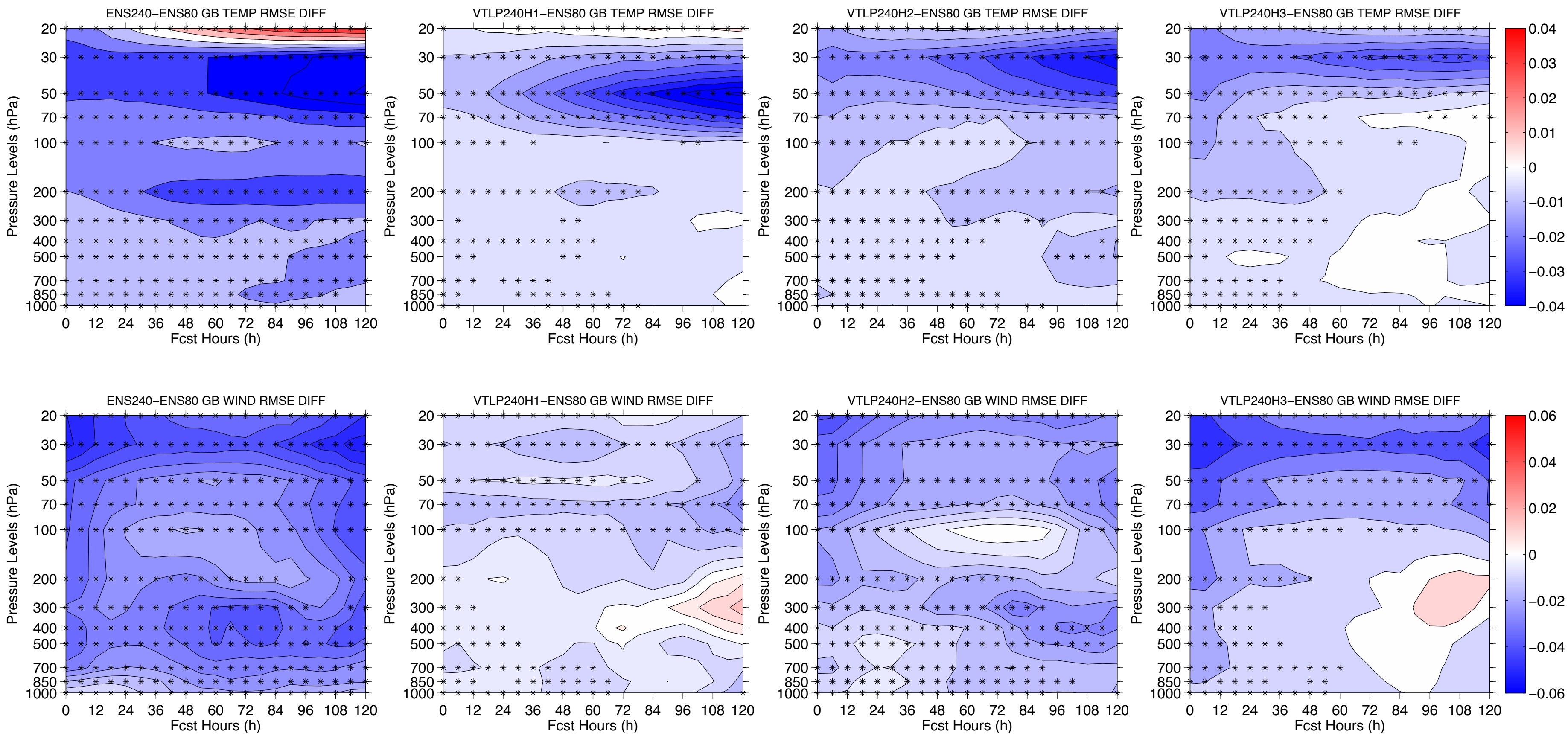
- VTLM: applying VTL to **the lagged ensemble members** (Xu et al. 2008).
- VTLP: applying VTL to the **lagged ensemble perturbations**.

Collaboration with OU. Slide Courtesy of Bo Huang and Xuguang Wang

VTLP 0-5-day forecast verification against EC analysis (eight-week cycling)

Blue: improvement; Red: degradation.

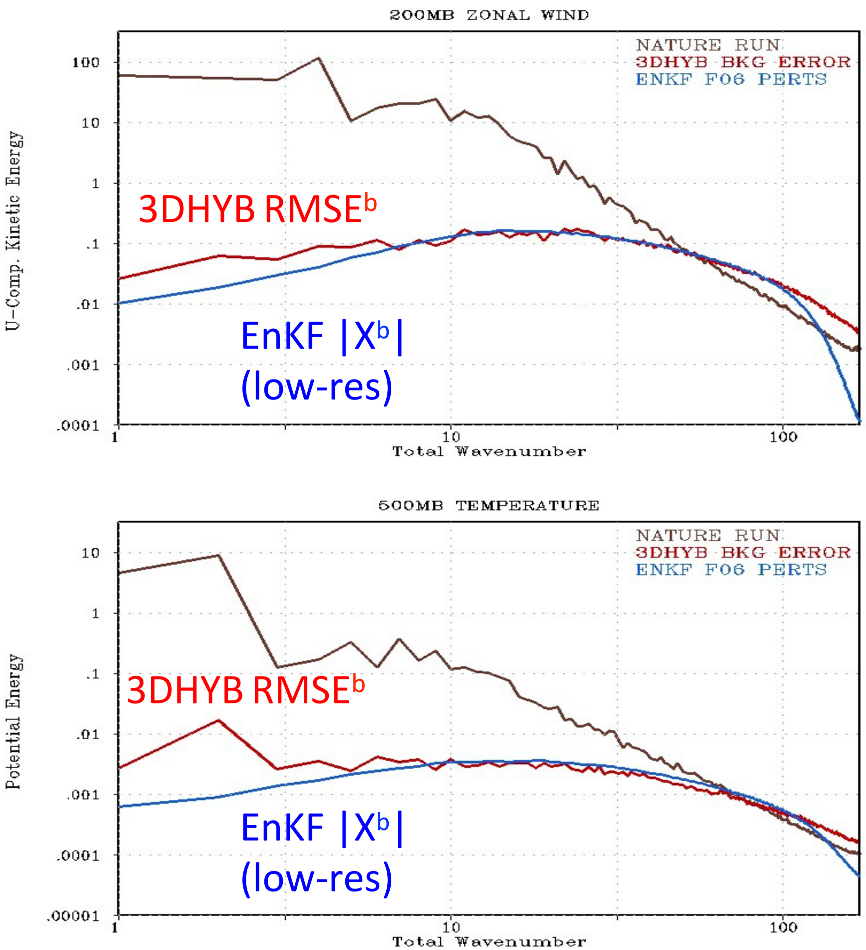
ENS240 – ENS80 | **VTLP240H1 – ENS80** | **VTLP240H2 – ENS80** | **VTLP240H3 – ENS80**



