WRF:
The Weather Research and Forecast Model

Overview and Program Status

Brief for Army Research Laboratory

6 July 2005

Vision

WRF is…

an inter-organizational partnership to create and sustain…

- **The next-generation mesoscale NWP modeling system for research and operations**
- **A common modeling infrastructure that facilitates operational NWP collaboration, scientific "interoperability" and accelerates the transfer of new science from research into operations**
- **A repeatable process that continuously infuses innovations and capabilities into the community mesoscale NWP modeling system**

WRF Three-phase Strategy

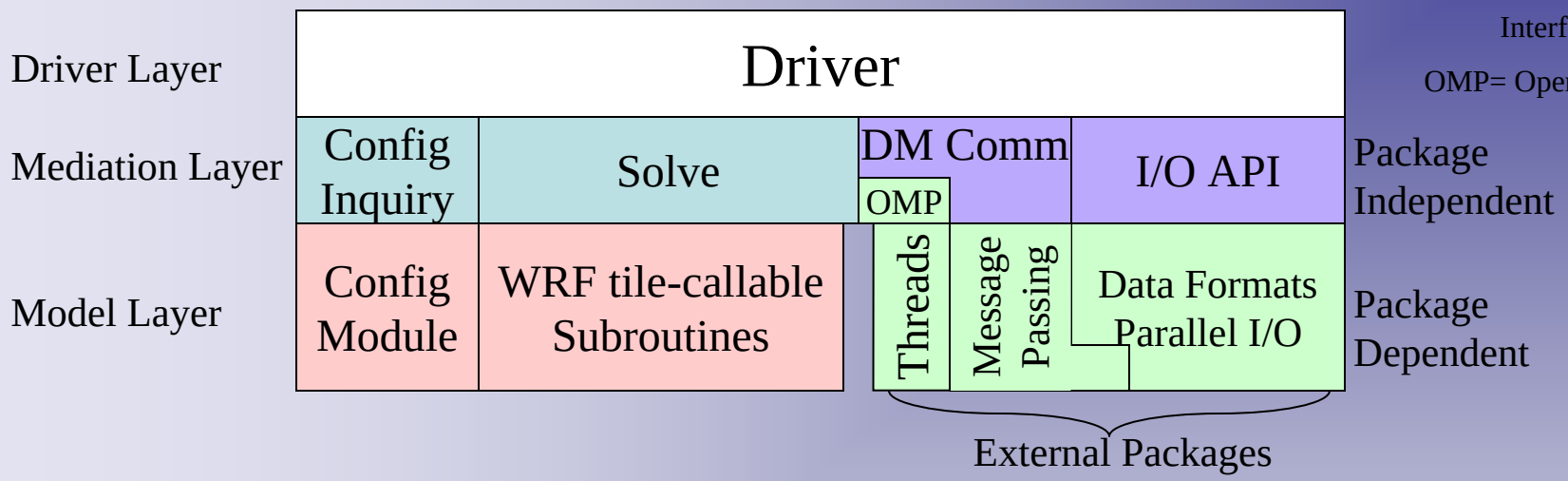
- **Phase 1: Develop and implement WRF as the next-generation mesoscale NWP modeling system, infrastructure and process…**
  - **- Activate inter-organizational collaborations between research and operations**
  - **- Streamline the transfer new science into both research and operations**
- **Phase 2: Use the WRF process and infrastructure to sustain the flow of new science and technology into the WRF modeling system…**
  - **- to improve operations**
  - **- to open new research opportunities**
- **Phase 3: Extend the WRF collaboration into other modeling areas of mutual interest—e.g., Ocean modeling, Global modeling, Diagnostic and Statistical post-processing**

The WRF Software Framework, or "Infrastructure" (NCAR)

DM=Distributed Mem.

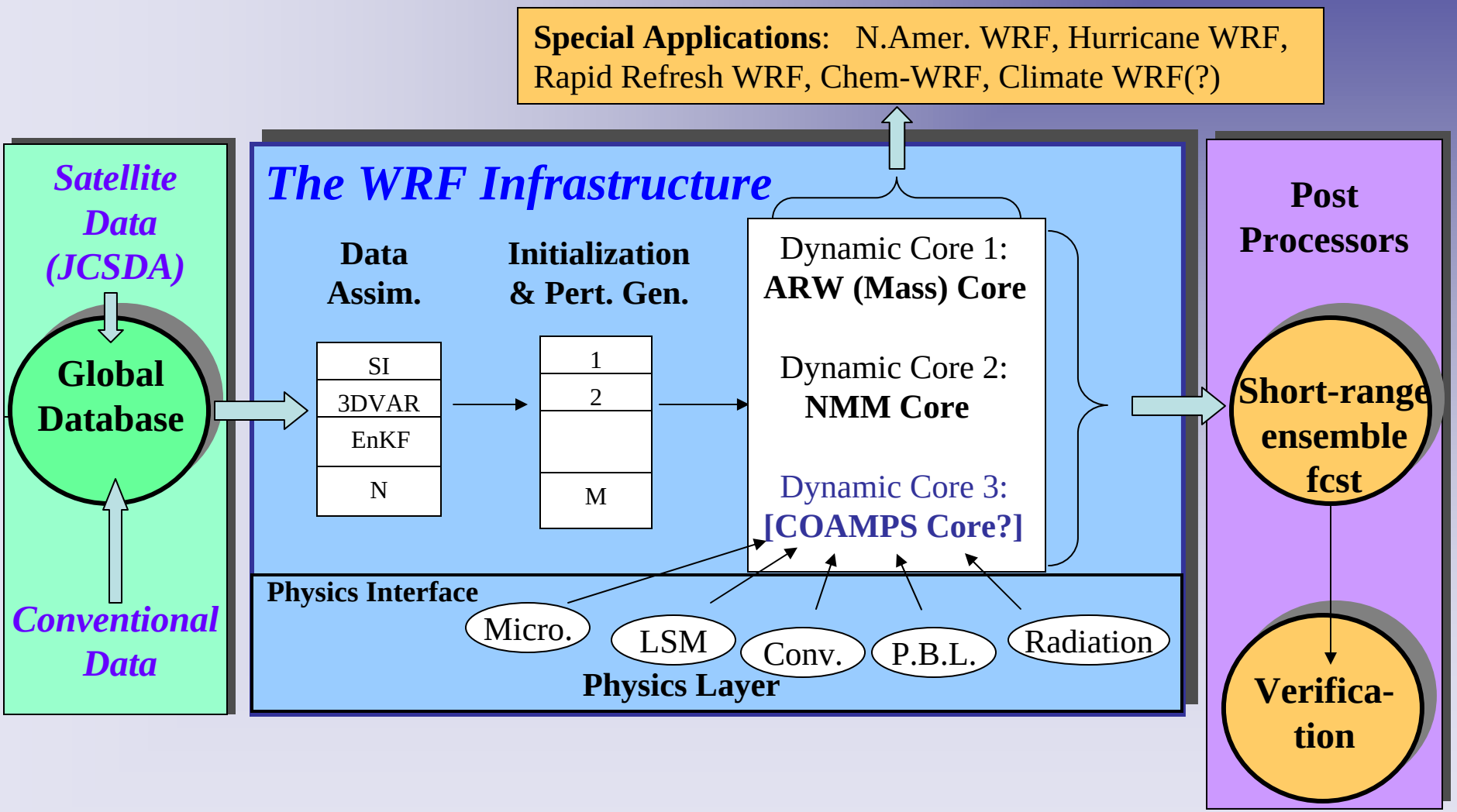
API= Application Program Interface

OMP= Open MP



1. **Objective:** Insulate the scientist from parallelism and other architecture-specific details.
2. **Three-Level Hierarchy:**
   - **Driver Layer:** Responsible for top-level control of initialization, time-stepping, I/O, domain set-up, nesting, domain decomposition, computer processor topologies and other aspects of parallelism
   - **Mediation Layer**: "Glue" between driver and model layers; tiling, communication, time step control; makes driver layer transparent to model layer.
   - **Model Layer**: Subroutines that perform actual model computations; meteorological codes, physics
   - **Package Dependents**: Open MP, parallel I/O libraries, message passing libraries, node thread packages

WRF is an End-to-End Modeling System for Deterministic and Ensemble Predictions



Two WRF Configurations in the WRF Software Framework

WRF-ARW (Eulerian mass) Core

- Terrain-following hydrostatic mass-field vertical coordinate, with arbitrary vertical resolution
- **Arakawa C-grid horizontal stencil**
- Two-way moveable grid nesting
- 3rd order Runge-Kutta time-split temporal differencing
- Conserves mass, momentum, dry entropy and scalars using 5th-order (or 6th order) upwind spatial differencing to advect fluxes

- ARW Physics:
  Noah unified 5-layer LSM
  Yong-Sei Univ. 1st order PBL
  WRF standard 5-moment microphysics (WSM5)
  Dudhia shortwave radiation
  RRTM longwave radiation

Nonhydrostatic Mesoscale Model (NMM)

- Terrain following hybrid sigma-to-pressure vertical coordinate, with arbitrary vertical resolution
- **Arakawa E-grid horizontal stencil**
- One-way moveable grid nesting (two-way nesting by end of 2005)
- Adams-Bashforth temporal differencing with time splitting
- Conserves rotational kinetic energy, total energy, mass, enstrophy and momentum using 2nd-order nine-point differencing for advection
- NMM Physics
  Noah unified 5-layer LSM
  Mellor-Yamada-Janjic 2nd order PBL
  Ferrier cloud microphysics

  Lacis-Hansen shortwave rad.
  Fels-Schwartzkopf longwave

ESMF - WRF Integration

ESMF is the Earth System Modeling Framework designed to turn diverse model codes into components of a coupled modeling system run with standardized drivers and interfaces.

