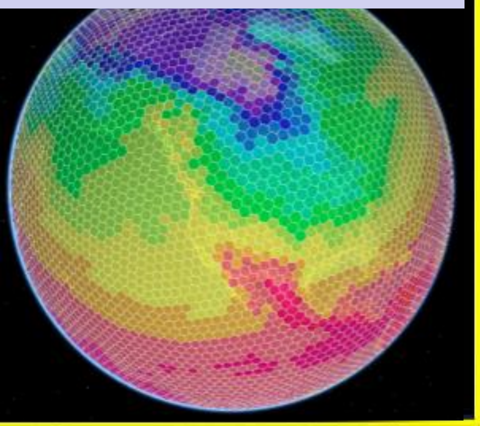
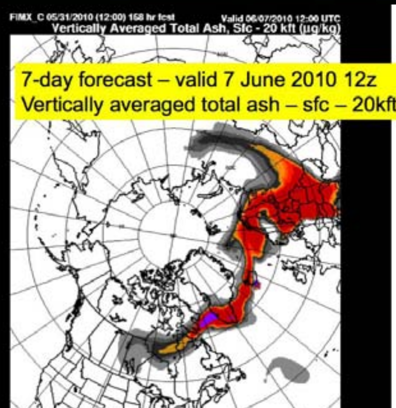
Modeling Activities at the ESRL Global Systems Division

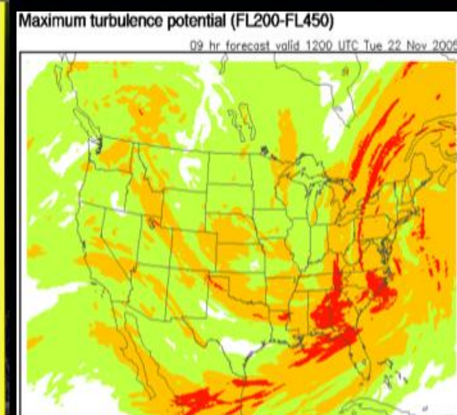
Steven E. Koch, Director

FIM icosahedral grid

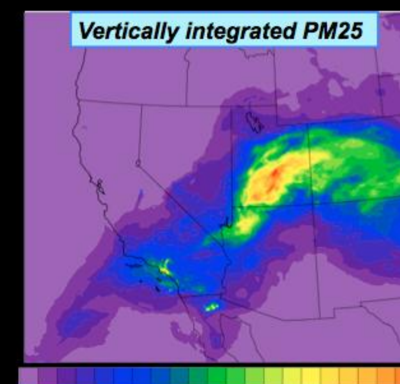




FIM Volcanic ash



RUC Turbulence

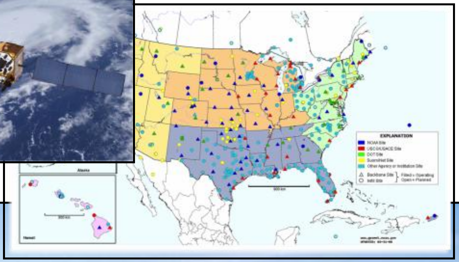


Presentation to the UNIDATA Policy Committee

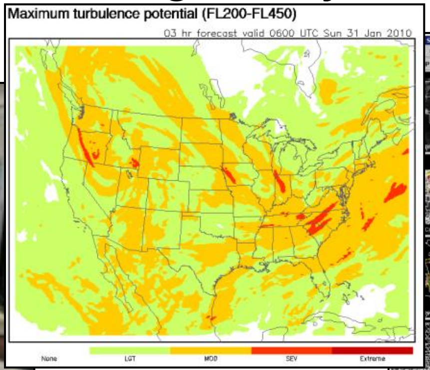
October 21, 2010

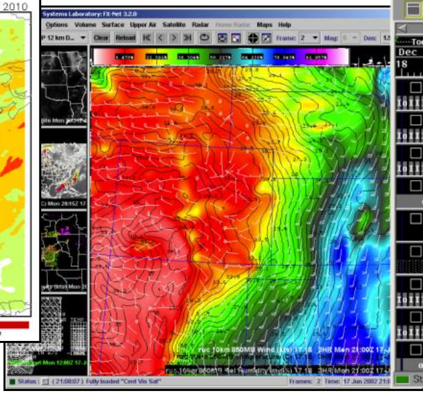
GSD (FSL) Technologies transferred to or used by Operational Weather Services

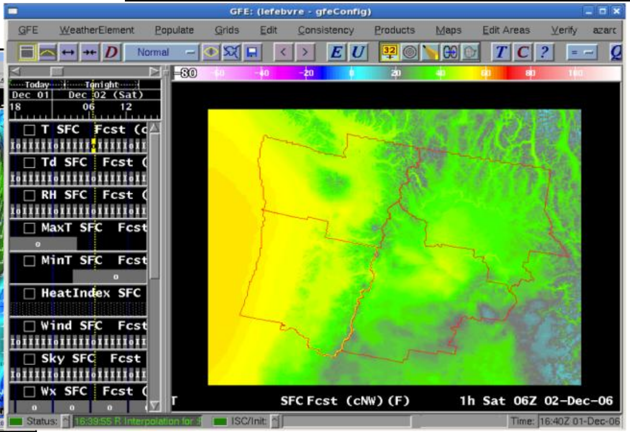
Transition of 26 research technologies since 2000 to operations at NWS Forecast Offices, NCEP/EMC, DOD, private industry, and international meteorological agencies:



- Information Systems
- Observing Systems and Data Impact Studies
- Regional to Global Data Assimilation and Models
- Distributed Local high-resolution Modeling Systems
- Aviation Weather Services & Assessments
- International Meteorological Systems

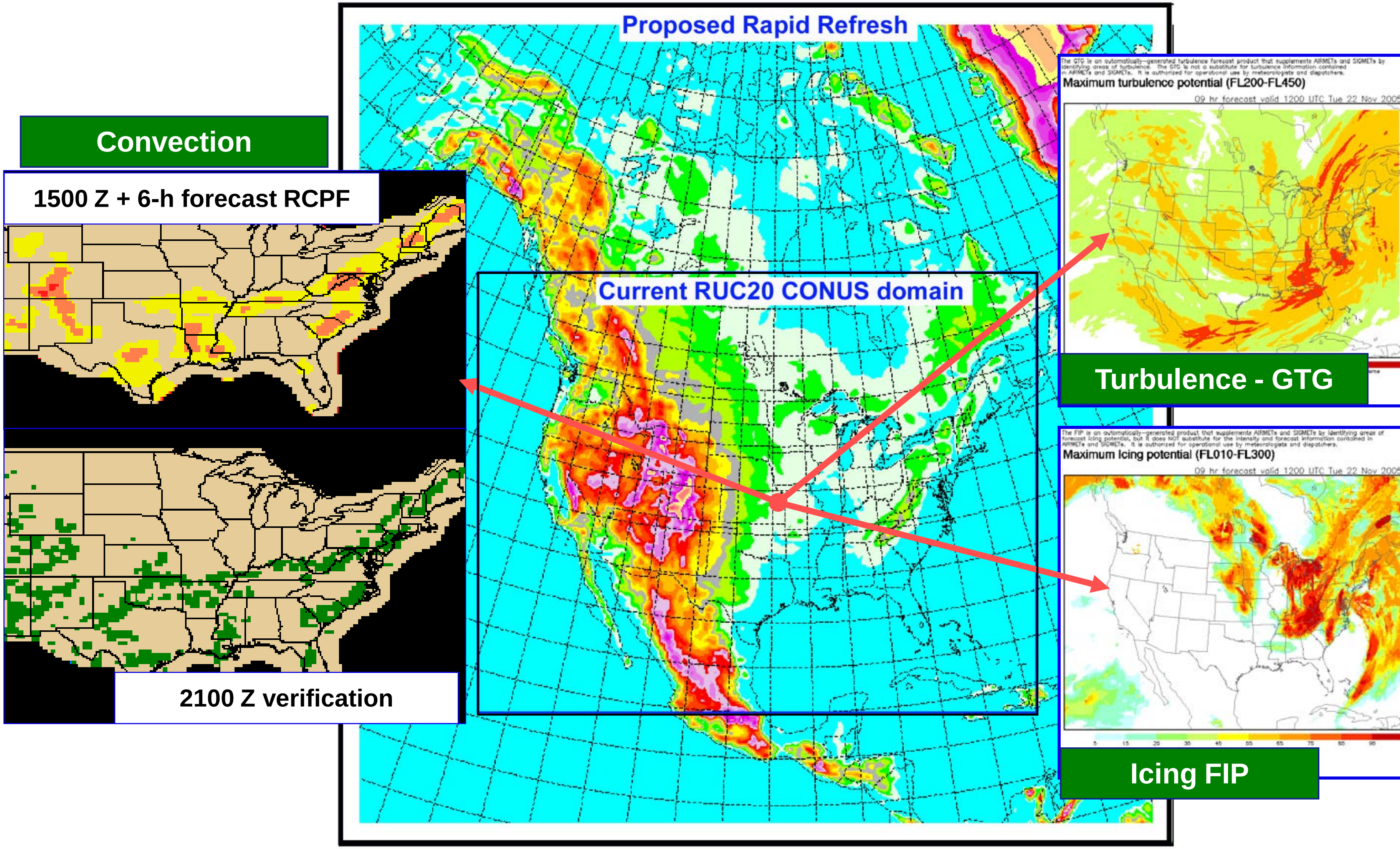






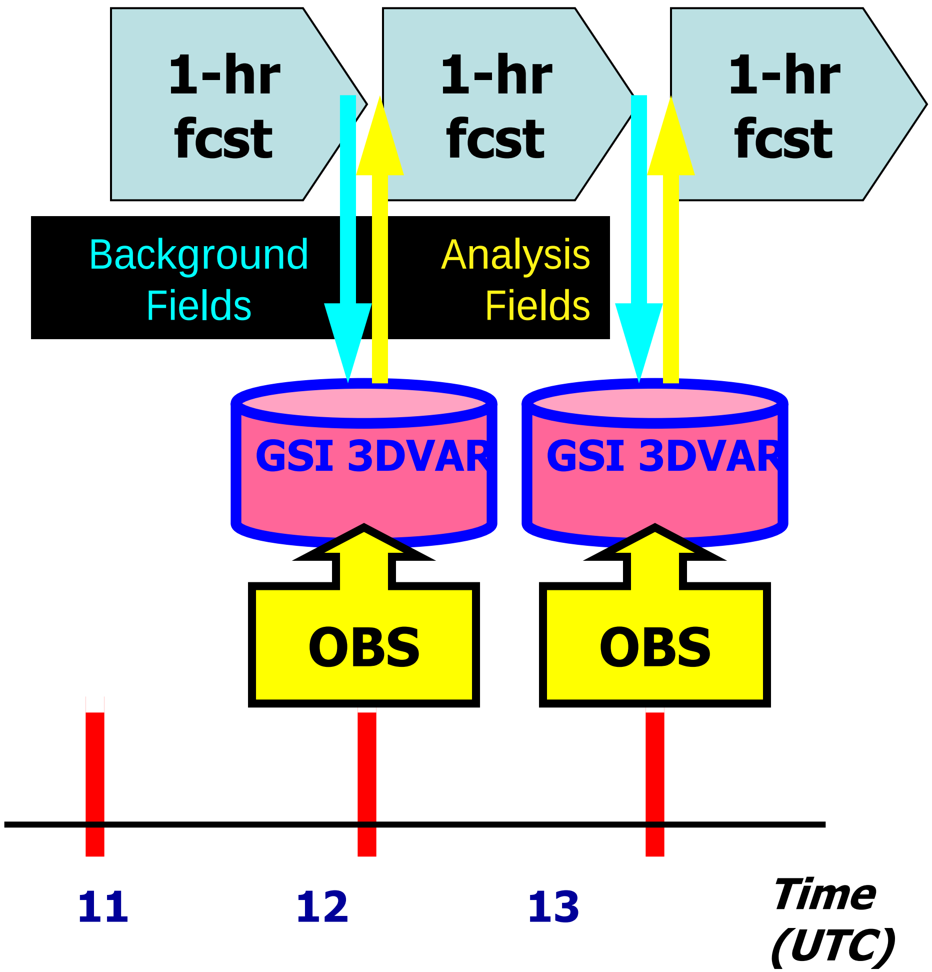
Rapid Update Cycle (RUC) & WRF Rapid Refresh models:

Backbone for high-frequency aviation products



Rapid Refresh model
Hourly Assimilation Cycle

Cycle hydrometeor, soil temp/moisture/snow plus atmosphere state variables



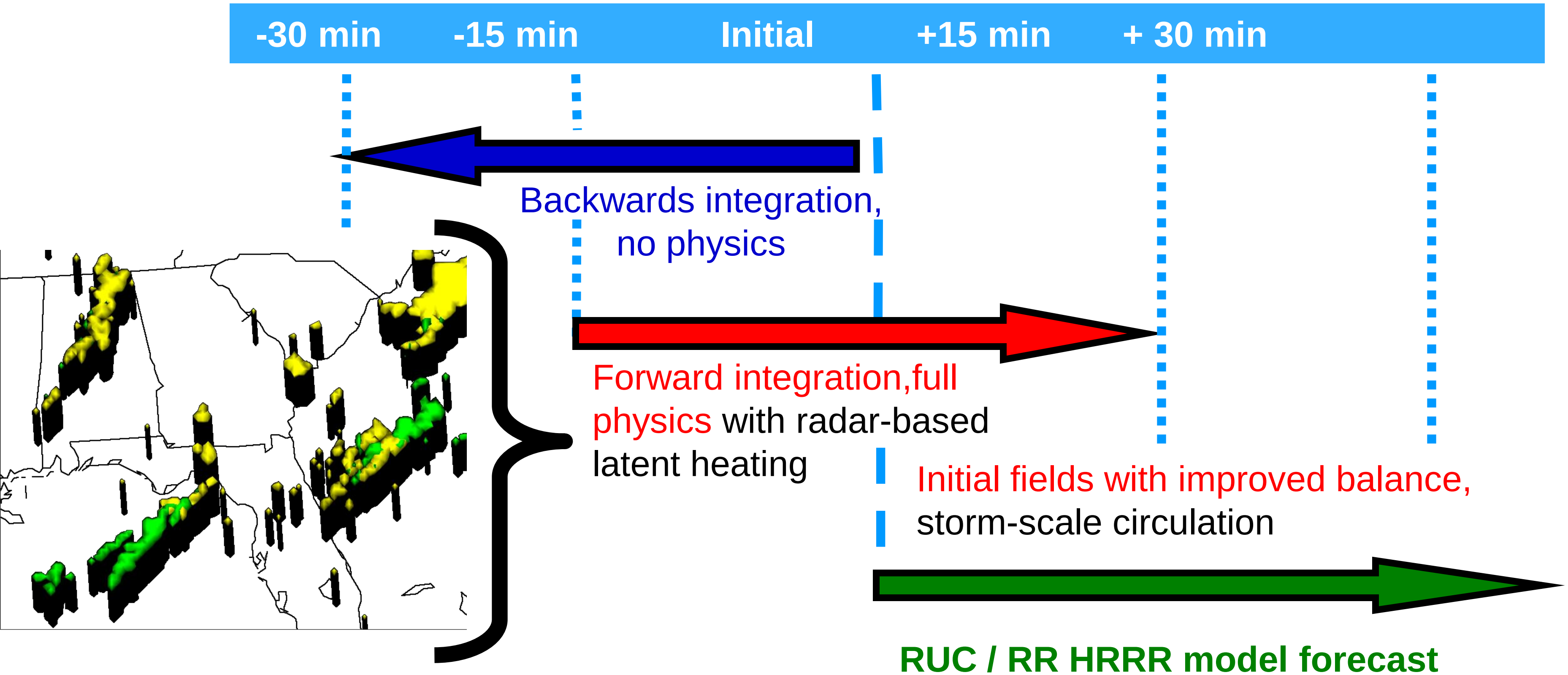
Hourly obs

Data Type	**~Number**
Rawinsonde (12h)	150
NOAA profilers	35
VAD winds	120-140
PBL – CAPS/RASS	~25
Aircraft (V, T)	3500-10000
TAMDAR (V, T, RH)	200-3000
Surface/METAR	2000-2500
Buoy/ship	200-400
GOES cloud winds	4000-8000
GOES cloud-top pres	10 km res
GPS precip water	~ 300
Mesonet (T, P)	~ 8000
Mesonet (V)	~ 4000
METAR-cloud-vis-wx	~ 1800
AMSU-A/B/GOES radiances	
Radar reflectivity/ lightning @1km	

Radar Reflectivity Assimilation

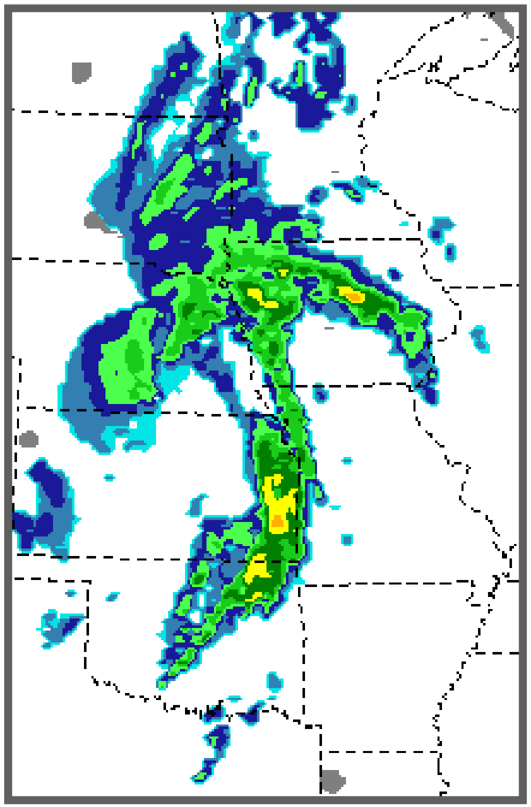
Diabatic Digital Filter Initialization (DFI)

initializes ongoing precipitation regions from observed reflectivity



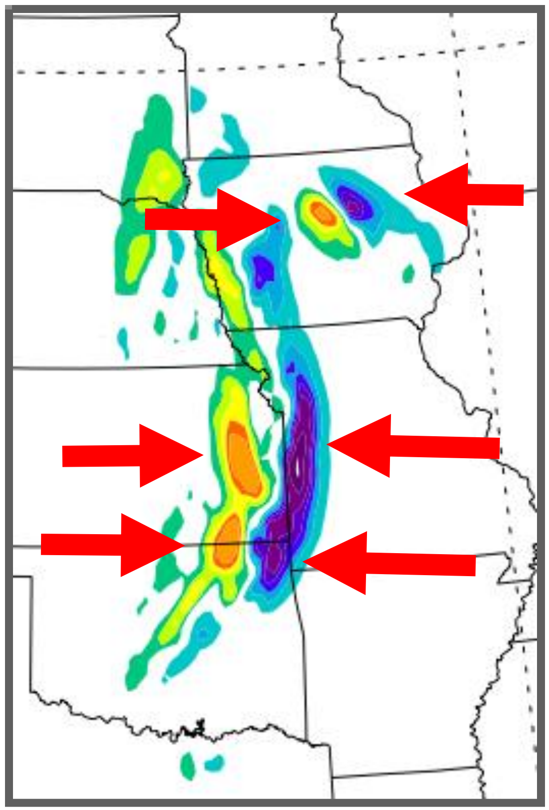
Rapid Refresh Radar Reflectivity assimilation example

NSSL radar reflectivity (dBZ)



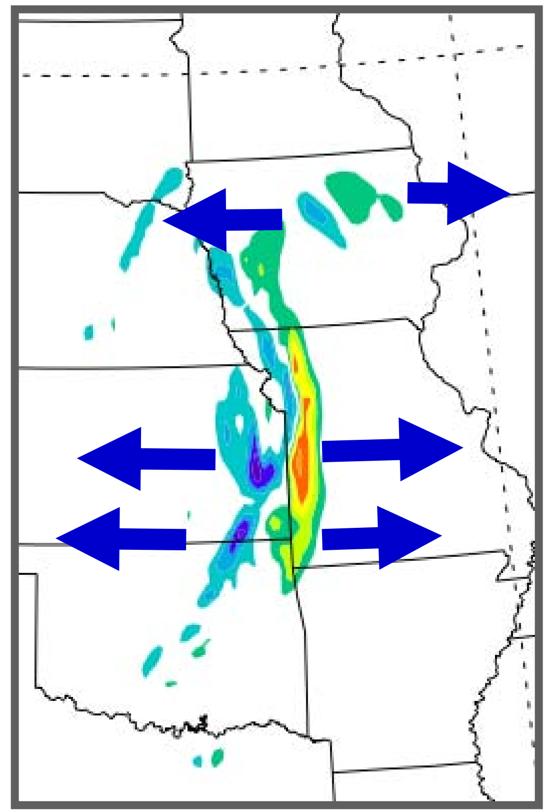
14z 22 Oct 2008
Z = 3 km

Low-level Convergence

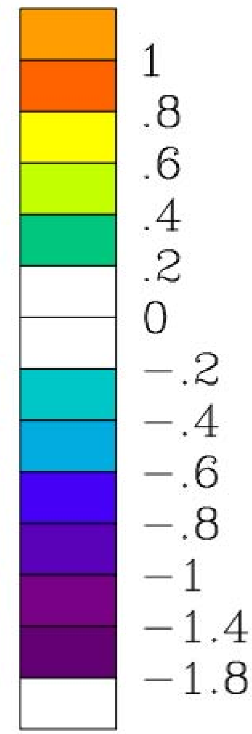


K=4 U-comp. diff (radar - norad)