Collaboration with OU. Slide Courtesy of Bo Huang and Xuguang Wang

Hybrid DA System (OSSE-based): Scale-Dependence

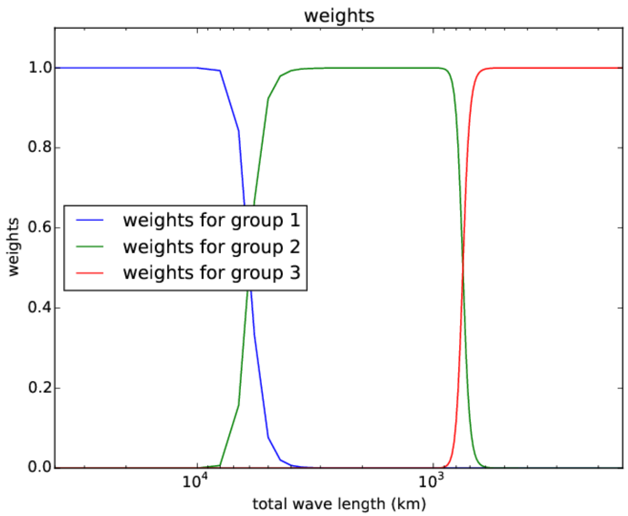
- Dual-resolution hybrid
  - Mismatch in power spectra of ensemble and actual background error
- Potential remedies
  - ***Scale-dependent weights***
  - ***Scale-dependent localization***
  - Dynamic constraints
  - Scale-dependent inflation

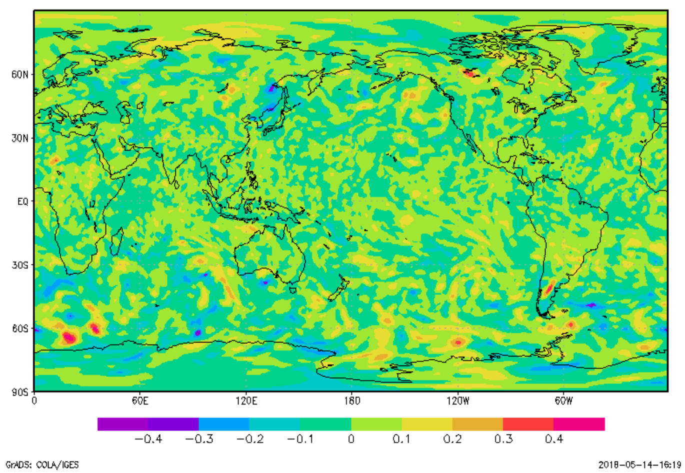


Scale dependent localization (and weighting)

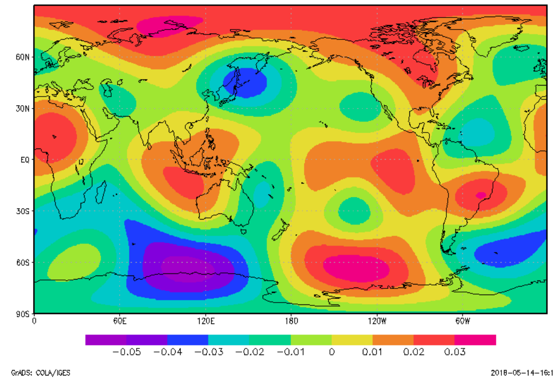
- Have been exploring scale-dependent hybrid weighting (SDW) for several years with some early success
  - ***Collaboration with CWB/Deng-shun Chen***
- UKMO and ECCC have been utilizing scale-dependent localization (SDL) over past several years
  - Work underway at NCEP to implement SDL (Ting Lei)
- Goal is to combine SDL and SDW into multi-scale data assimilation system

Partition ensemble into wavebands
Example: 500 hPa T (member 1)