Why WRF & ESMF?

- **Currently, the WRF framework and ESMF share few capabilities and functionality.**

- **Merger/integration will enhance WRF's ability to pursue its Phase 2 & 3 strategies.**

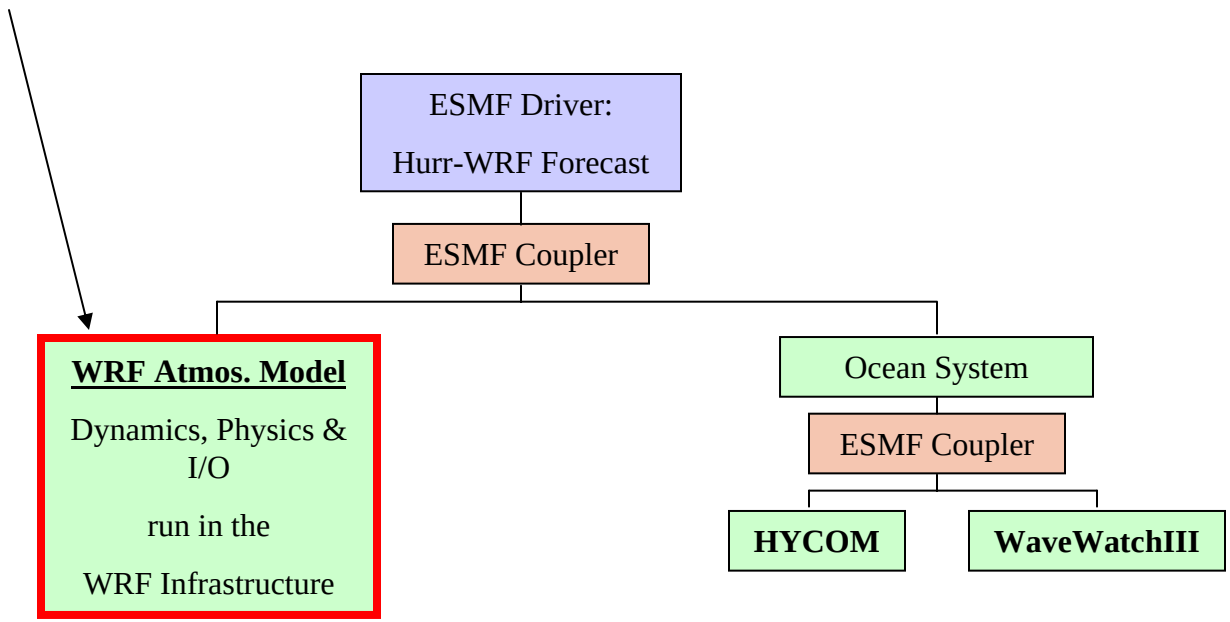
  Phase 2 Strategy: **…Sustain flow of new science and technology into WRF…**

  Phase 3 Strategy: **…Extend collaboration to other modeling areas of interest...**

Possible ESMF-WRF Integration Approach: Maximize use of existing WRF Infrastructure

NCAR/MMM is adapting WRF Infrastructure to conform to ESMF standards so WRF can tell ESMF <u>what it is</u> and <u>what it does</u>.

Application:
NCEP Hurricane WRF
Target implementation: FY07



Green: User's model components; Tan: User-written ESMF coupler; Violet: User-written ESMF Driver

Presentations at 2004 WRF-MM5 User's Workshop

Categorized by First-Author Affiliation

Affiliation	MM5 & others	WRF*		Total
WRF Partners:				
NCAR	3	22		25
FSL		6		6
NCEP	1	7	36	8
AFWA	1			1
NRL		1		1
U.S. Universities	12	15		27
Other Govt. Labs	1	2	23	3
Private	1	2		3
Foreign	14	4		18
TOTALS (64% WRF)	33	59		92

**Includes papers comparing both WRF and MM5*

Presentations at 2005 WRF-MM5 User's Workshop

Categorized by First Author Affiliation

Affiliation		MM5	WRF*		Total
WRF Partners:					
NCAR		1	23		24
FSL			6		6
NCEP			3	34	3
AFWA			1		1
NRL			1		1
U.S. Universities		7	23		30
Other Govt. Labs			9	51	9
Private		2	3		5
Foreign		17	16		33
TOTALS	(76% WRF)	27	85		112

**Includes papers comparing both WRF and MM5*

WRF in Operations

June 2005 WRF Upgrade at NCEP

- **First Operational Hi-Res. WRF Models:** Two deterministic WRF runs declared operational by NCEP in September 2004
  - WRF-ARW (10km/50 level)
  - WRF-NMM (8km/60 level)

- **New Developments:** Success of three recent experiments using explicit (4-5 km) configurations of the WRF model with no convective parameterizations
  - BAMEX 2003 *(WRF-ARW)*
  - SPC/NSSL Spring Program 2004 & 2005 *(WRF-ARW, WRF-NMM)*
  - DTC Winter Forecast Experiment 2005 *(WRF-ARW, WRF-NMM)*

Courtesy - Geoff DiMego

Prior Experience: BAMEX

BAMEX Success:
Mode of Convection

WRF ARW | Observed Reflectivity

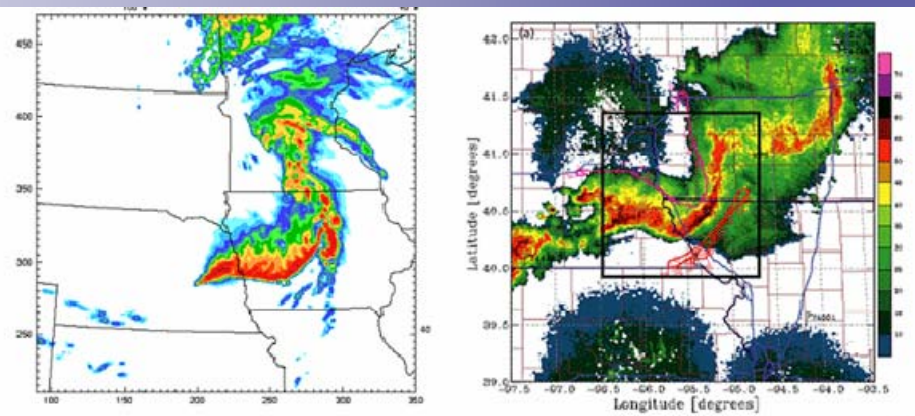


Fig. 1: 30h WRF forecast (left) and NEXRAD radar observations (right) of maximum reflectivity for June 10, 2003 at 06 UTC, during the BAMEX field program