Upper-level Divergence



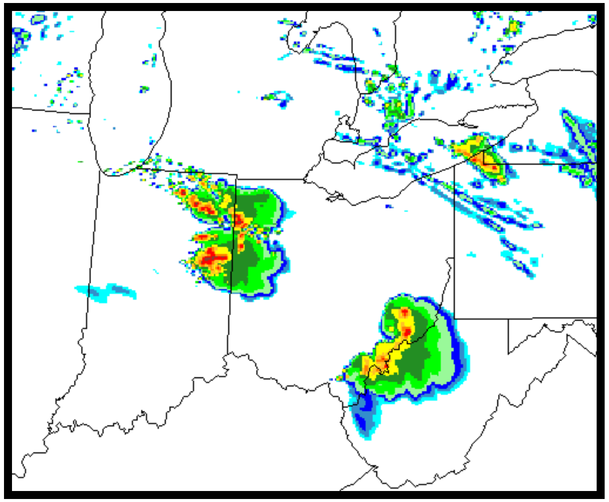
K=17 U-comp. diff (radar - norad)



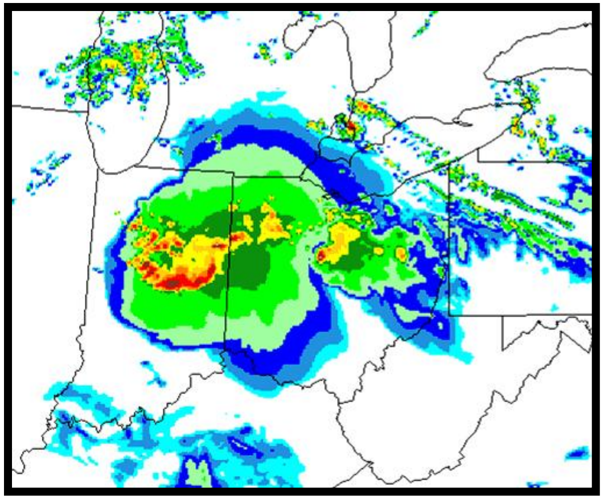
Initializing Convective Storms

Digital Filter-based reflectivity assimilation greatly improves thunderstorm prediction

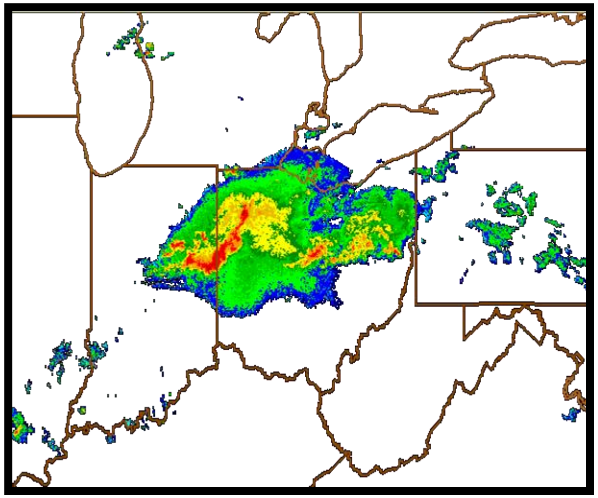
No radar assimilation



RUC radar assimilation



NSSL radar verification



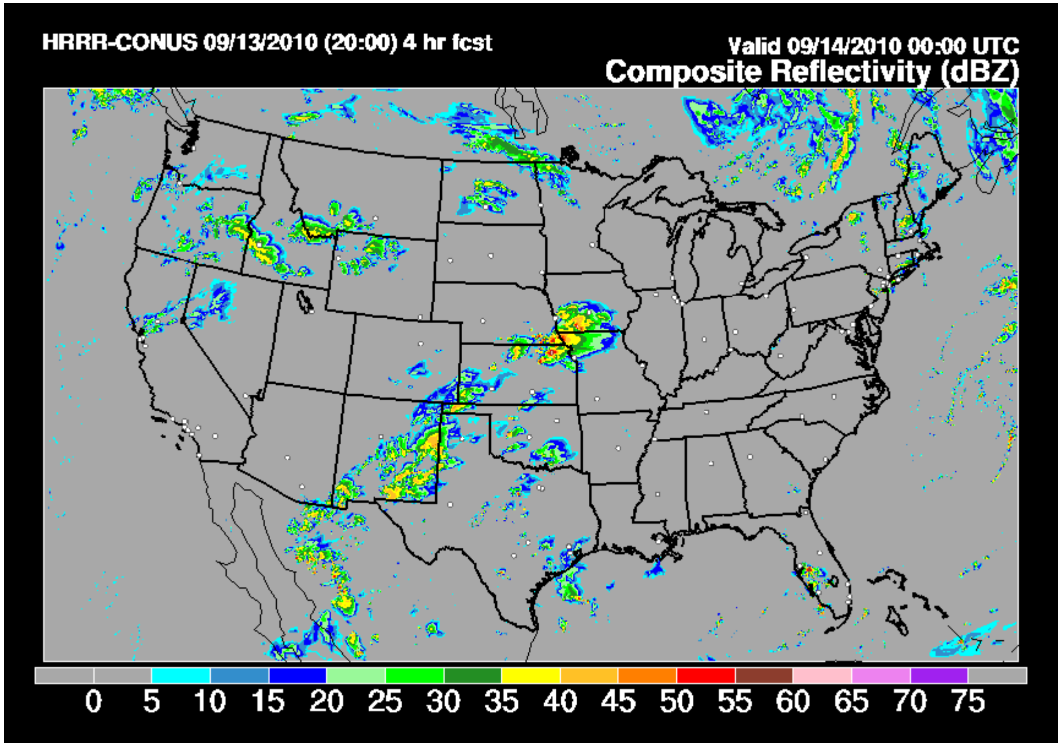
Hi-Res Rapid Refresh 6-h forecasts

06 UTC 16 Aug. 2007

High-Resolution Rapid Refresh (HRRR)

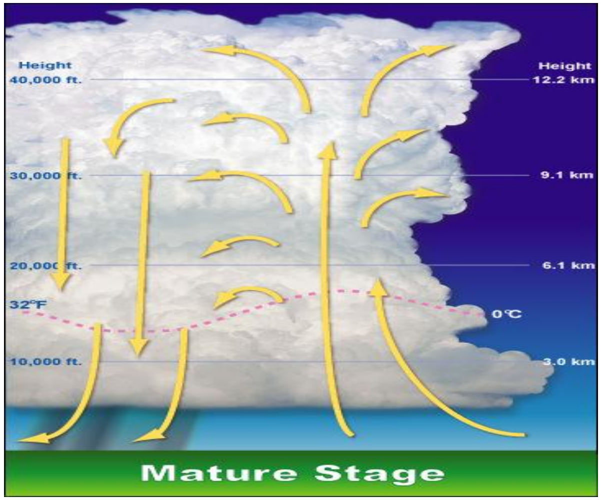
- First hourly-updated storm-scale (3-km) model
- Assimilation of radar reflectivity
- Critical for improved severe weather forecasting

(related applications: aviation, renewable energy, hydrology)

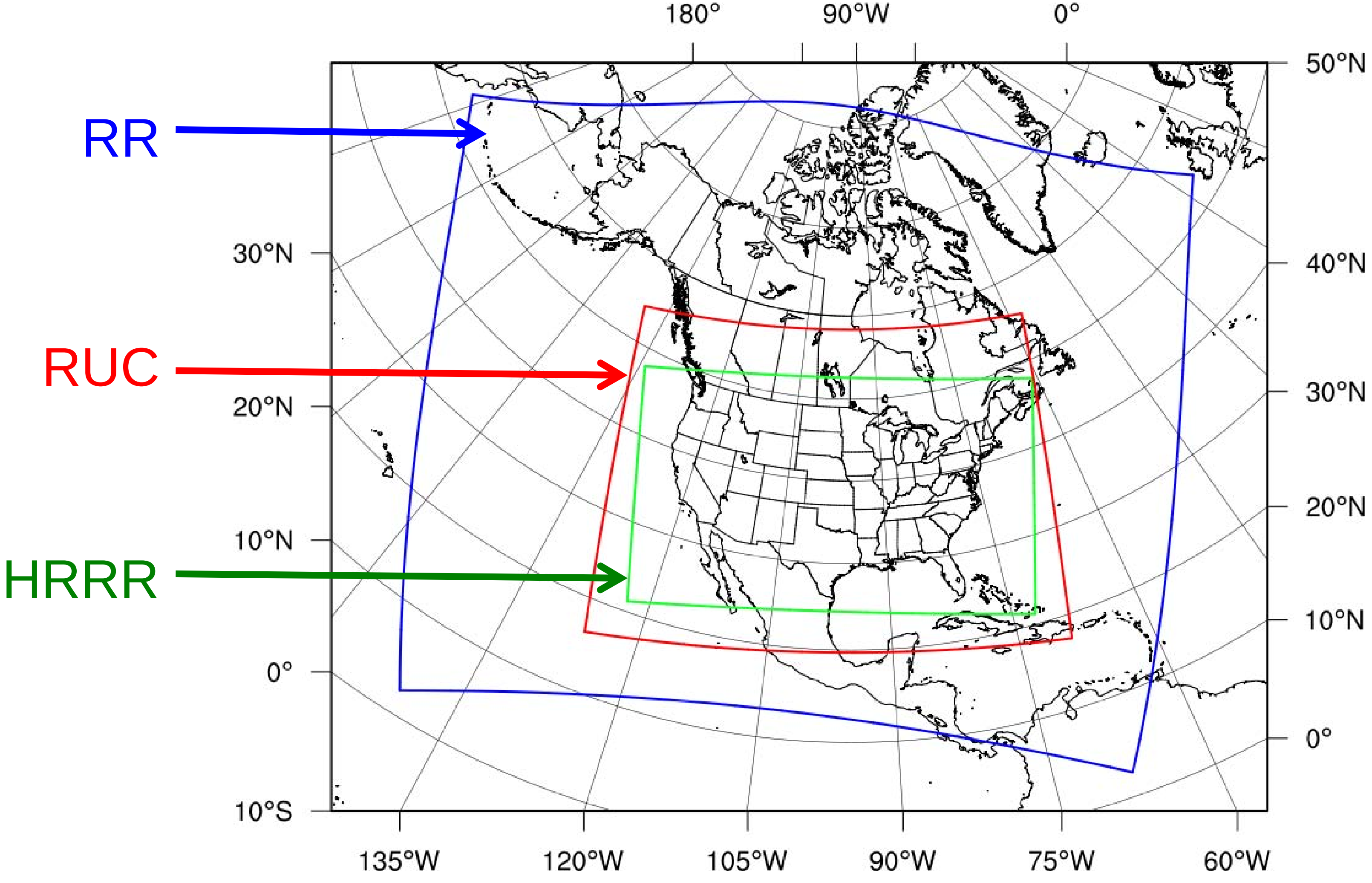


HRRR developed by NOAA ESRL
- Collaboration with NSSL, NCAR, U. Oklahoma

Current status – demo at ESRL on NOAA HPCS computer, FAA/NWS use



Current Model Domains



Regional Rapidly Updated Models at Global Systems Division

Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Height Lowest Level	Pressure Top
RUC	CONUS	451 x 337	13.5 km	50	Sigma/ Isentropic	5 m	~50 mb
RR	North America	758 x 567	13.5 km	50	Sigma	8 m	10 mb
HRRR	CONUS	1799 x 1059	3.0 km	50	Sigma	8 m	85 mb