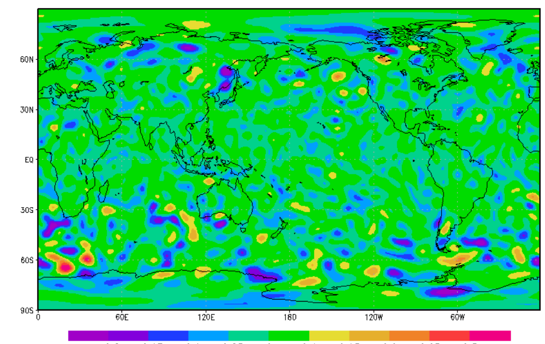




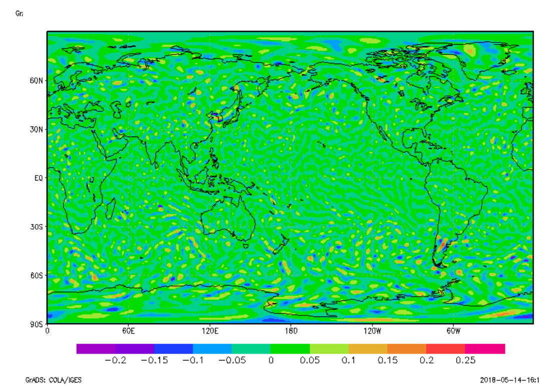
Raw Perturbation



Large



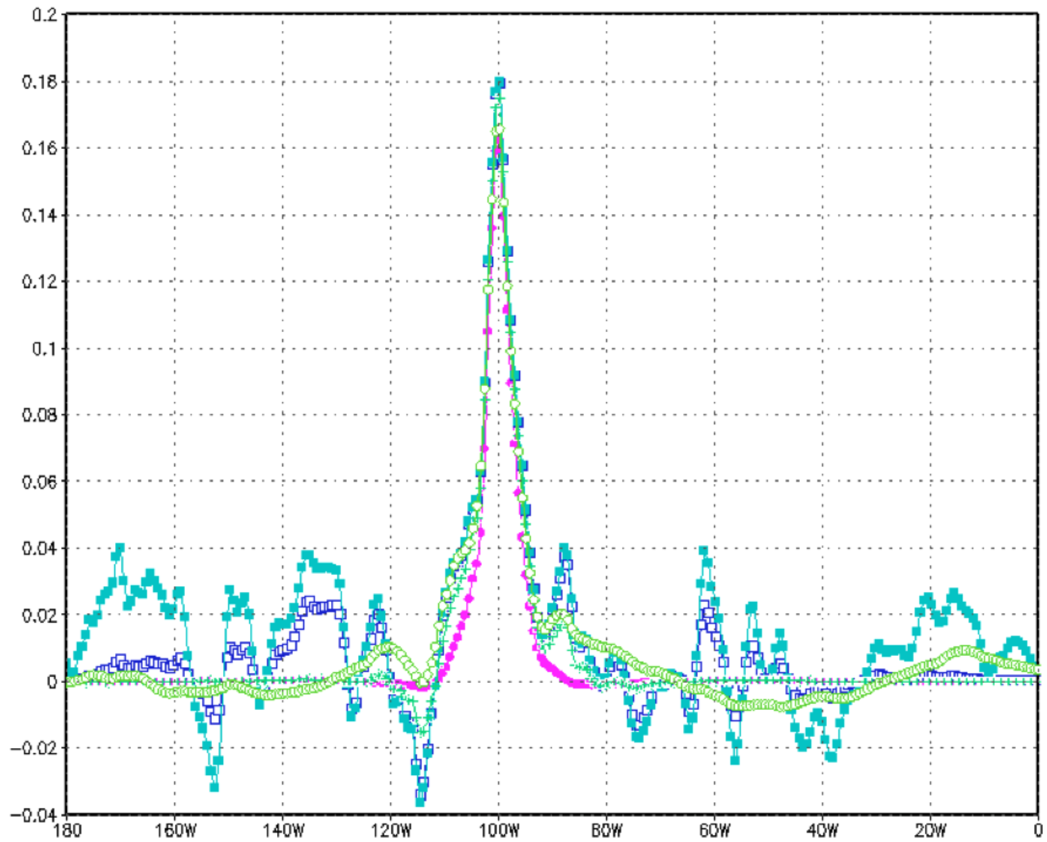
Medium



Small

Ting Lei, EMC

SDL Single Observation Example



- Single scale localization experiments (cyan, blue, purple) compared to SDL scheme (green)