"Bow echo" mode

"Cellular line" mode

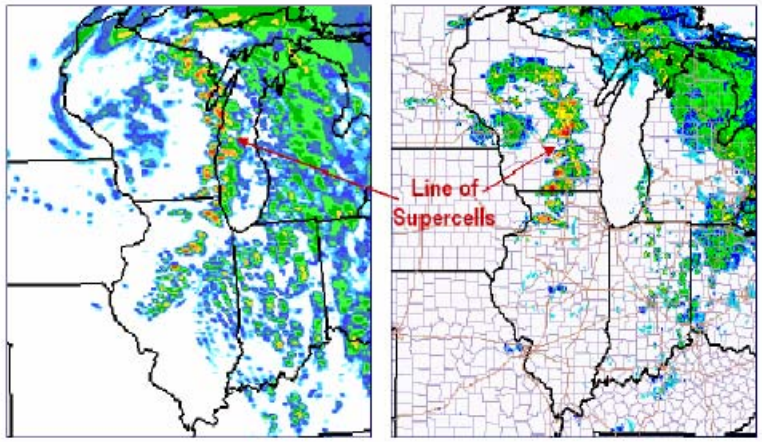


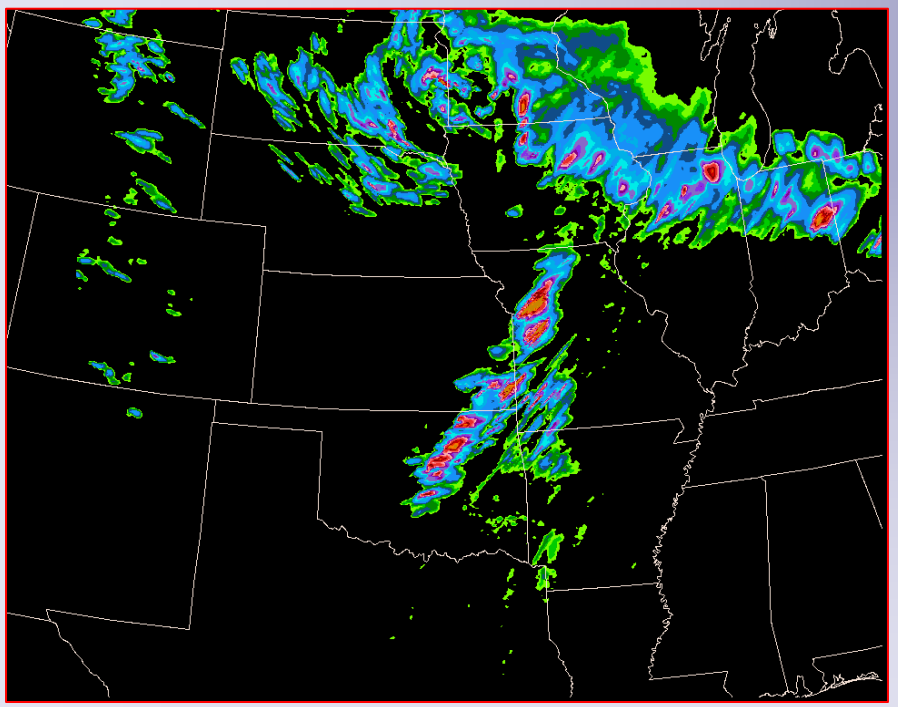
Fig. 2: 23h WRF forecast (left) and NEXRAD radar composite (right) of the maximum reflectivity for May 30, 2003 at 23 UTC, during the BAMEX field program

Courtesy - Geoff DiMego/NCEP

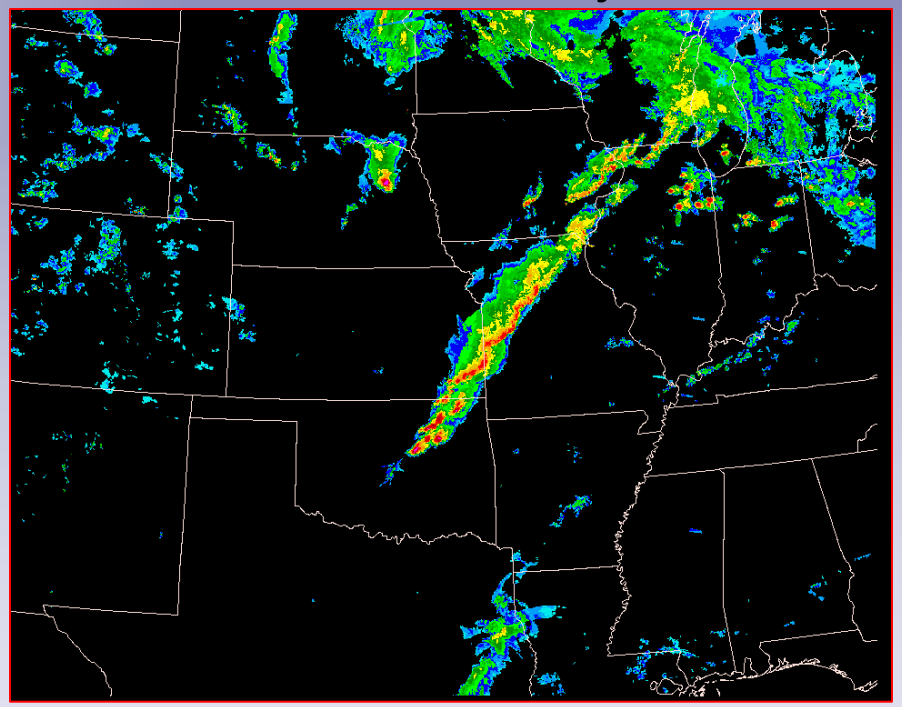
Prior Experience: SPC 2004 Spring Experiment