Model	Version	Time-Step	Forecast Period @NCEP	Initialized	Boundary Conditions	Run Time	# of CPUs
RUC	---	18 s	18 hrs	Hourly (cycled)	NAM	45 min	36
RR	WRF-ARW 3.2	60 s	15 hrs (soon: 18)	Hourly (cycled)	GFS	25 min	160
HRRR	WRF-ARW 3.2	15-20s	15 hrs	Hourly (no-cycle)	RUC	50 min	1000

Model and Data Assimilation Details

Model	Assimilation	DFI	Microphysics	Radiation	Convection	PBL	LSM
RUC	RUC-3DVAR	Yes w/radar	Thompson	RRTM/Dudhia	Grell-Devenyi	MYJ	RUC
RR	GSI	Yes w/radar	Thompson	RRTM/Dudhia	Grell-Devenyi	MYJ	RUC
HRRR	None: uses RUC I.C.	No	Thompson	RRTM/Dudhia	None	MYJ	RUC

HRRR modifications currently being made:

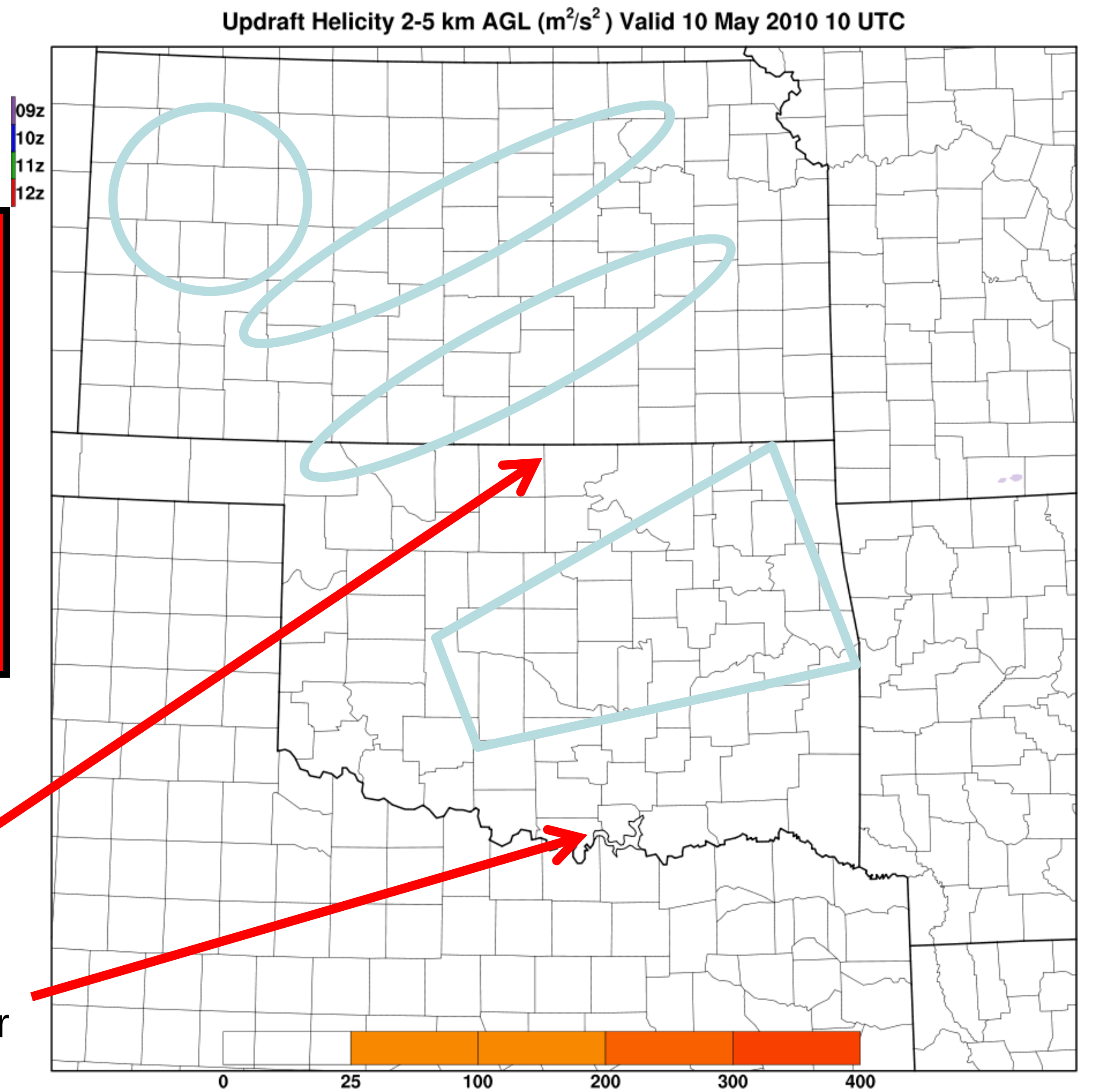
1. Change initial/boundary conditions from RUC to RR
2. Assimilation of radar reflectivity in HRRR @ 3km to:
   - Specify/clear hydrometeors (rain, snow, graupel)
   - Establish 3-D radar temperature tendency (latent heating)
   - Apply diabatic digital filter initialization (DFI)

HRRR Forecasts for Warn On Forecast

Tornado Outbreak KS/OK
10 May 2010

Updraft helicity from four consecutive HRRR runs **09-12 UTC** (color coded by run)

Tornado Reports Up to valid time (red dots)

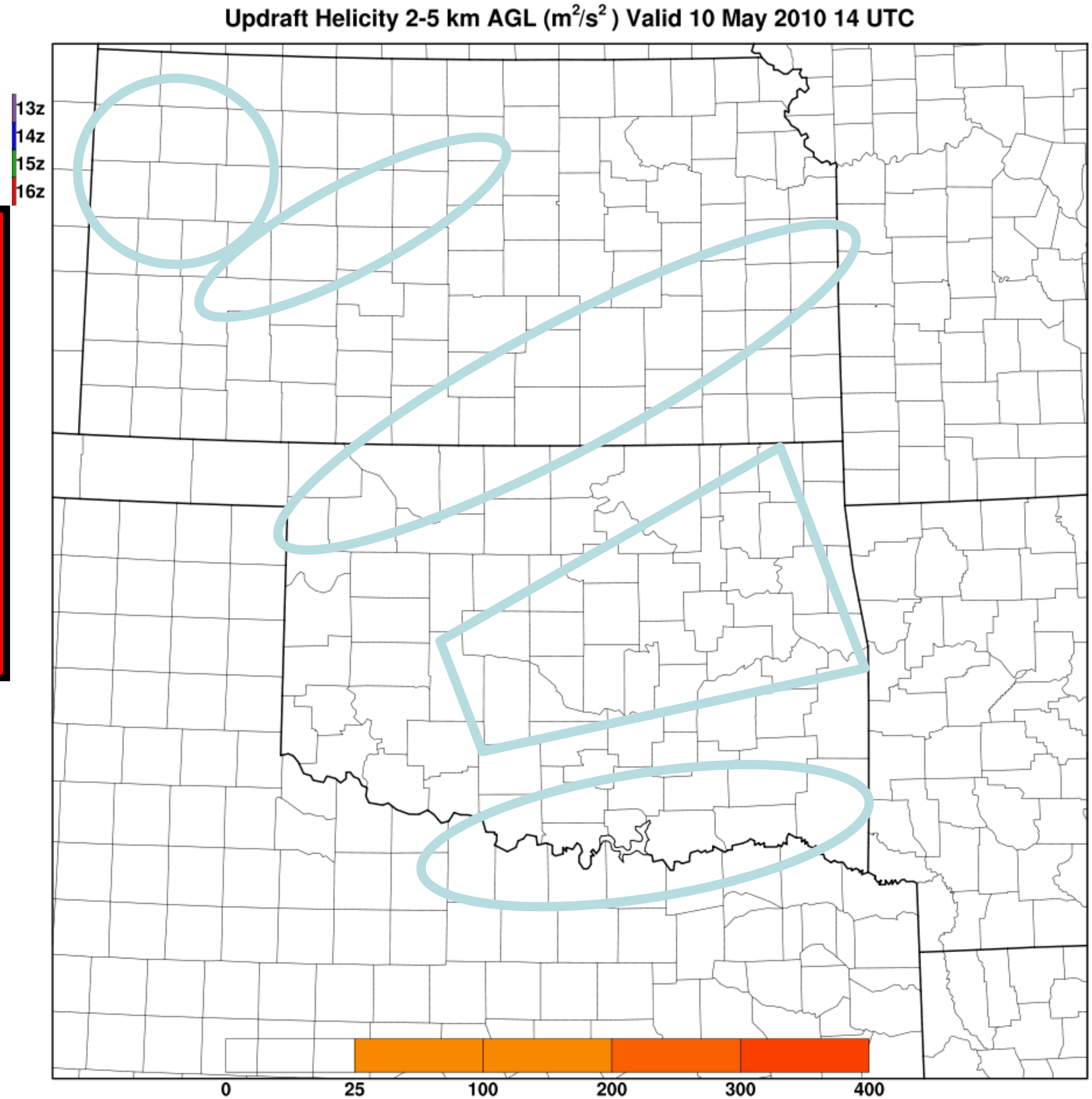


No organized convection forecasted near storm track

No organized convection Forecasted near Red River

HRRR Forecasts for Warn On Forecast

Tornado Outbreak KS/OK
10 May 2010



Updraft helicity from four consecutive HRRR runs **13-16 UTC** (color coded by run)

Tornado Reports
Up to valid time
(red dots)

GSD Mission Statement

Global Systems Division conducts research and development to provide NOAA and the nation with observing, prediction, computer and information systems that deliver environmental products ranging from local to global predictions of short-range, high impact weather and air quality events to longer-term intraseasonal climate forecasts.

Transferring science and technology to the Nation's weather and climate services

NOAA Grand Challenge

Develop and apply holistic, integrated Earth system approaches to understand the processes that connect changes in the atmosphere, ocean, space, land surface, and cryosphere with ecosystems, organisms and humans over different scales.