Ting Lei, EMC

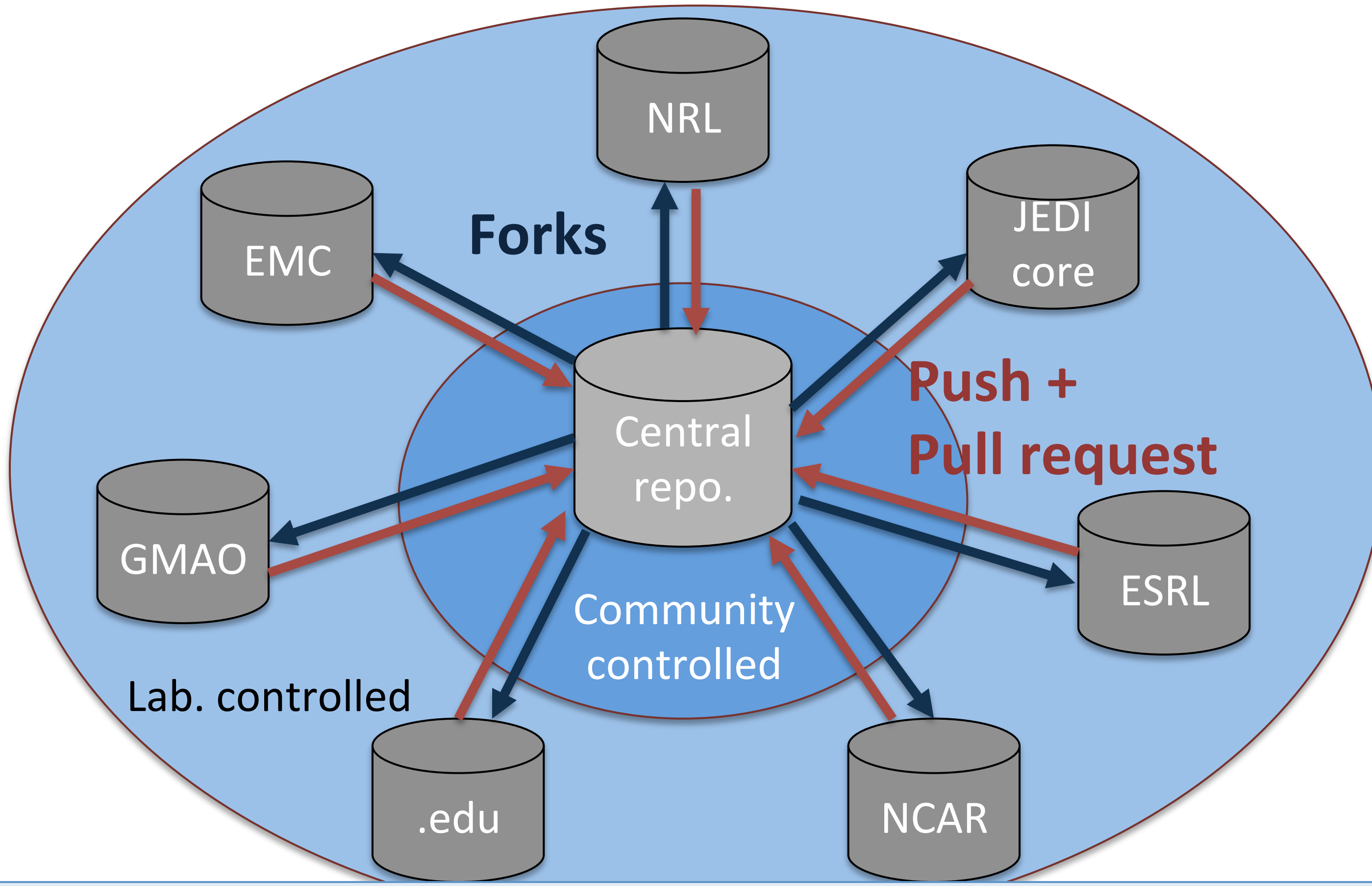
Path of the JEDI

Joint Effort for Data assimilation Integration

Thomas Auligné. Director, Joint Center for Satellite Data Assimilation (JCSDA)

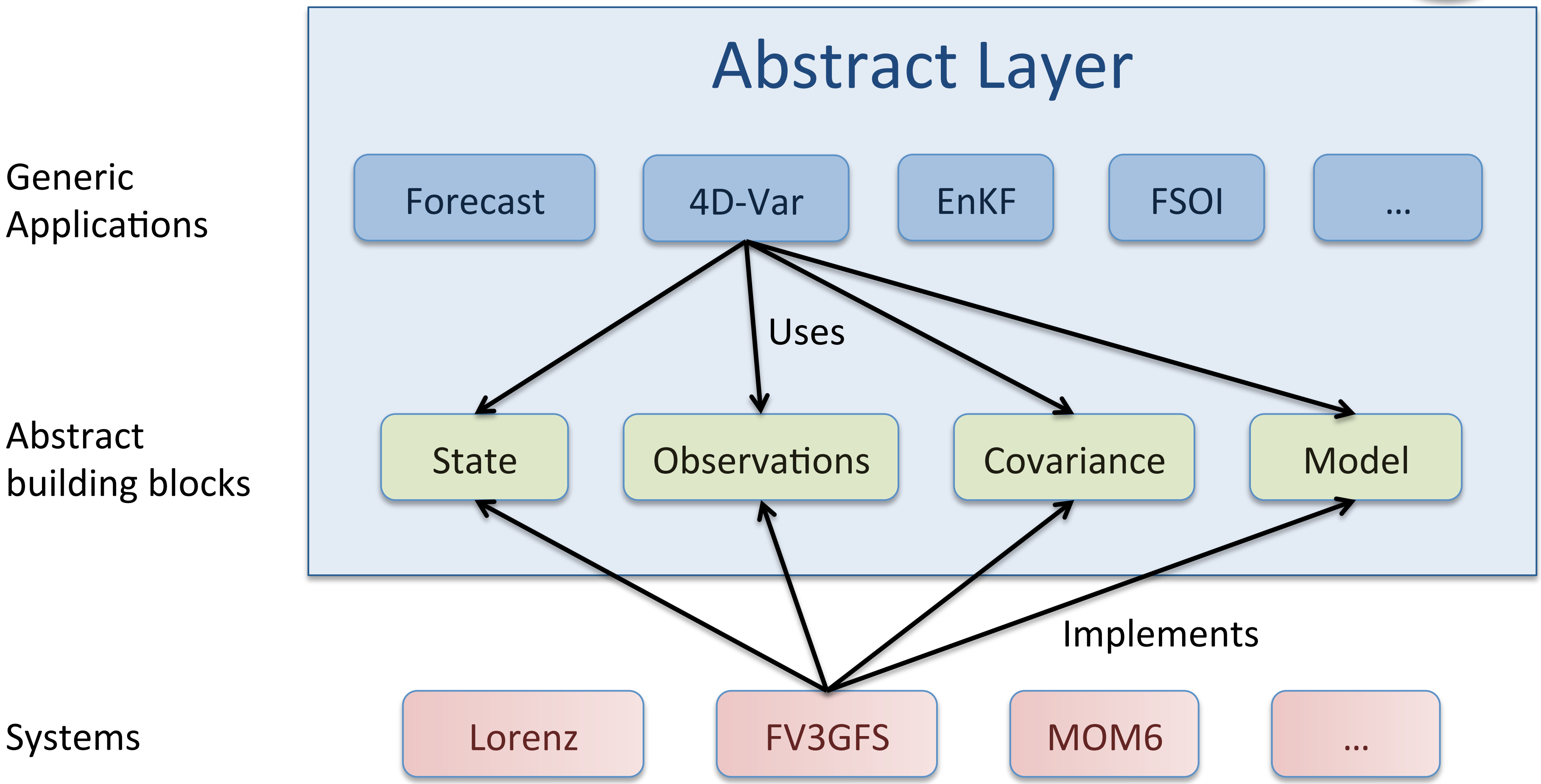
JEDI Team (so far): Amal El Akkraoui, Anna Shlyaeva, Ben Johnson, Ben Ruston, Benjamin Ménétrier, BJ Jung, Bob Oehmke, Bryan Flynt, Bryan Karpowicz, Chris Harrop, Clara Draper, Dan Holdaway, David Davies, David Rundle, Dom Heinzeller, François Vandenberghe, Gael Descombes, Guillaume Vernières, Innocent Souopgui, Jeff Whitaker, Jili Don, Jing Guo, John Michalakes, Marek Wlasak, Mariusz Pagowski, Mark Miesch, Mark Potts, Ming Hu, Rahul Mahajan, Ricardo Todling, Santha Akella, Sarah King, Scott Gregory, Sergey Frolov, Steven Herbener, Steve Penny, Steve Sandbach, Stylianos Flampouris, Tom Auligné, Travis Sluka, Will McCarty, Xin Zhang, Yannick Trémolet (Project Lead).