24-hr forecast, valid 00Z April 21, 2004

WRF-NMM 4.5 km forecast of 1-hr accumulated precipitation

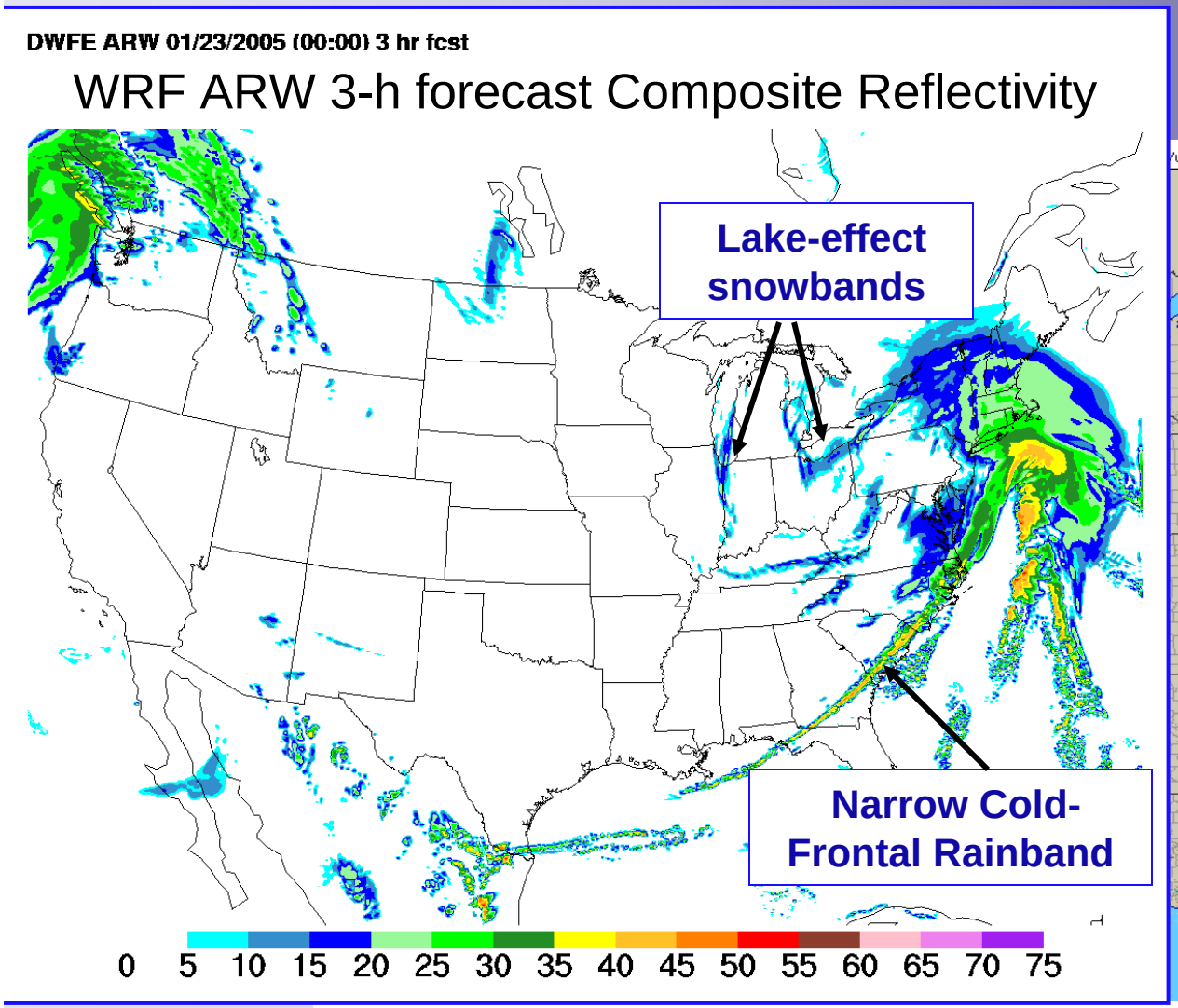


Verifying 2-km observed Radar reflectivity

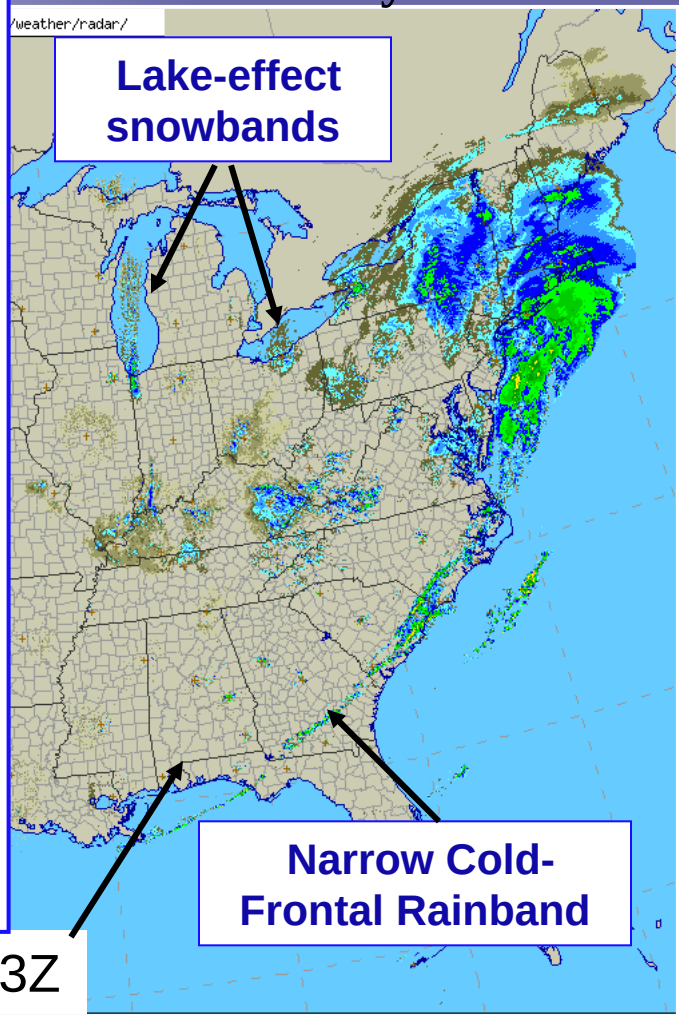


Courtesy - Jack Kain, SPC

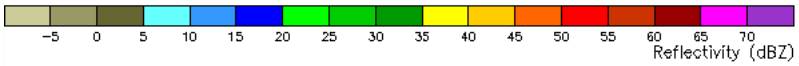
Prior Experience: DWFE - WRF Winter Forecast Experiment



Observed reflectivity 23 January 2005



Observed Composite Reflectivity at 03Z



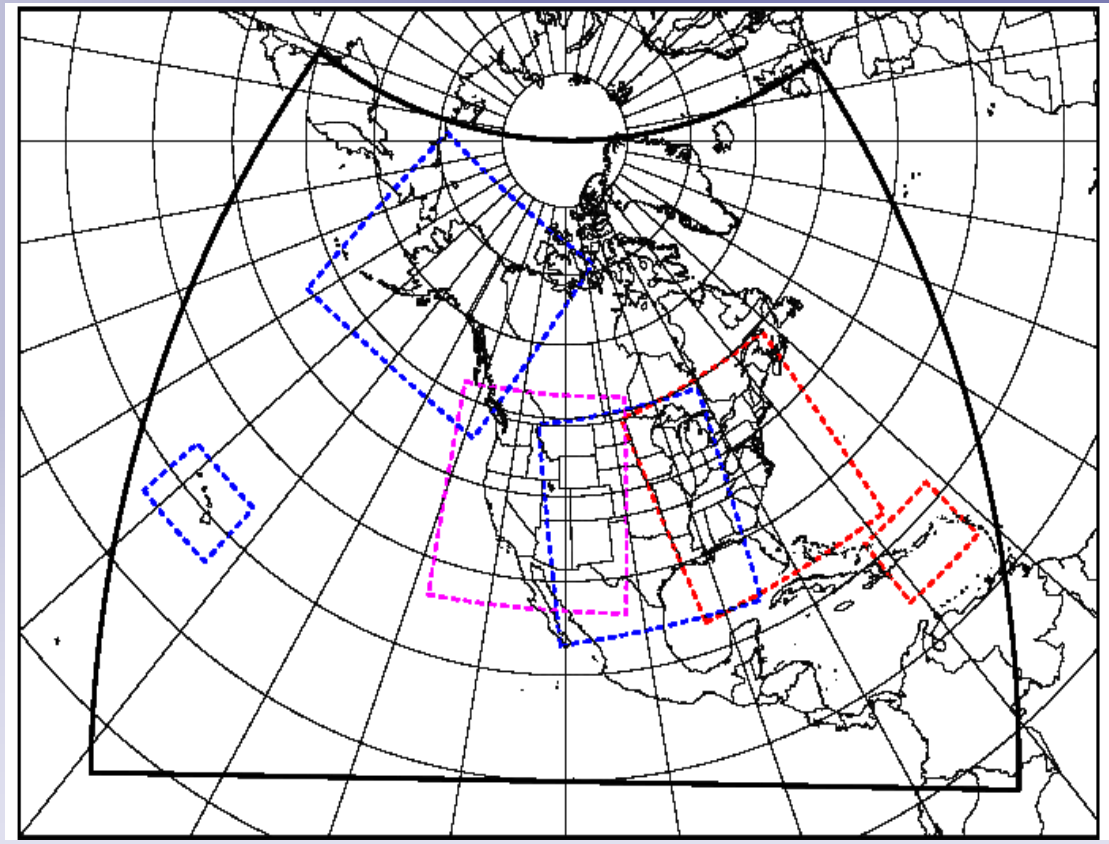
Courtesy – Steve Koch, DTC

NCEP Hi-ResWindow Fixed-Domain Nested Runs

On 28 June 2005, Explicit WRF runs for two configurations became operational at NCEP:

WRF-ARW at 5.8km/35levels and WRF-NMM at 5.1km/35levels

- FOUR routine runs made at the same time every day
- 00Z : Alaska & Hawaii
- 06Z : Western & Puerto Rico
- 12Z : Central & Hawaii
- 18Z : Eastern & Puerto Rico
- Everyone gets daily high resolution runs of both WRF versions ***if & only if*** GFDL hurricane runs are not needed



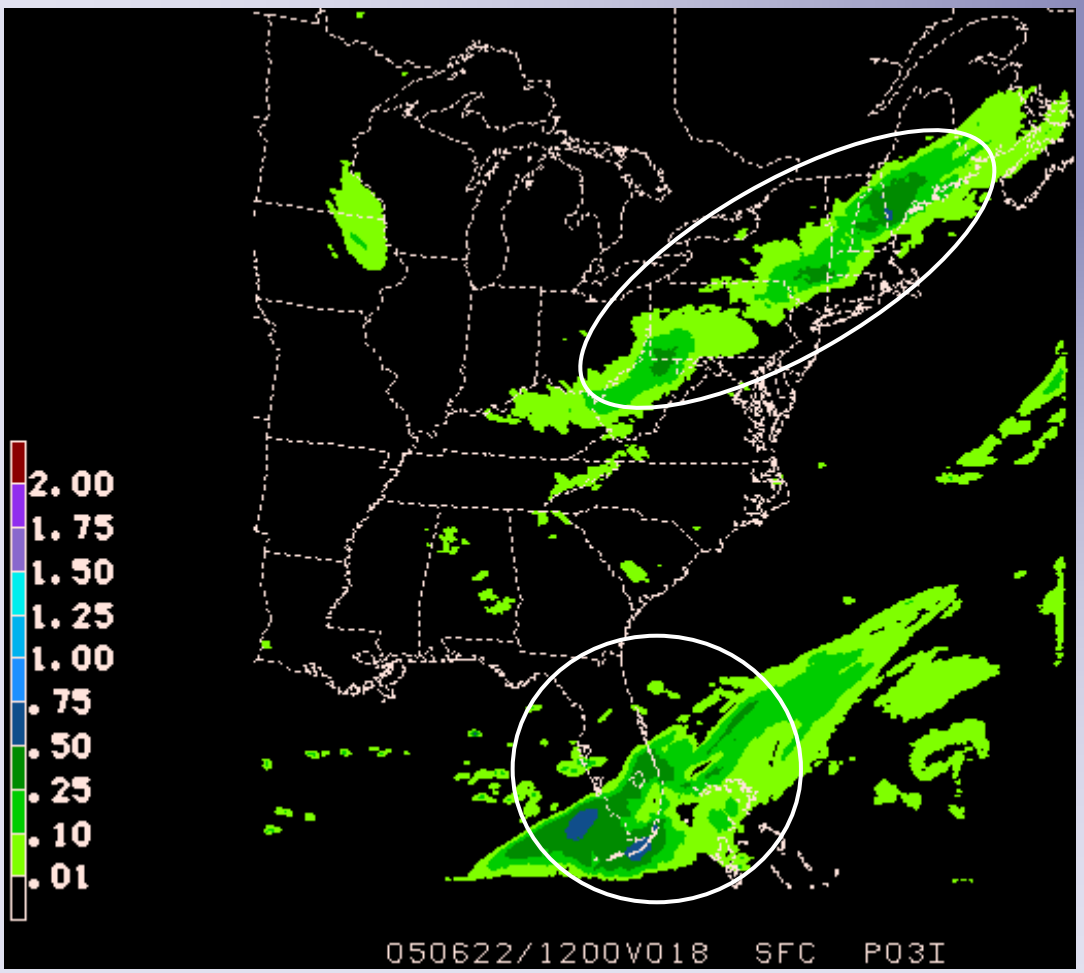
http://www.emc.ncep.noaa.gov/mmb/mmbpll/nestpage/

Alaska domain is smaller than depicted

Courtesy - Geoff DiMego/NCEP

"Old" 8-km operational WRF-NMM in NCEP Eastern Hi-Res. Window Domain

3 h precipitation total (in.)