**As identified at the NOAA Science Workshop (April 2010) + NGSP*

Modeling and Data Assimilation Activities at ESRL/GSD

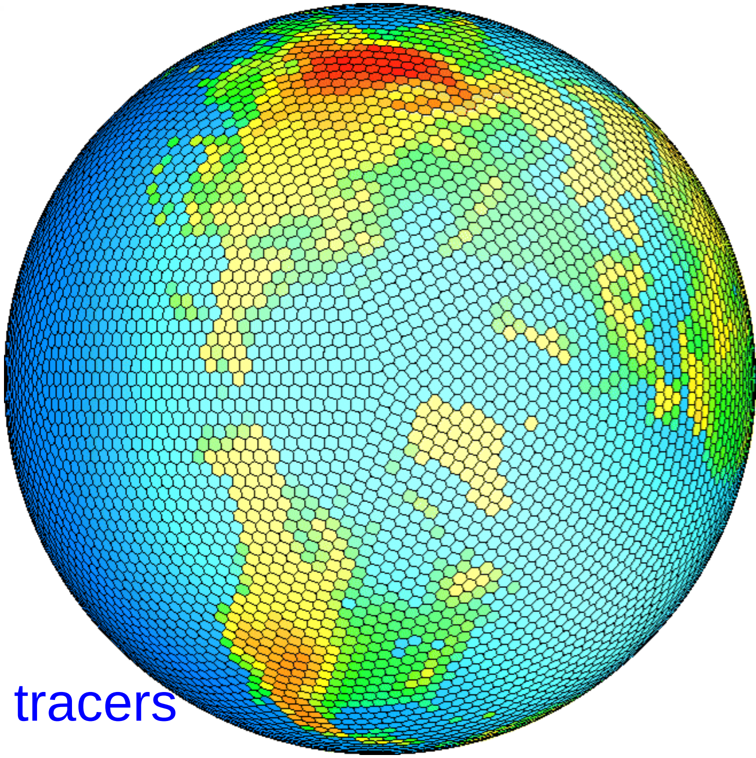
Current

- Rapid Update Cycle Model Guidance for Aviation and Severe Weather Forecasting: AWC, SPC, HWT
- FIM Global Atmospheric Model
- Hurricane Intensity and Track Forecast Improvements
- WRF-Chem Air Quality (Ozone, PM2.5) Prediction
- Observing System Impact Assessments (OSE)
- Ensemble modeling systems: HMT, HFIP, …

Future

- Warn On Forecast – High Resolution Rapid Refresh
- NIM Global Earth System Model
- Weather-Climate Linkage Prediction (MJO)
- Global Aerosol and Volcanic Ash Transport
- Observing System Simulation Experiments (OSSE)
- Common Earth System Modeling Framework (ESMF) using model ensembles (NUOPC)

Flow-following, finite volume Icosahedral Model (FIM)



- Finite volume numerics for conservation
- Icosahedral grid for grid size near-uniformity
- Flux form hybrid isentropic-sigma coordinate for tracers
- Hydrostatic dynamics tested down to 10 km resolution (future: NIM)
- Coupling with air chemistry, ocean, land surface components under ESMF
- Initialized with GFS 3DVAR GSI analysis or EnKF data assimilation methods
- Employs latest GFS physics suite (others being tested)

- Runs to 10 days
- Domains: CONUS, W.Pac, W.Atl, Arctic, S. Hem, Africa, Europe/Asia

http://fim.noaa.gov

Earth System Research Laboratory

Flow-following finite-volume Icosahedral Model (FIM)

Current and Forecast Graphics

FIM Plots

30km FIM (GSI-GFS init)
30km FIMY (EnKF init)
60km FIMX (FIM-Chem-Ash - 08/04 - EnKF init)
60km FIM (GSI-GFS init)
30km FIMZ (08/01 - EnKF init)
15km FIMZ (EnKF init)

HFIP-FIM-EnKF- Tracks - Fcsts
FIM GRIB viewer
Ice/snow - SST

Soundings

Interactive (Java)

FIM Status

FIM/FIMX/FIMY Status

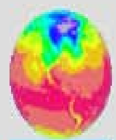
Other NOAA Model Products

NCEP Model Products (GFS,etc.)

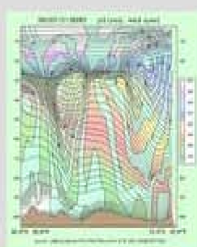
Organization

RUC home
Rapid Refresh home
FIM Staff
AMB/GSD Staff
ESRL/GSD

The FIM Global Model



Icosahedral grid



Isentropic-hybrid vert coord

A unique combination of 3 numerical design features

- Icosahedral horizontal grid, mostly hexagons except for 12 pentagons ("I" in FIM)
- Isentropic-sigma hybrid vertical coordinate, adaptive, concentrates around frontal zones, tropopause, similar to RUC model ("F" for Flow-following in FIM)
- Finite-volume horizontal transport (Also under "F", for "finite-volume" in FIM)

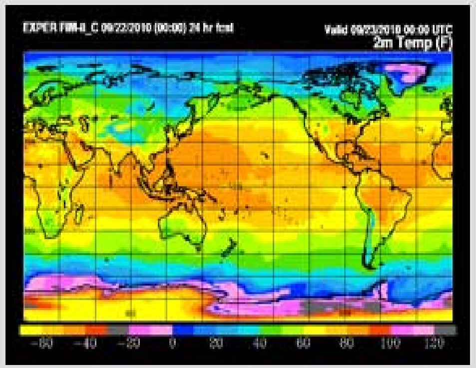
News Items

- ***14 Sept 2010 - Update:***

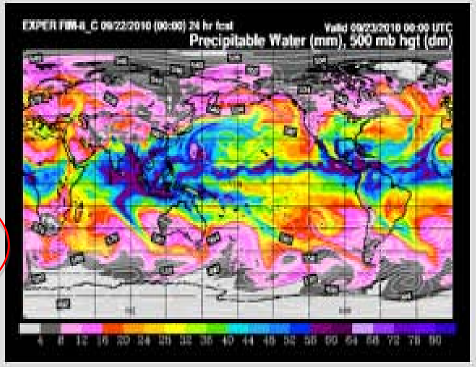
All FIM runs are now updated to "new" (2010) GFS physics suite, including the vanilla 30km FIM run with GSI initial conditions.

- ***1 Sept 2010 - Update:***

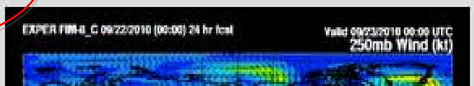
1. 15km FIM added (using new GFS physics and EnKF initial conditions) - run daily at 00z.