Joint Effort >> Infrastructure >> Framework >> System



- Community repositories on github.com/JCSDA + flexible build system
- Improved collaborative environment
  (Zenhub issue tracking, Sphinx/ReadTheDocs/Doxygen, Singularity containers)
- Enforce software quality (correctness, coding norms, efficiency)
- Initial work toward continuous integration

Joint Effort >> Infrastructure >> Framework >> System

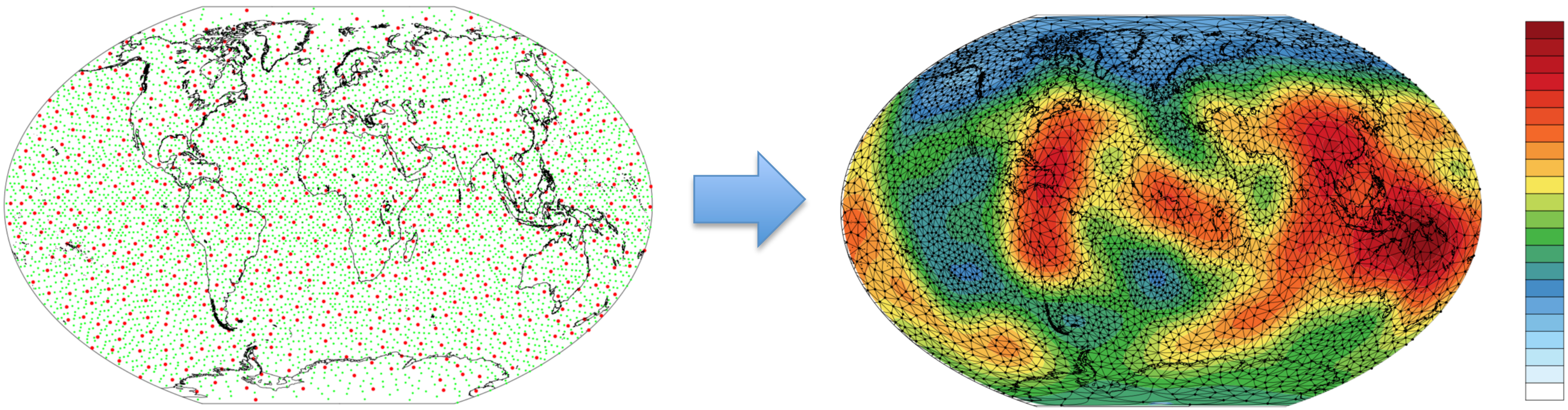


The key idea is separation of concerns

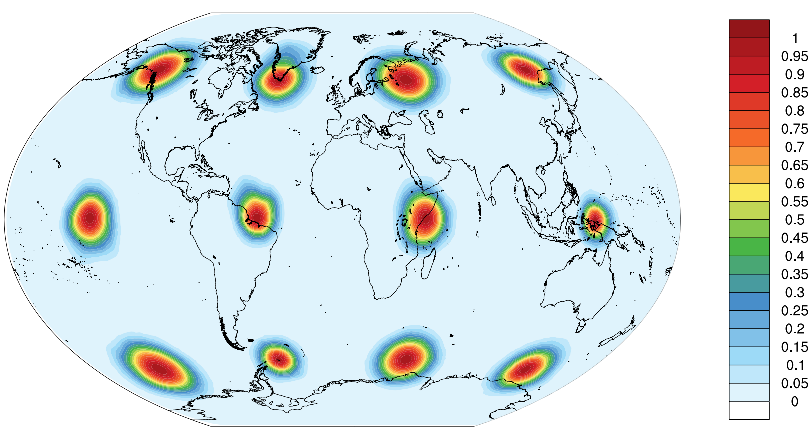
- All aspects exist but scientists focus on one aspect at a time. Nobody can know it all!
- Different concepts should be treated in different parts of the code (interfaces, interfaces!)