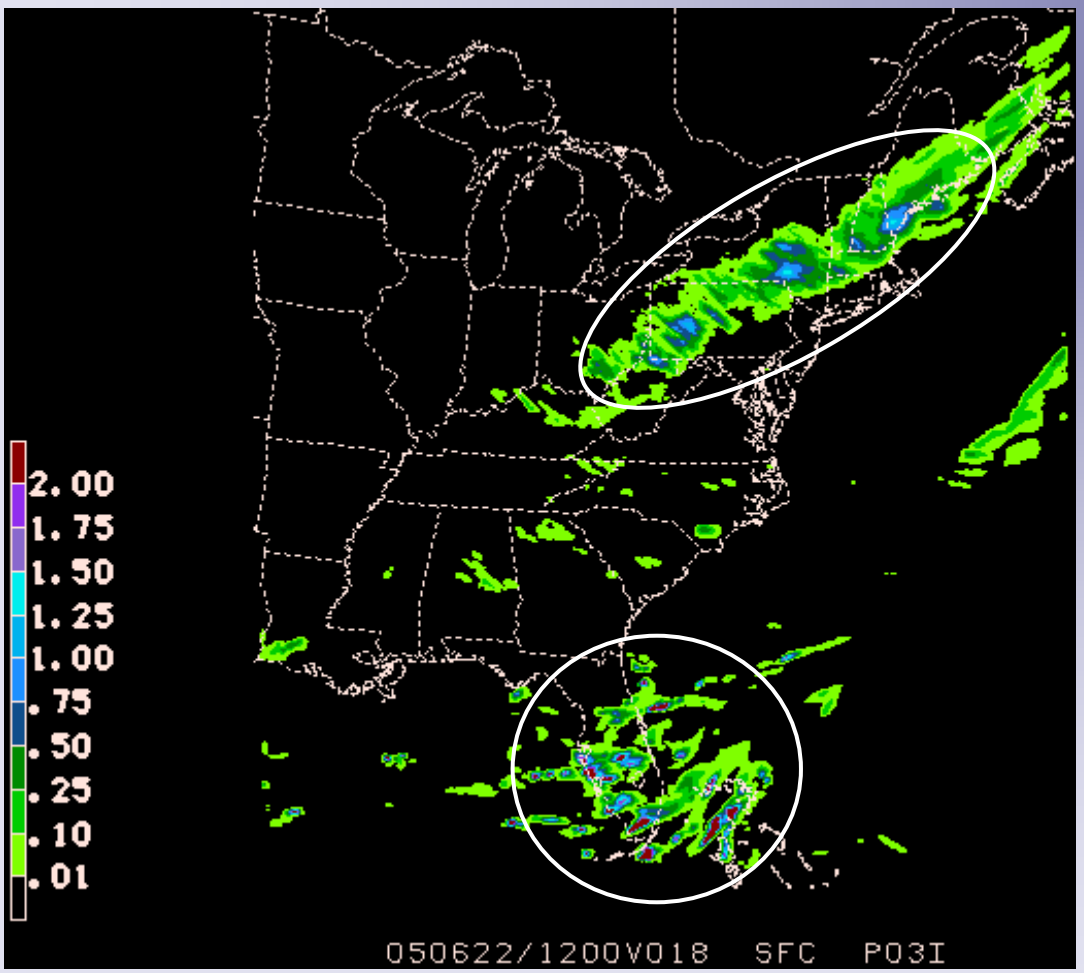


BMJ parameterized convection produces broad, smooth precipitation patterns in the old 8-km WRF-NMM

Courtesy - Geoff DiMego/NCEP

New 5.1-km operational WRF-NMM in NCEP Eastern Hi-Res. Window Domain

3 h precipitation total (in.)



Without parameterized convection, th**e new 5.1-km WRF-NMM produces…**

- more intense, localized maxima

- generally, less spatial coverage

Courtesy - Geoff DiMego, NCEP

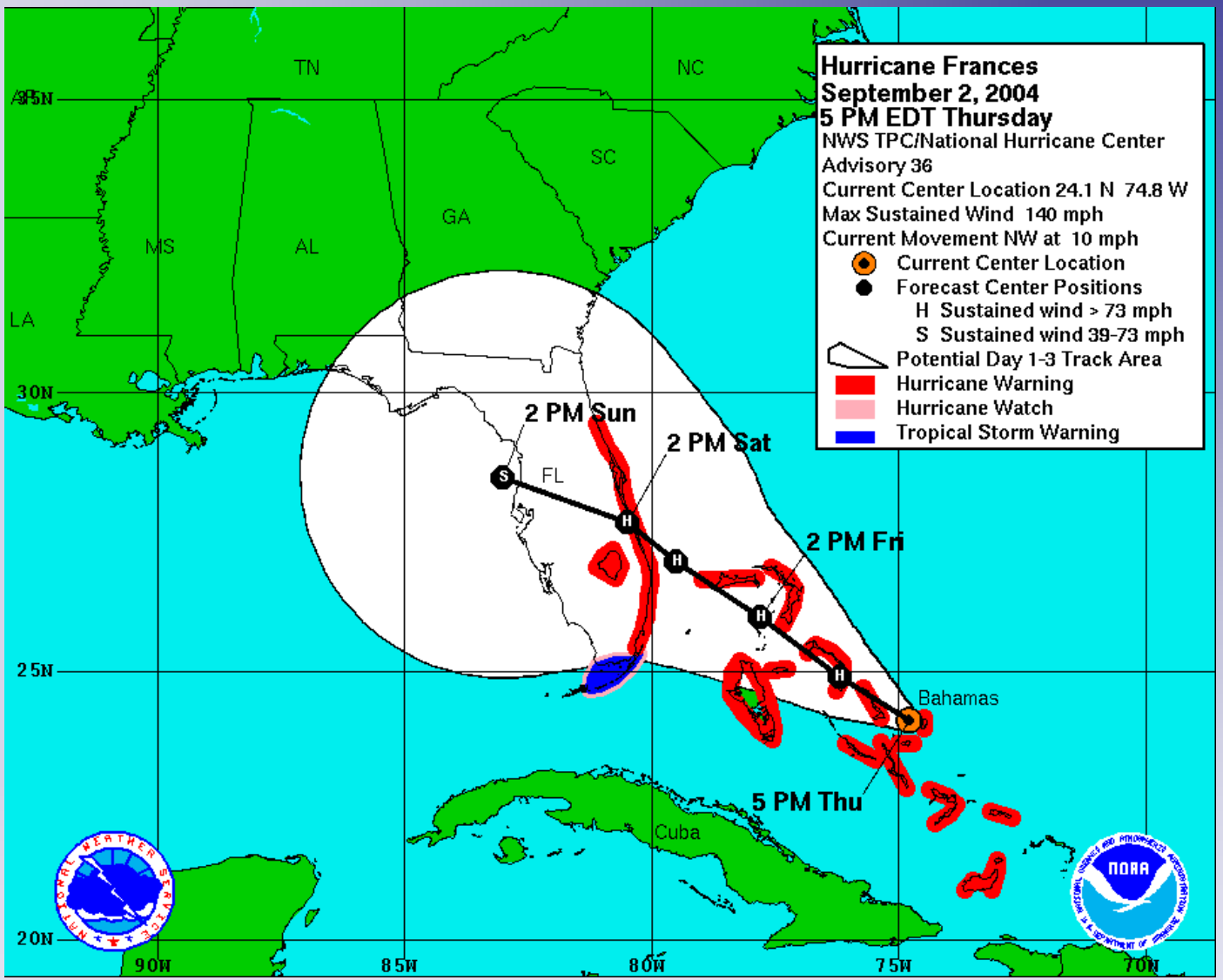
NCEP North American Mesoscale (NAM) WRF Replaces the Operational Eta Model

2006 WRF-NMM specifications for NAM implementation

• **Implementation date:**	**2Q FY06 (March 2006)**
• **Horizontal resolution:**	**10 km**
• **Vertical:**	**60 layers, model top at 2 mb**
• **Grid stencil:**	**Arakawa E grid**
• **NAM domain:**	**Same as old Eta domain**
• **Physics:**	**See previous slide**
• **Run schedule:**	**4 X day to +84 h**
• **Completion time:**	**+3.3h**
• **Map projection:**	**Rotated Lambert conformal**
• **Output frequency:**	**Hourly, available incrementally**
• **Output format:**	**GriB2**
• **Analysis:**	**Fully cycled Gridpoint Statistical Interpolation (GSI) 3dVar**