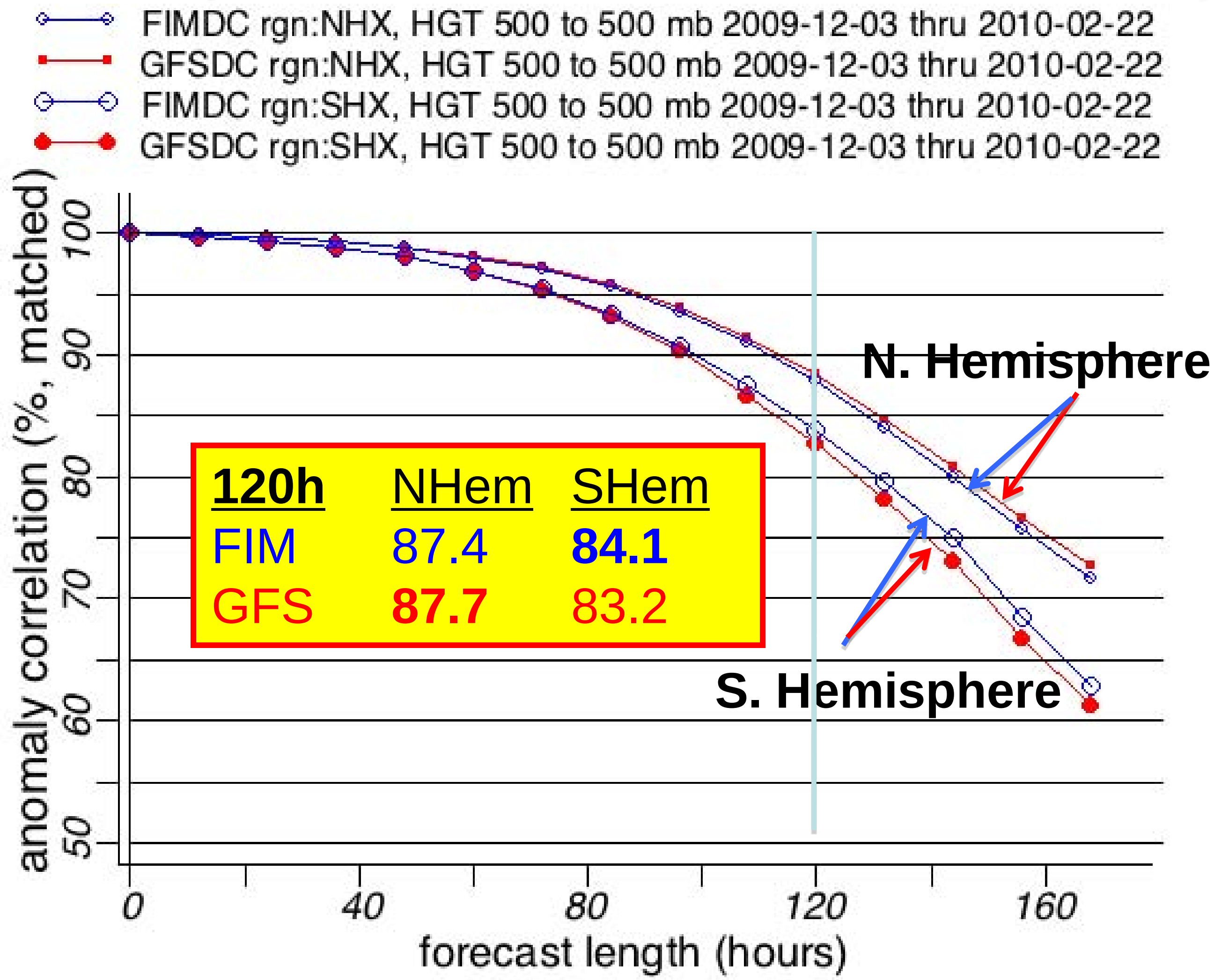
2-m Temperature



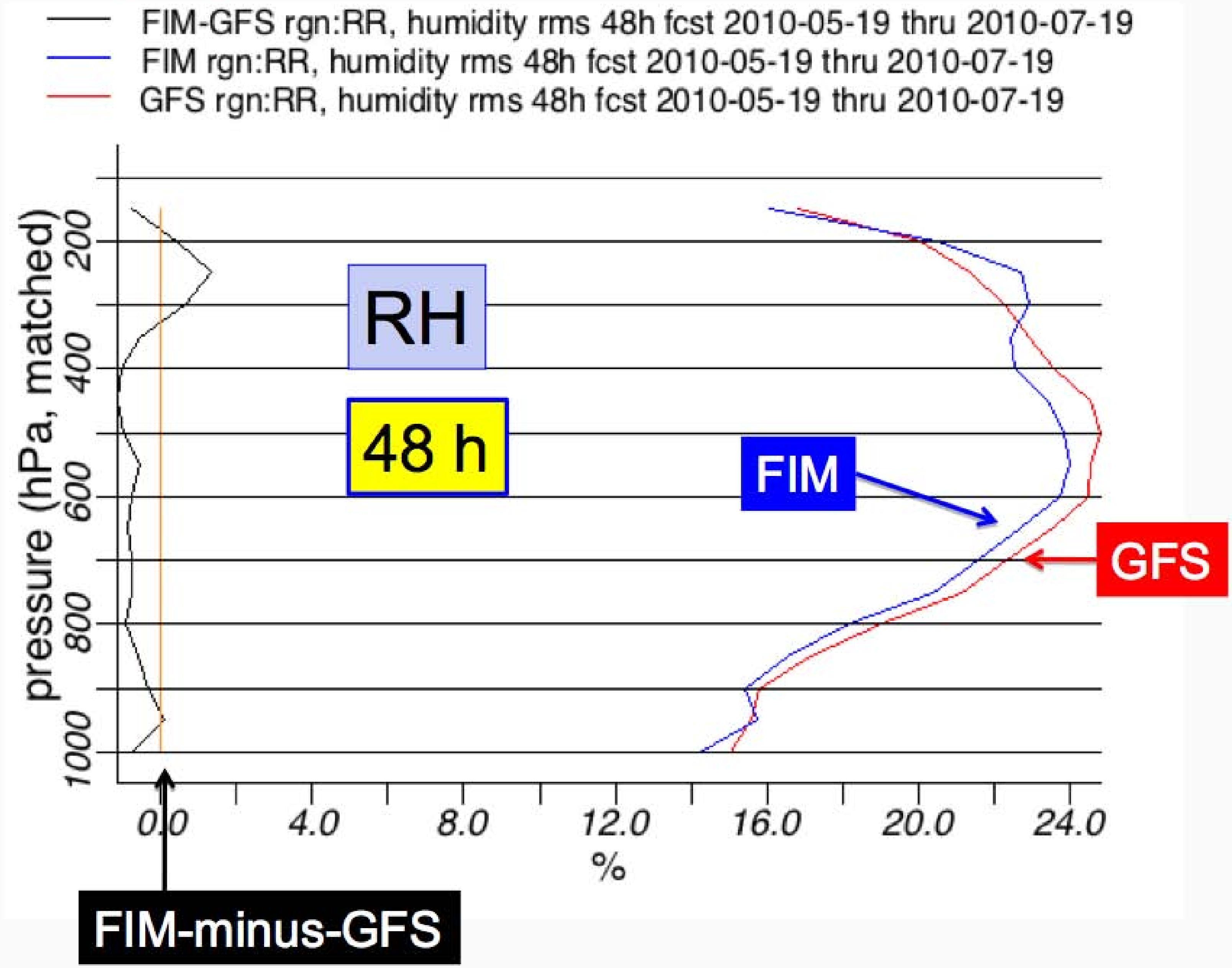
Precipitable Water/500hPa Height



30-km FIM vs. GFS, 500-hPa anomaly correlation (GSI initial conditions for both)



FIM vs. GFS verification vs. raobs over N. America



LOA for Possible Implementation of FIM into NCEP Operations

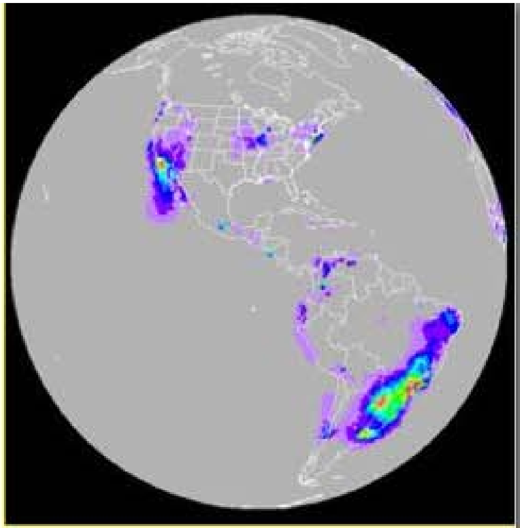
LETTER OF AGREEMENT
between NCEP and ESRL/GSD

Pertaining to the Cooperative
Development and Transition of
the Flow-following finite-volume Icosahedral Model (FIM)
to the NCEP Developmental Software Suite

NCEP is in the process of building a new operational modeling system, fully compatible with the community-based Earth System Modeling Framework (ESMF). This National Environmental Modeling System (NEMS) will house model components for both Development and Testing (D&T) and operational applications.

The NOAA/OAR/ESRL and NOAA/NWS/NCEP are mutually agreed to collaborate on a phased D&T, evaluation, and possible transition of the FIM for operational application if criteria for Transition to Operations (T2O) are satisfied. The first two phases will cover incorporation of the FIM into the NEMS D&T code and evaluation of the FIM as a potential component for NAEFS. In addition, the FIM may be used to evaluate advanced horizontal and vertical coordinates with potential for operational use.

Chemistry in FIM

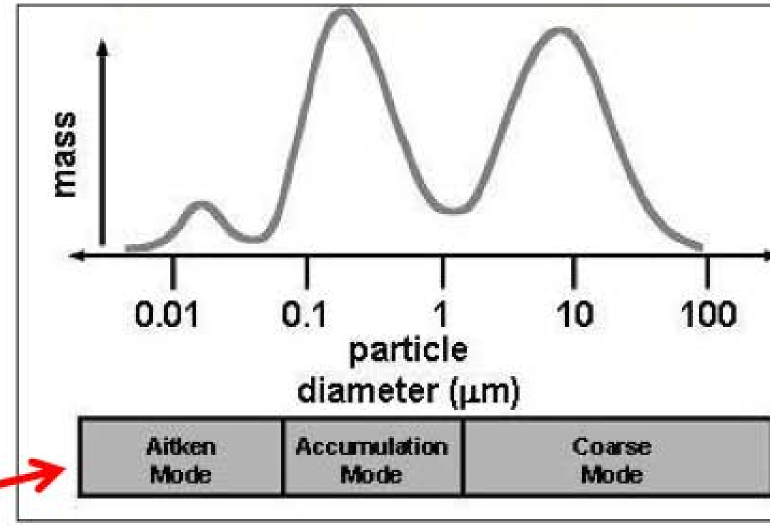


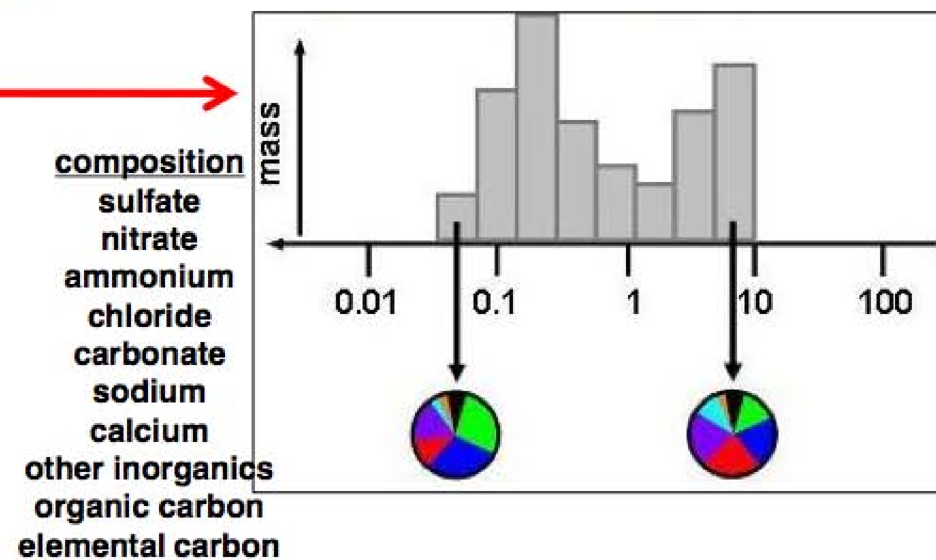
- FIM-Chem is an "online" model
  - Chemistry and meteorology integrated together
  - Feedback from Chemistry to Meteorology is allowed through atmospheric radiation
- FIM-Chem can use chemistry from **WRF-Chem**
  - Various choices for chemical mechanisms as well as aerosol modules
  - Biogenic emissions modules, fire plume-rise, anthropogenic emissions based on RETRO/EDGAR
- Effect of volcanoes also was recently included

In future the online approach should also open doors for significant improvements in data assimilation

Currently available aerosols modules in WRF/chem available for FIM

1. Total aerosol mass transport, emissions, and deposition only
2. Simple aerosol modules from Goddard Chemistry Aerosol Radiation and Transport model (GOCART) (sections for dust and sea-salt only)
3. Modal approach
4. Sectional approach