B-matrix Unstructured Mesh Package (BUMP)

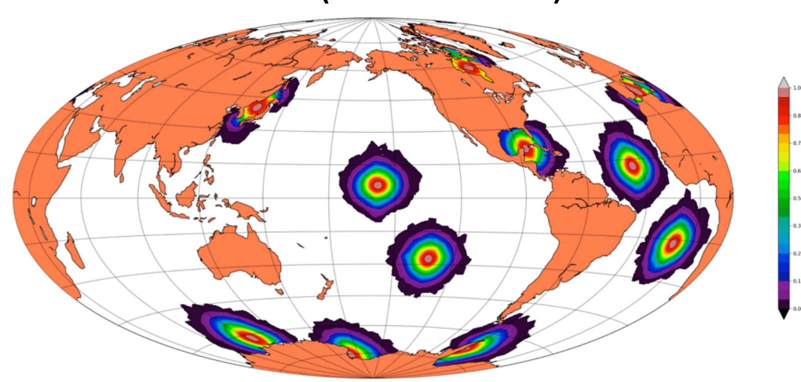
Scope: Generic prototype background error covariances (Ménétrier, 2018)



Atmosphere



Ocean (land-aware)



Global Ocean: Example of localization function for sea-surface temperature

Model Interfacing Status

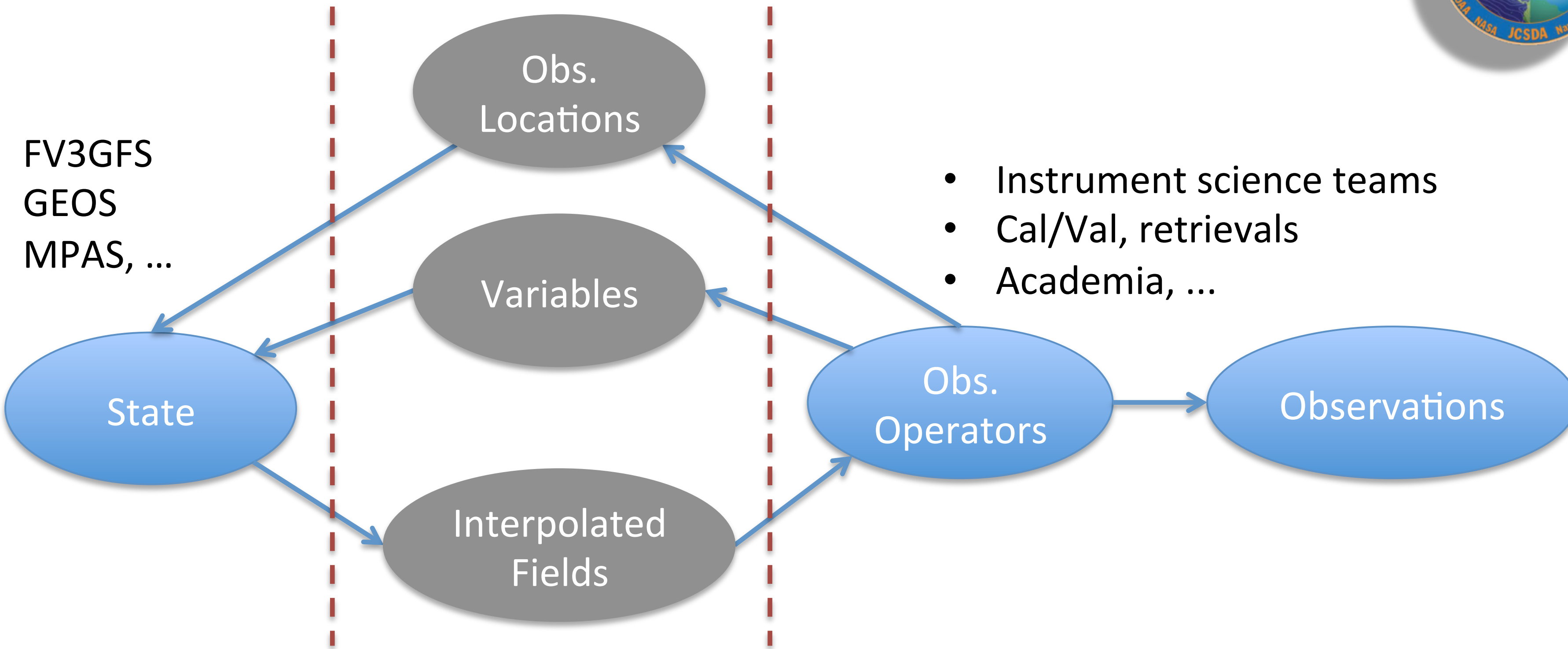
	State	3D H(x)	M(x)	4D H(x)	3D-Var	TL/AD	4D-Var
FV3-GFS (NOAA)	✓	✓	✓	✓	✓	✓ (in progress)	✓ (in progress)
FV3-GEOS (NASA)	✓	✓	✓	✓	✓	✓ (in progress)	✓ (in progress)
MPAS (NCAR)	✓	✓	✓		✓	N/A	N/A
WRF (NCAR/NOAA)	✓ (in progress)						
LFRic (UKMO)	✓	✓	✓ (in progress)		✓	?	
NAVGEM (NRL)	✓ (in progress)						
NEPTUNE (NRL)	✓					?	
CICE5 (JCSDA/NOAA)	✓	✓			✓	N/A	N/A
MOM6 (JCSDA/NOAA)	✓	✓			✓	N/A	N/A

✓ = technically working ✓ = in progress

Note: these are technical results, other aspects in progress or to come:

- B matrix on Unstructured Mesh Package (BUMP, B. Ménétrier).
- Observation error covariance, QC, bias correction

UFO: the interface advantage



- JEDI/UFO introduces standard interfaces between the model and observation worlds
- Observation operators are independent of the model and can easily be shared, exchanged, compared
- **Unified Forward Operator (UFO),** the 'App Store' of Observation Operators

JEDI Project: Ambitious Timeline

Initial Design

- Feb 2017: Collect requirements
- Avr 2017: Unified DA Planning Meeting

Functional Prototype

- Aug 2017: Coding begins
- Mar 2018: Basic 3DEnVar prototype

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Rapid Development

- Aug 2018: Improved prototype, incl. basic Hybrid 4DVar
- Sep 2018: Prototype evaluation panel