Development: WRF Forecasting of Hurricane Frances

National Hurricane Center Forecast 2 Sept. 2004

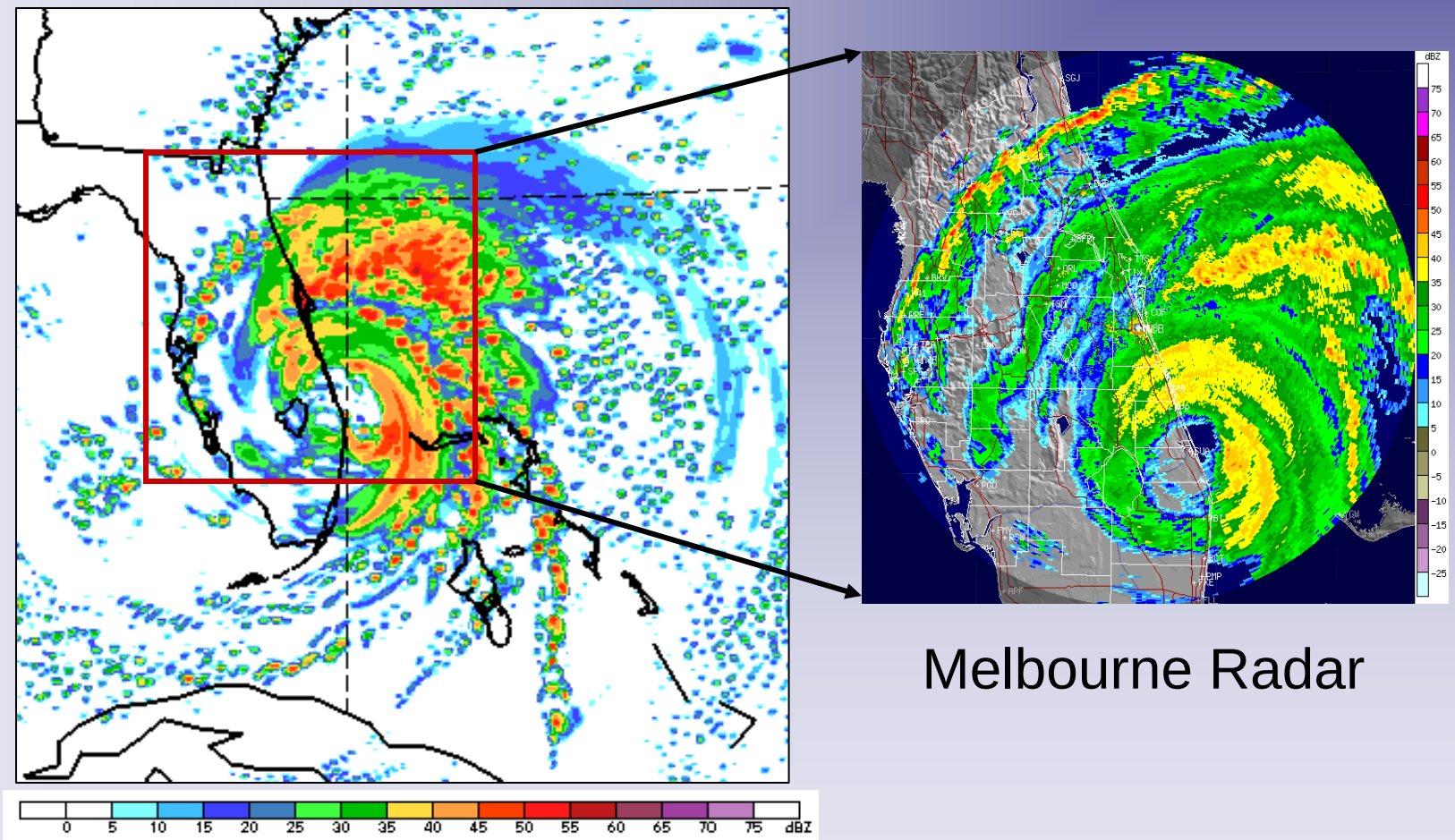


Courtesy – Joe Klemp, NCAR

Hurricane Frances - Reflectivity at Landfall

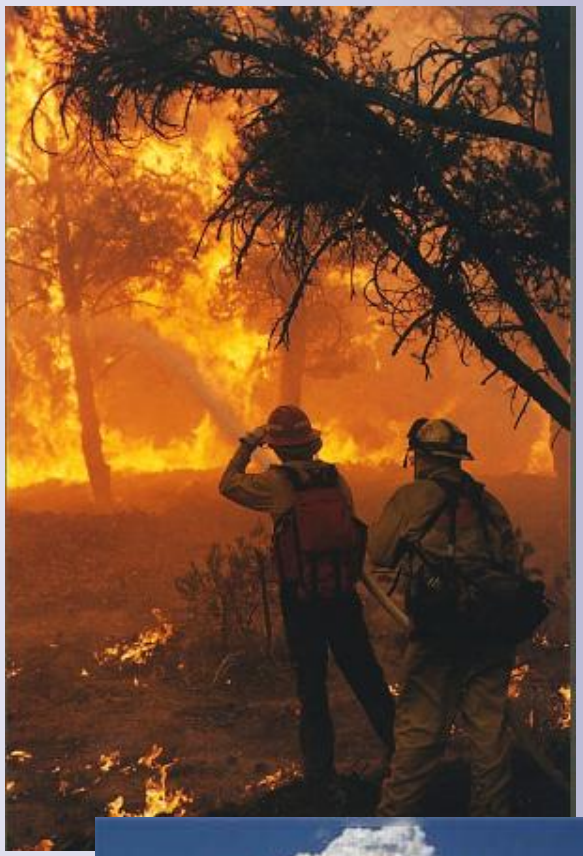
Valid: 05 Sep 2004 06 Z

30 h forecast from 4 km WRF-ARW



Melbourne Radar

Courtesy – Joe Klemp, NCAR



WRF-Fire

A coupled atmosphere-fire-fuels module for WRF

Janice Coen and
Ned Patton (NCAR)

Courtesy – Rich Wagoner, NCAR/RAL

Three Environmental Factors that affect Wildland Fire Behavior: Duff (fuel), Weather, Topography

Of these three factors, **weather** is the most rapidly changing and is the "wildcard" in wildland fire operations.

Moreover, there are complex interactions between fire and atmospheric winds.

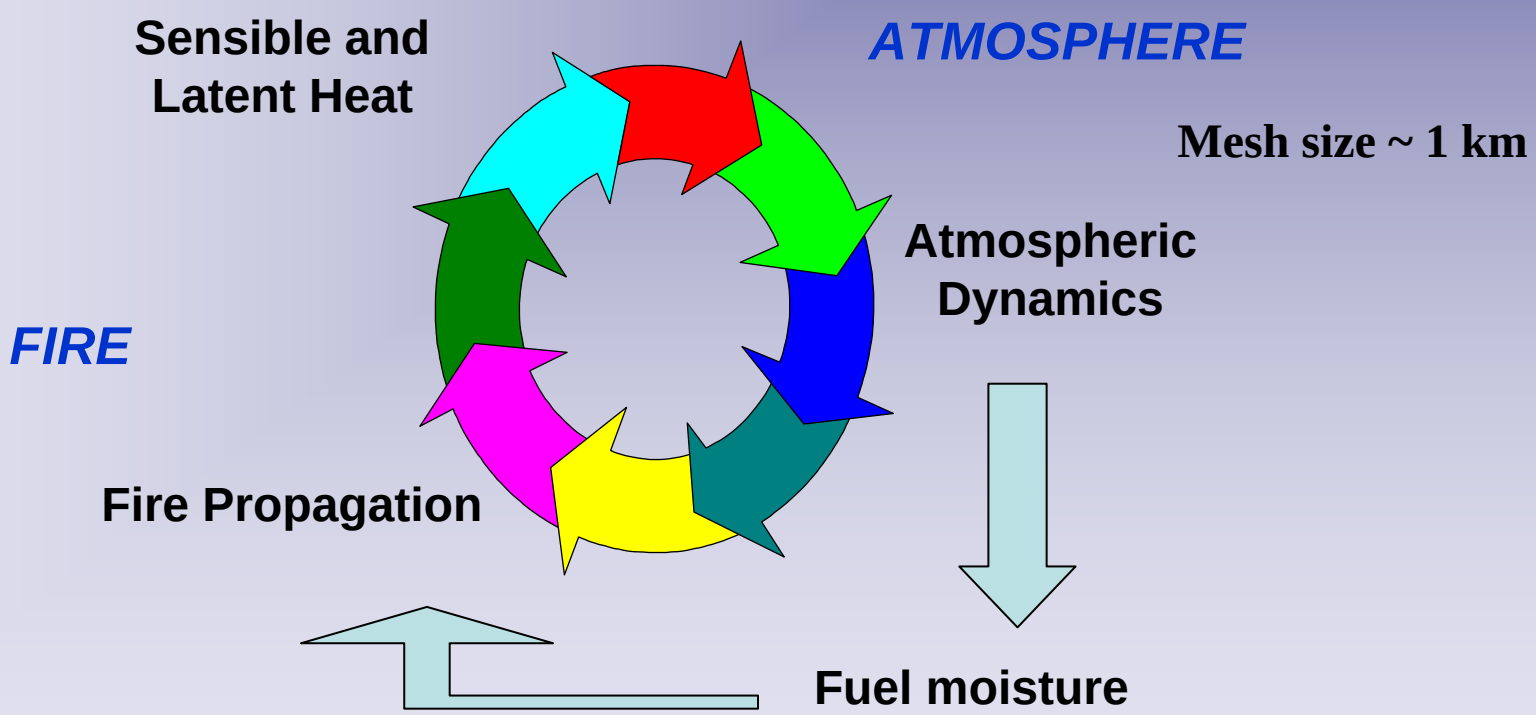
These occur even in grass fires, but are especially important for extreme fire behavior such as crown fires and blowups.