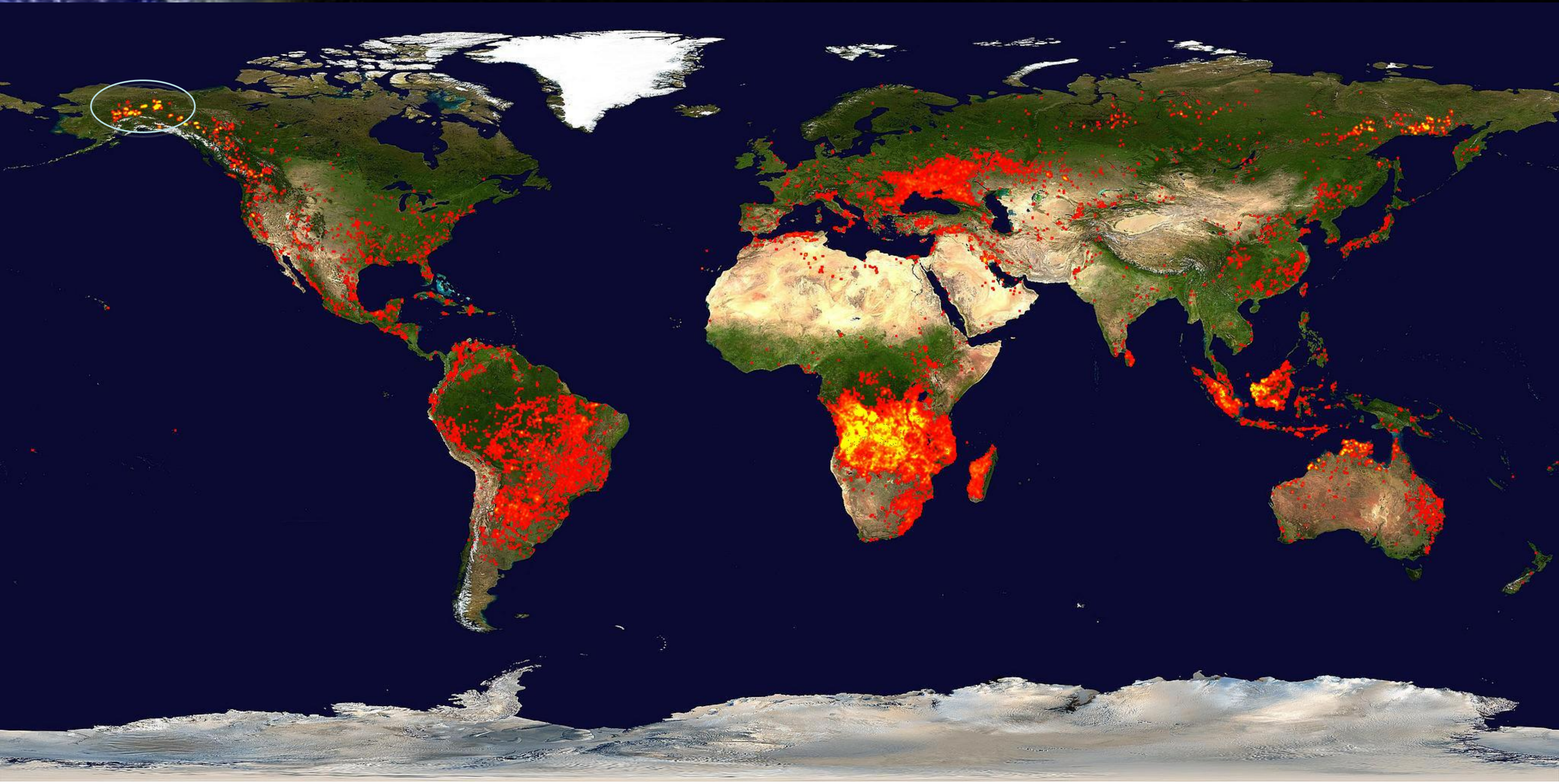




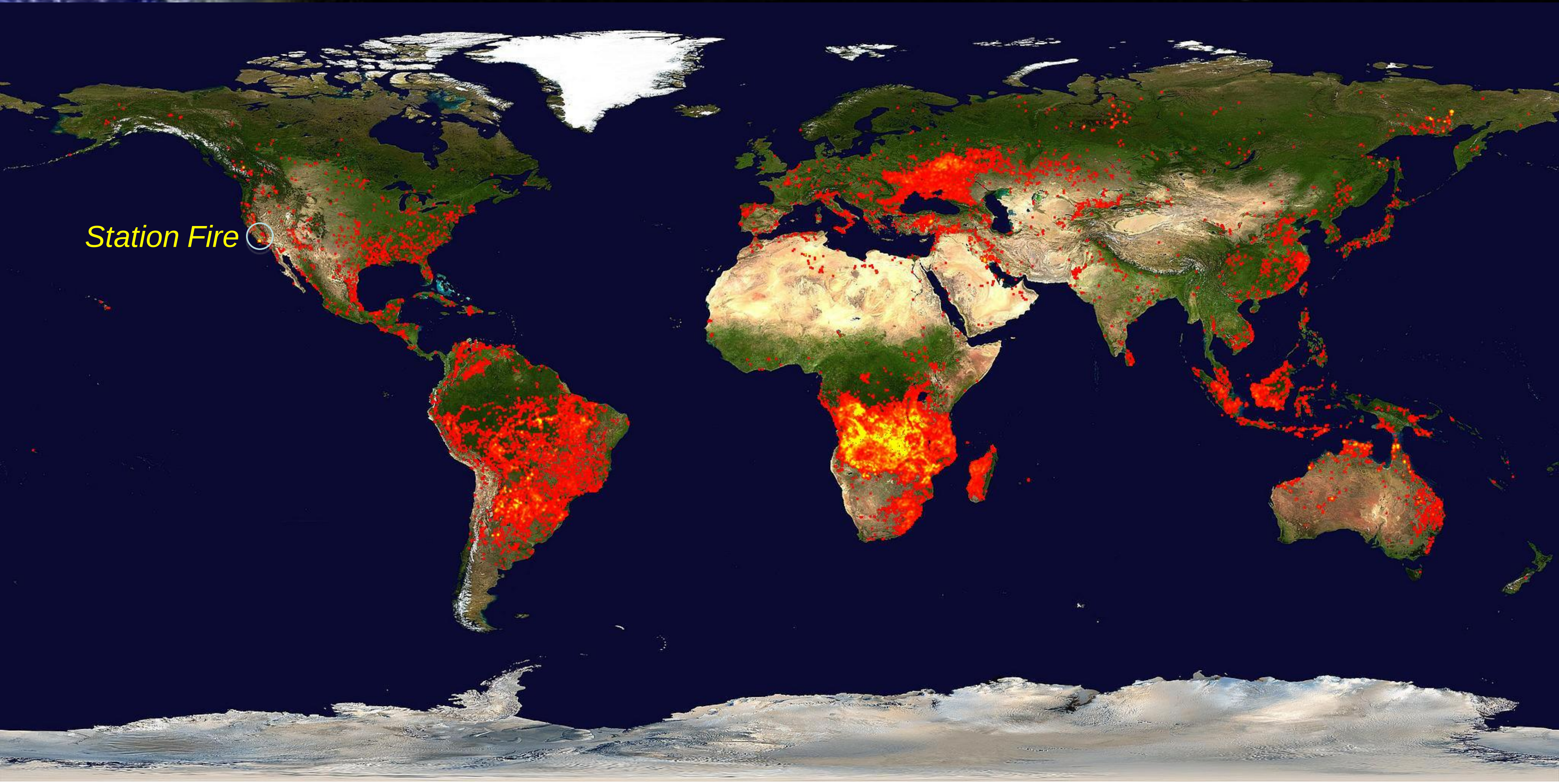
Aerosol radiation and microphysics interaction is included for (3) and (4)

Calculates total aerosol mass only

MODIS Fire Map 30 July – 8 August 2009



MODIS Fire Map 09 – 19 August 2009



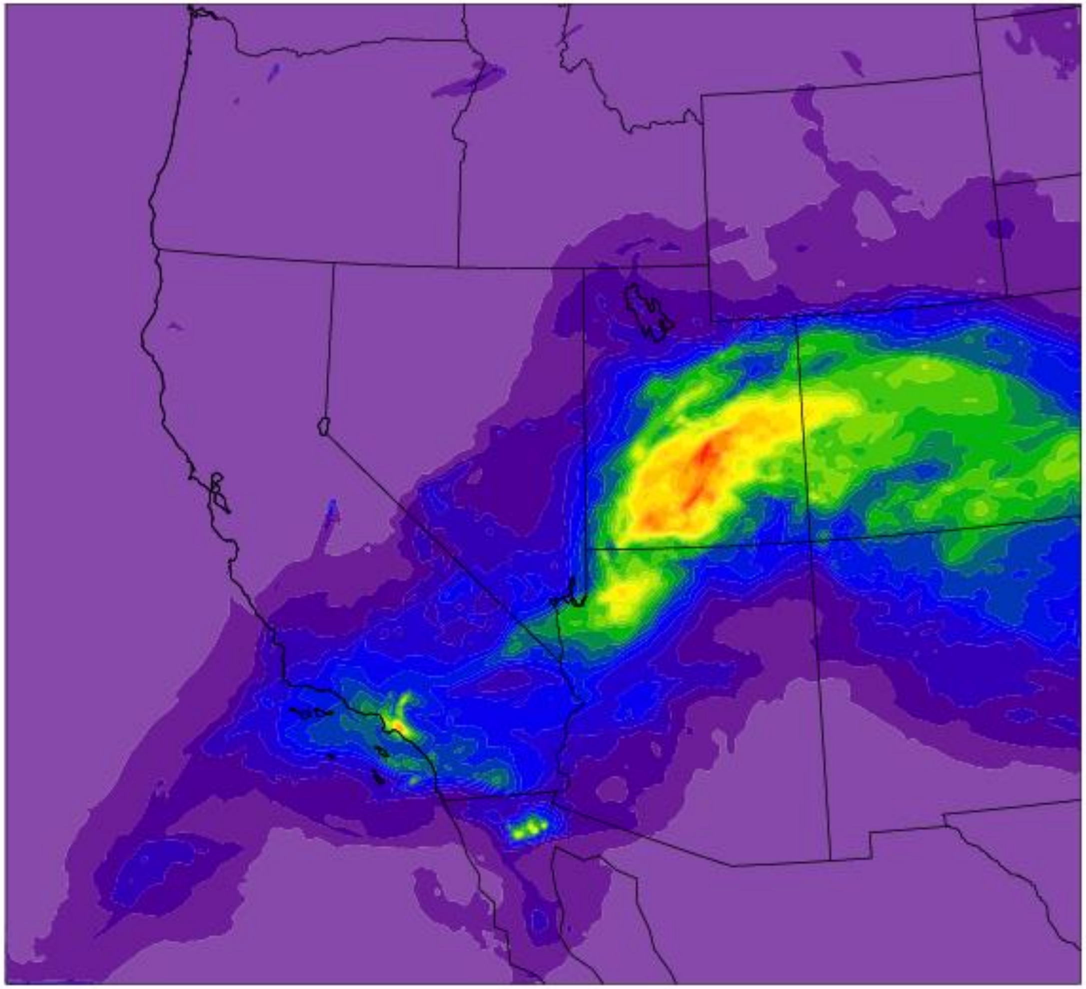
A plane drops fire retardant on a burning hillside above homes in Altadena. The Station fire has consumed more than 21,000 acres, propelled by temperatures that eclipsed 100 degrees and single-digit humidity.

A group of young men watch the Station fire from a hill overlooking Tujunga on Monday night.

A back fire burns along a ridge above homes on Sky Ridge Drive in Glendale.

(Don Bartletti / Los Angeles Times / August 31, 2009) A towering pyrocumulus cloud from the super-heated Station fire in Angeles National Forest billows into a blue sky behind downtown Los Angeles.

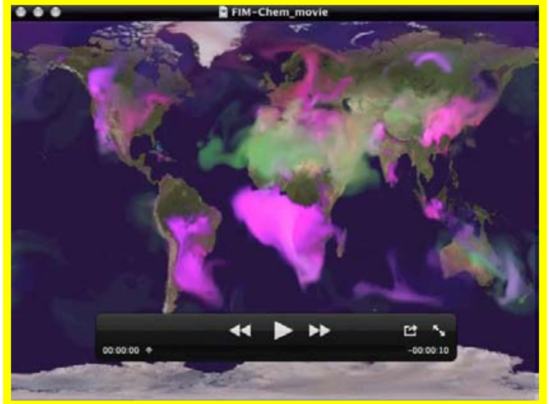
(HRRR-Chem Vertically Integrated Small Aerosol Concentration (relative units) 1200 UTC 2 Sep 2009