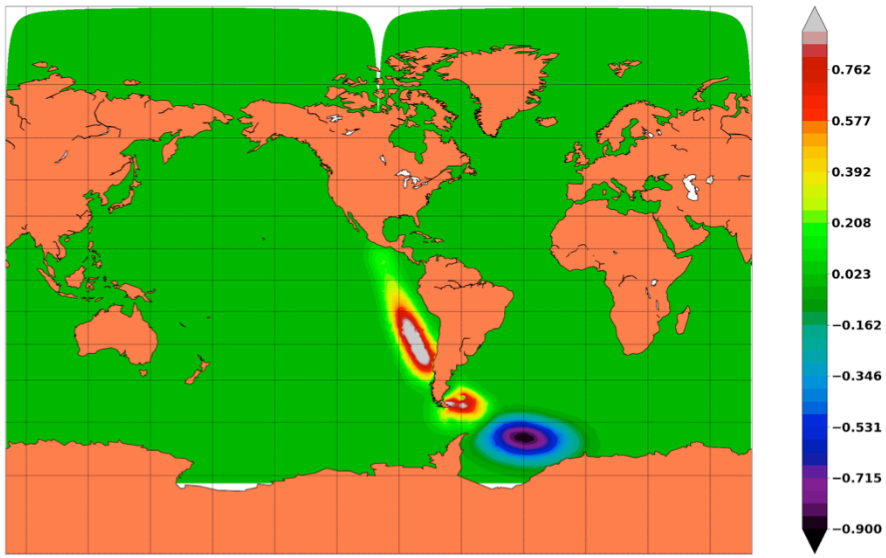
Toward Operations

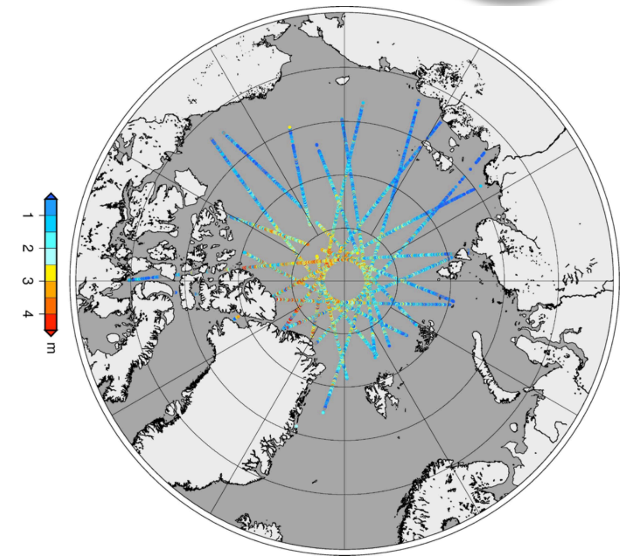
- Nov 2018: Code release and JEDI Academy
- Mar 2020: JEDI-UFO operational implementation
- Mar 2021: JEDI-Solver (Var + Ens.) operational implementation

Basic Prototype: MOM6/SIS2 Increments

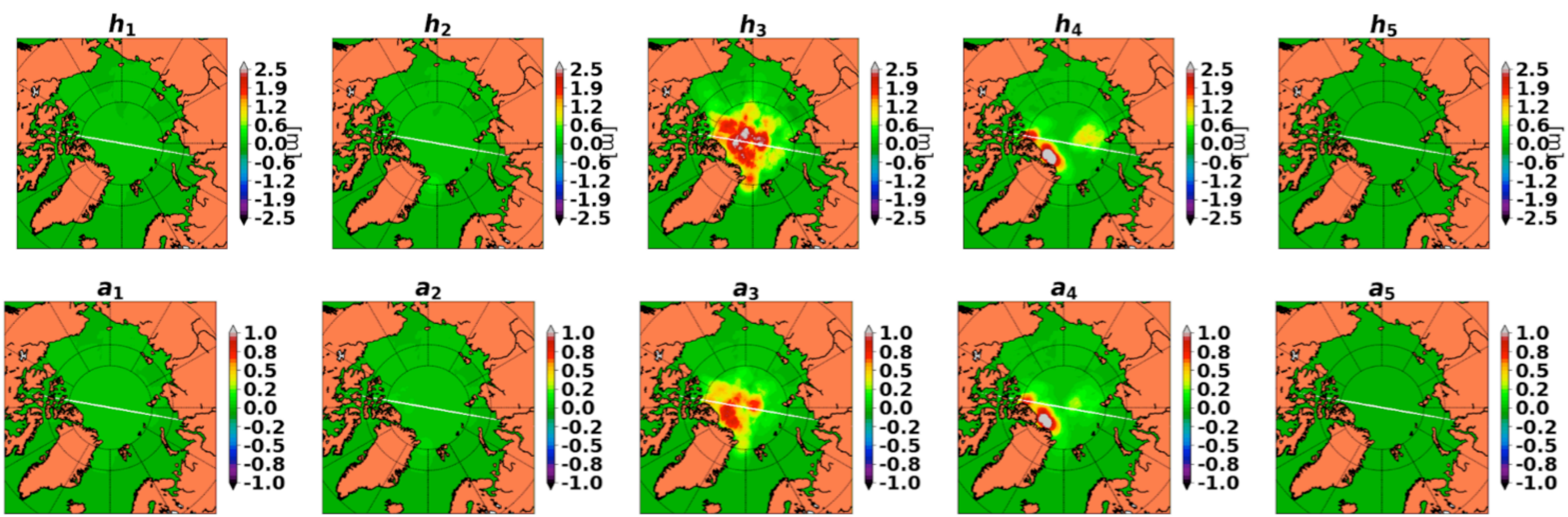
Engineering results only! 3DEnVar prototype (No cycling, many remaining issues)

Increment [m] from the assimilation of absolute dynamic topography from Jason-2.