Current operational tools cannot include these fire-atmosphere interactions.

Courtesy – Rich Wagoner, NCAR

Status of CAWFE – A "Pre-WRF" Forecast Model for Wildfire Behavior

Coupled Atmosphere – Wildland Fire – Environment model (CAWFE)



Courtesy – Rich Wagoner, NCAR/RAL

WRF-Chem-Fire

GOALS:

- Simultaneous modeling of meteorology, fire, and chemistry
- Community tool with research and operational capabilities
- Accurate spatial distribution of fire emissions into the atmosphere
- Better temporal distribution of fire emissions
  - Smoldering vs. flaming

Courtesy - A. Guenther, J. Coen, N. Patton, C. Wiedinmyer, NCAR

Coupling with WRF-Chem

- **Forecast the impact of fire emissions on air quality**
  - Naturally incorporate vertical transport
  - Include impact of fire evolution/intensity on emissions
    - species composition
    - aerosol particle size
    - concentration

Courtesy –
Rich Wagoner, NCAR

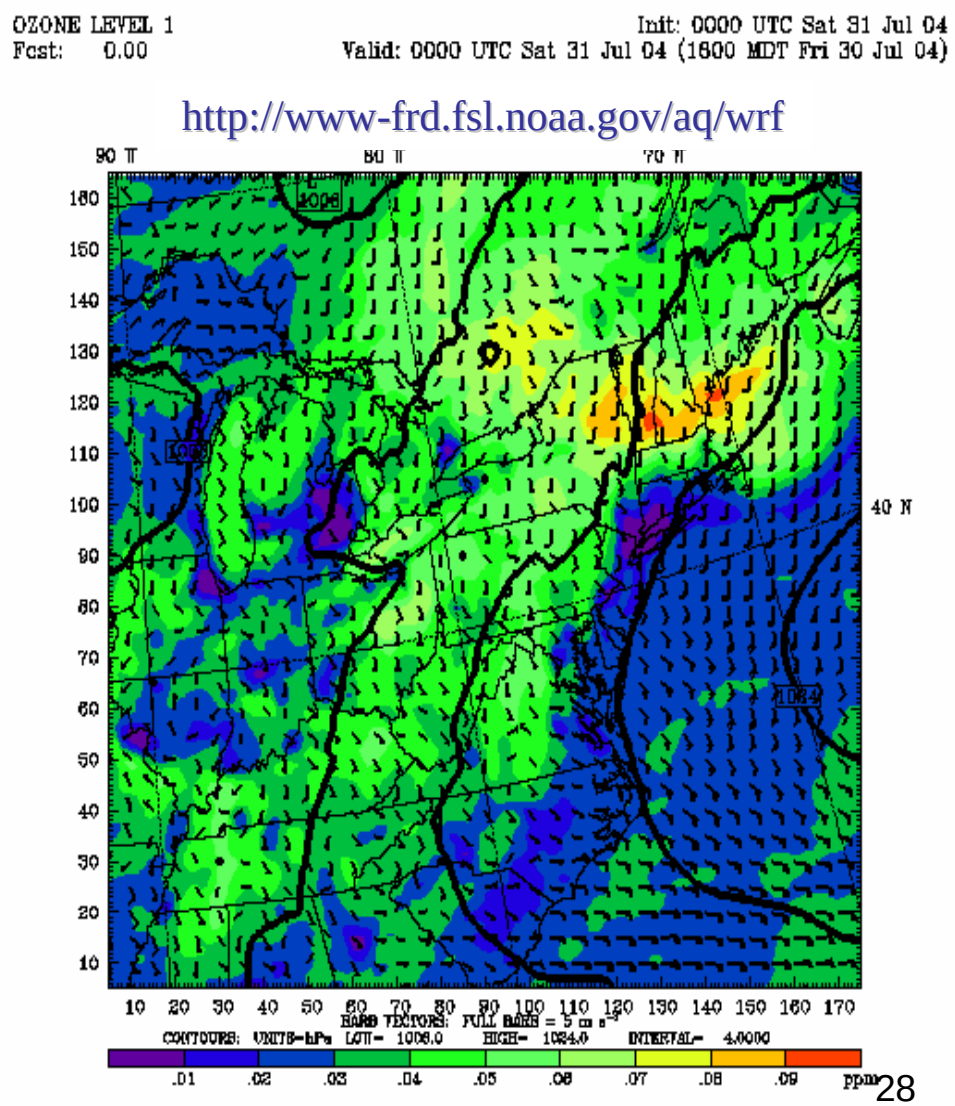
WRF-Chem Applications:
Air Quality Forecasting with 4-km WRF-ARW

Details:

- WRF-Chem: 36-h forecast, twice daily
  - Start at 0000 UTC and 1200 UTC
- Initial and boundary conditions:
  - RUC analysis fields
  - ETA boundary conditions
- Chemical species initialized from previous 12-h forecast
- On-line chemistry (met and chem interact at each time step)
- Comprehensive evaluation of WRF/Chem with surface, ship, and aircraft data during field experiment

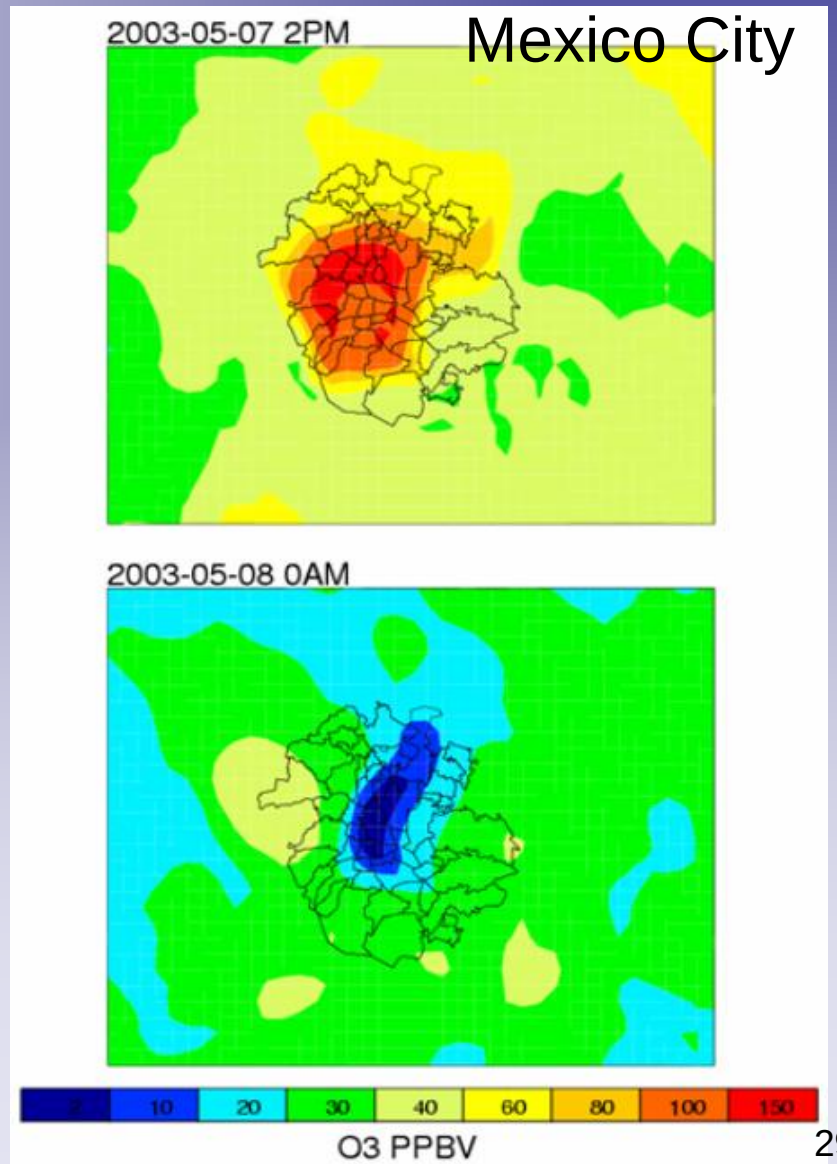
G. Grell et al., NOAA FSL

WRF-Chem ICs for wind, pressure and ozone



WRF-Chem Applications:
MIRAGE-Mex Field Campaign

- Pre-campaign
  - Characterize plume extent, prevailing outflow patterns
  - Predict evolution of chemical reactivity
- During (Feb-Mar 2006)
  - Real-time chemical forecasts
  - Aid in flight planning
- Post-campaign
  - Evaluations with measurements
  - Model-model intercomparison
  - Identify model shortcomings, future improvements