Vertically integrated PM2.5

Sources are primarily wildfires, largest in San Gabriel Mtns, southern CA

Valid 12z
2 Sept 2009

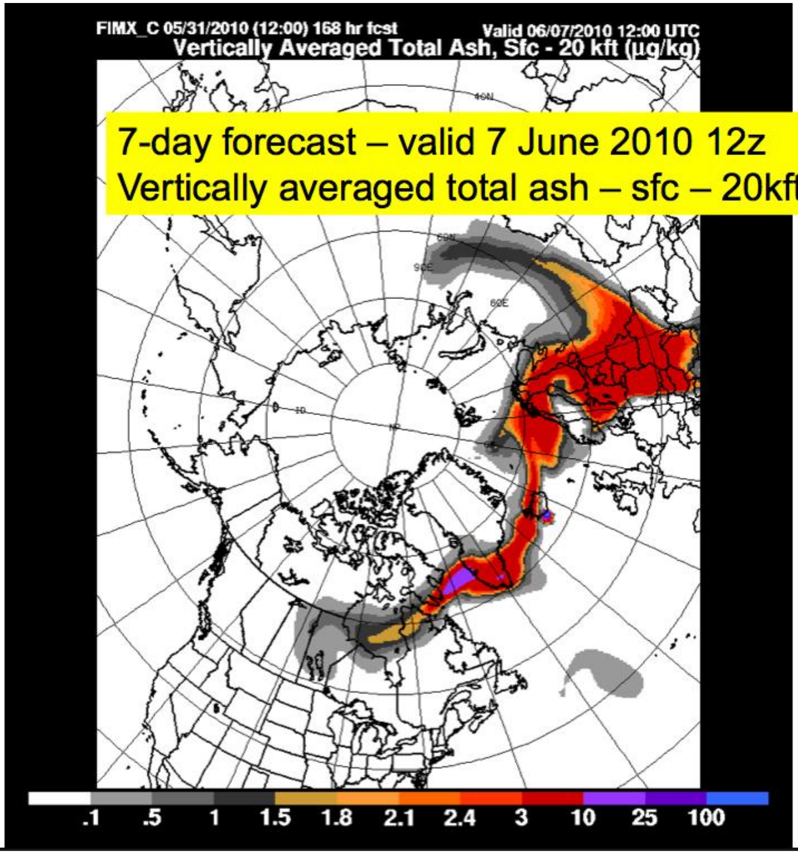


FIM-Chem-Ash

Vertically averaged total ash to 20 kft (μg/kg)
1200 UTC 7 June 2010

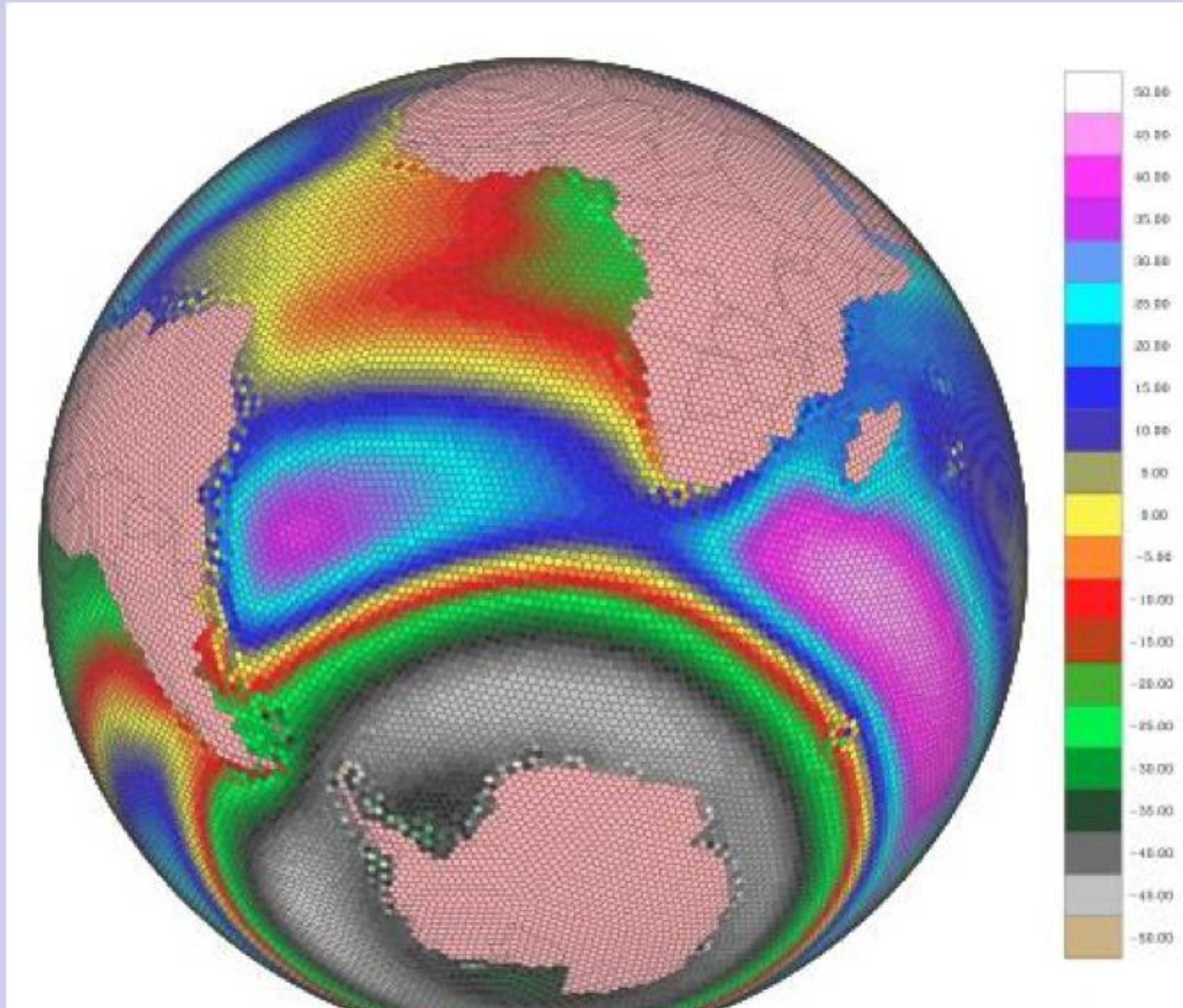
FIM-Chem-Ash

- Fully online chemistry/ash, not just transport
- 16 prognostic aerosol variables
  - Volcanic ash in 4 size bins
  - Dust, organic carbon, black carbon, etc.
  - Non-ash aerosols are a variant of GOCART
- 1 gaseous variable (SO_2)
- Cycled since 14 April, response to Eyjafjallajokull eruption
- FIMX run under http://fim.noaa.gov
- Running at 60km resolution to 7 days, 2x/day
- Also assimilates real-time global fire data- MODIS/GOES

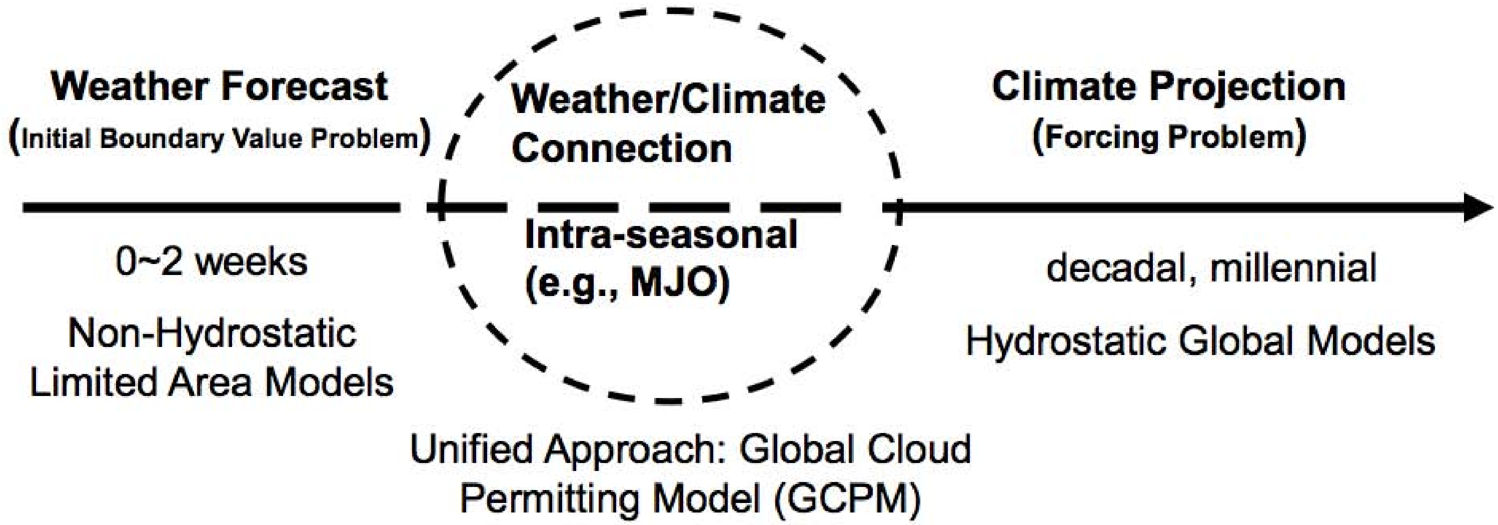


Recent ESRL effort: Develop mirror FIM-HYCOM Atmosphere-Ocean on same icosahedral grid

Initial atmos/ocean coupled FIM:
Sea surface height
- *After 5-yr spinup of a 4-layer isopycnic ocean forced by time-invariant zonally averaged zonal wind stress extracted from FIM initial conditions.*
- *Horizontal resolution ~120 km (G6)*



From Weather to Climate



- **GCPM to "Explicitly Resolve" Tropical Convective Cloud Systems**
- **Lateral Boundary Limitation**
- **Inadequate GCM Cumulus Parameterizations**

Predictability

- Limit for mid-latitude weather systems = two weeks
- Why? Sensitivity of forecasts to atmospheric initial conditions
- But, longer-range forecasts can be made using predictions from a fully coupled atmosphere – ocean system
- Sources of predictability:
  - Inertia or “Memory” of a climate variable (e.g., ocean heat content, soil moisture)
  - Feedbacks between climate variables (e.g., teleconnections, equatorial waves)
  - External forcing of climate (e.g., volcanoes)
- Necessary to improve accuracy of intraseasonal predictions:
  - Better representation of Madden-Julian Oscillation (MJO) – and other types of equatorial waves
  - MJO requires global explicit representation of organized tropical convection
  - Need fully coupled atmosphere – ocean models

Future Outlook for NWP/DA at GSD

- The hydrostatic FIM model is a contender for implementation as a member of NCEP global ensemble. A non-hydrostatic, finite volume, icosahedral model (NIM) is under development for study of intraseasonal weather/climate linkages.
- FIM contains models for chemistry, ash, ocean. GFS and WRF physics packages are being incorporated into NIM as they have been for FIM. Need to add additional earth system model components and test.
- Develop hybrid Ensemble Kalman Filter/4DVAR approaches to data assimilation incorporating continued advances in cloud and precipitation data assimilation.
- Implement 3-km HRRR at NCEP by 2013, North American Rapid Refresh Ensemble (NARRE) by 2016, and HRRR Ensemble by 2020.
- Develop advanced software engineering tools and GPU computing for managing complex forecast model work flows, assuring fault tolerance for model ensemble reliability, attaining true performance portability across diverse computer architectures, and dramatically increasing computational power.
- Lead the DTC Ensemble Testbed – research will include new methods for capturing nonlinear, non-Gaussian analysis errors; estimating forecast error covariance; optimally linking data assimilation and initial ensemble perturbation generation methods; representing model uncertainty; post-processing ensemble members using Bayesian and debiasing techniques.