CryoSat-2 Ice thickness retrieval

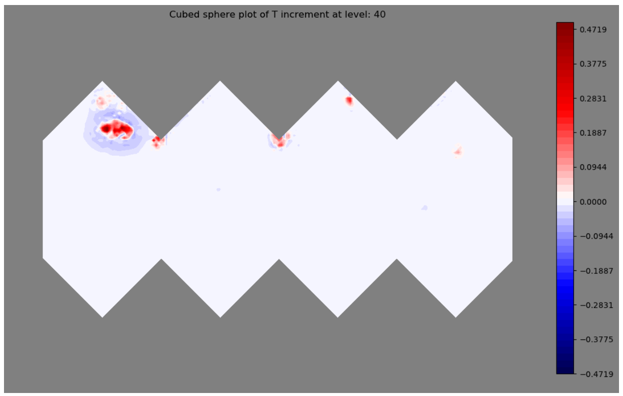


Basic Prototype: FV3 Analysis Increments

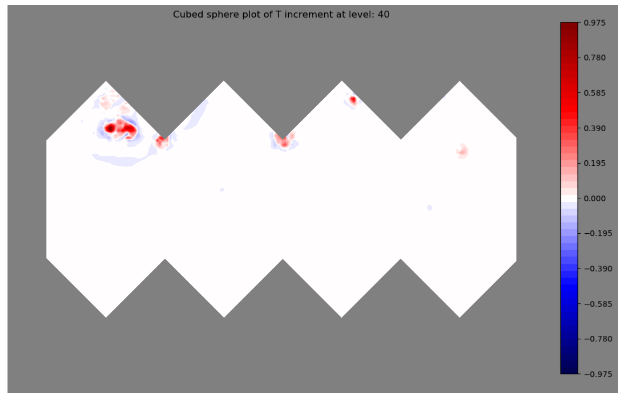
Engineering results only! **4DVar**

- Realistic background; B = I
- 2 outer loops: 20/10 inner loop iterations
- C48 (200km) resolution
- 915 Radiosonde observations from 27 stations.
- Interpolation to observations using BUMP.
- DRIPCG solver from OOPS.

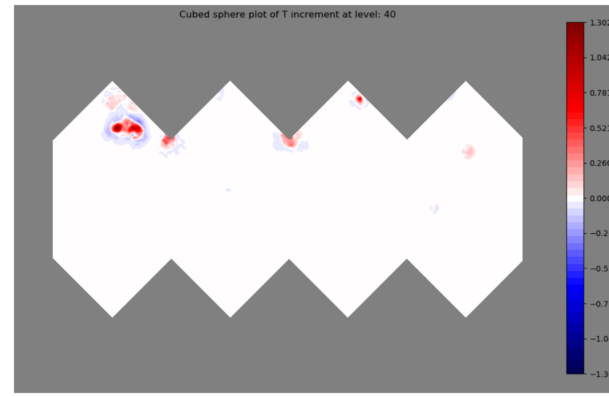
1h

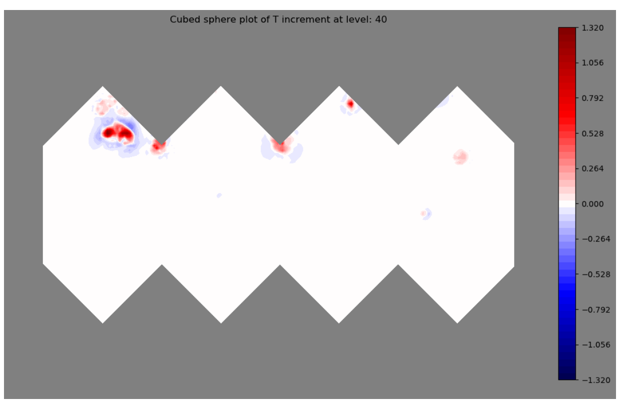


2h

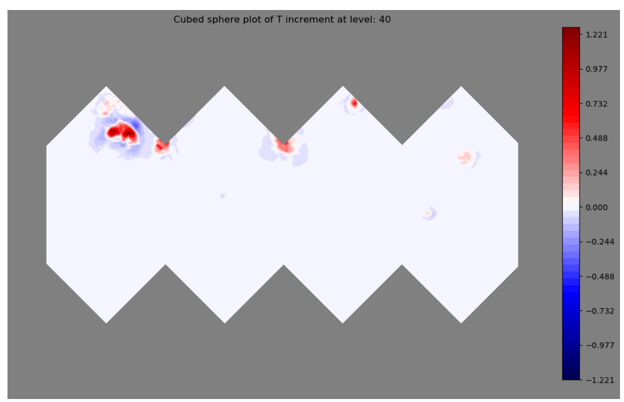


3h

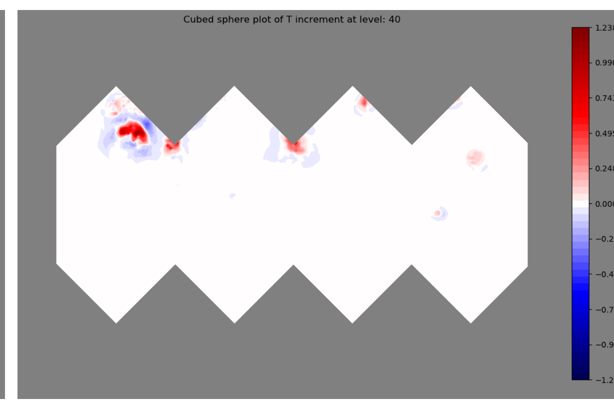




4h



5h



6h

Thank you!