X. Tie and S. Madronich, NCAR/ACD

WRF-AqChem Applications:
Evaluation of chemical transport processes

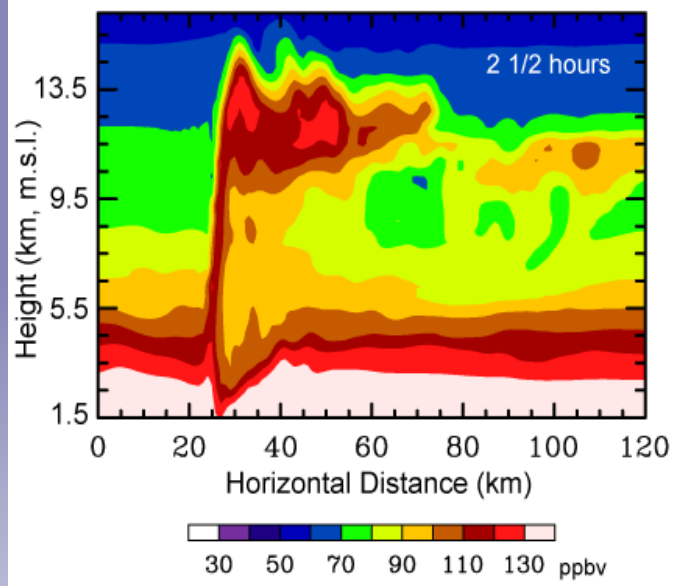
Test of aqueous chemistry & vertical transport by a squall line:

Cross section of [CO] and [CH_2O]
(total concentrations from
gas + cw + rain + ice + snow + hail)

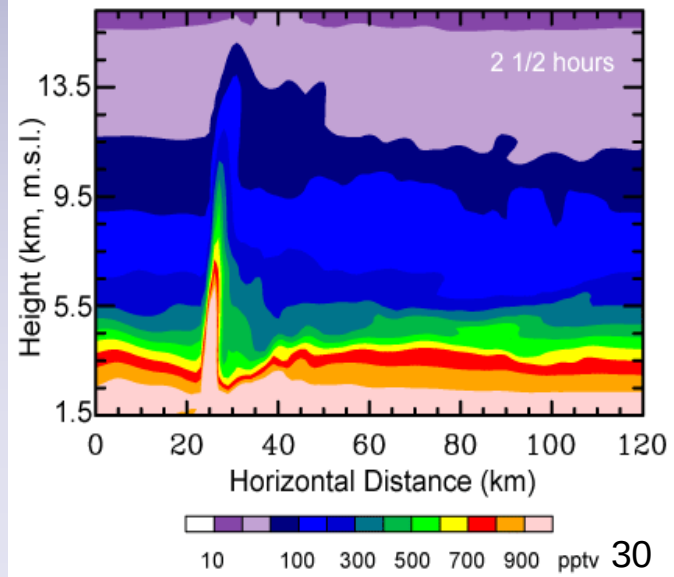
- CO (insoluble): transported to upper troposphere
- CH_2O (soluble): relatively less reaching into upper troposphere

Mary Barth et al., NCAR MMM/ACD

CO (ppbv)



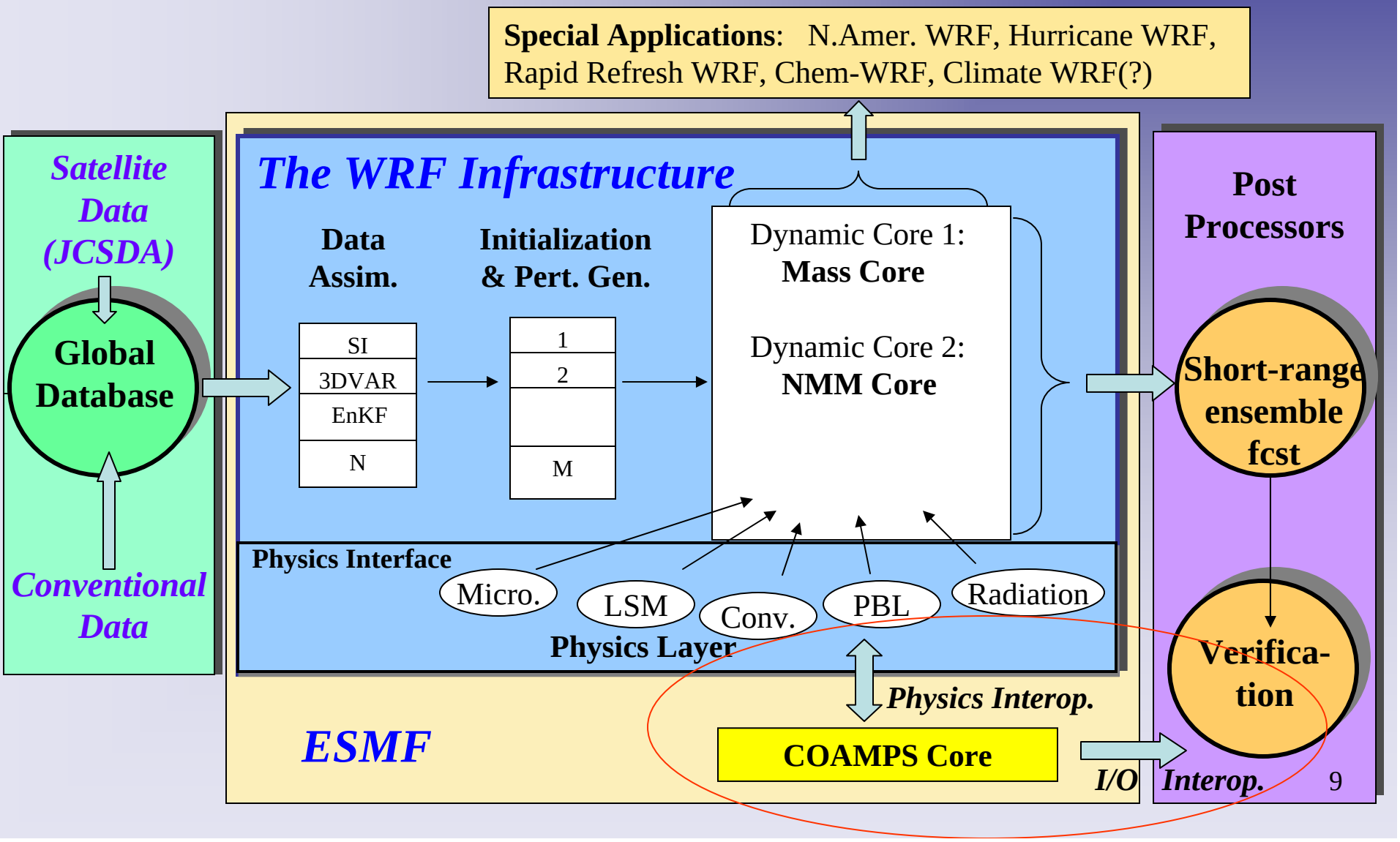
CH_2O (pptv)



End

Questions?

Concept: ESMF-WRF could be adapted to provide WRF interoperability with COAMPS



Why move to WRF?

- **CAWFE Model**
  - **No ongoing development**
  - **No support**
  - **Difficult for new users**
  - **Difficult to link with emissions inventories or chemistry**

- **WRF Model**
  - **Community model**
    - Multi-agency effort
    - Fully supported
    - State of the art technology
    - Runs on 7 platforms ranging from desktop PCs to supercomputers
    - Easy to switch and/or add physics or numerics
    - Pre-built analysis tools
  - **Immediate link with chemistry modules, land surface models, etc.**
  - **Service to the community**
  - **Ready for real-time applications**

Courtesy – Rich Wagoner, NCAR/RAL