Data Assimilation and Superparameterization

Steve Lord
& EMC Staff

National Centers for Environmental Prediction
Environmental Modeling Center
Washington D.C. USA

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Overview

- Data assimilation
  - Basics
  - Clouds and precipitation
  - NASA-NOAA-DOD Joint Center for Satellite Data Assimilation
  - Observing System Simulation Experiments (OSSEs)
- NCEP's global forecast system
  - Short-term drift (< 1 year)
  - Current performance of coupled forecast system
- Uses of Super-parameterization

Data Assimilation (for the atmosphere)

- Data assimilation brings together all available information to make the best possible estimate of:
  - The atmospheric state
  - The initial conditions to a model which will produce the best forecast.

Data Assimilation Context

- Information sources
  - Observations
  - Background (forecast)
  - Dynamics (e.g., balances between variables)
  - Physical constraints (e.g., $q > 0$)
  - Statistics
  - Climatology

Overview

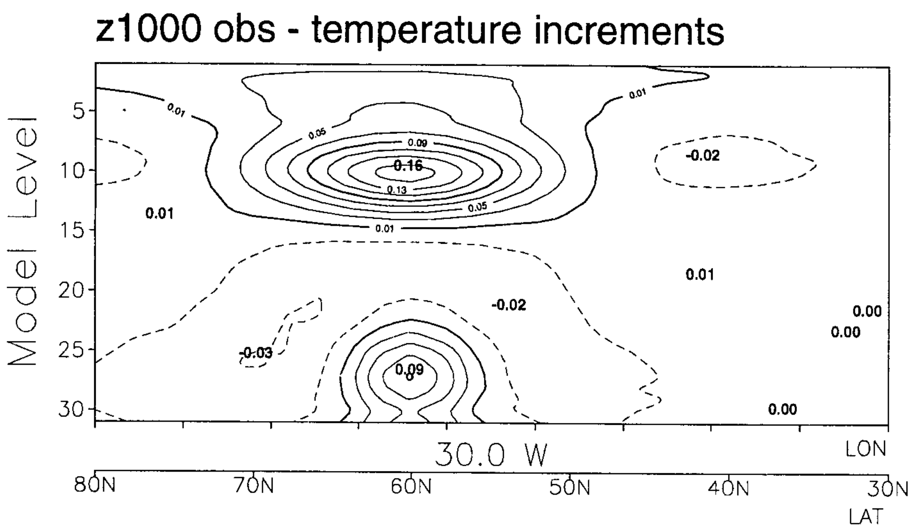
- Basic analysis equation

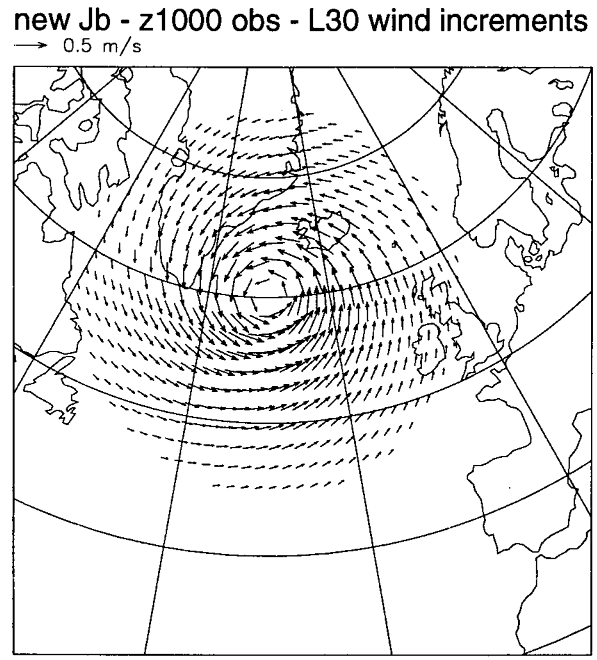
$J = (x-x_b)^T B^{-1}(x-x_b) + (H(x)-O)^T(E+F)^{-1}(H(x)-O) + \dots$

J = Fit to background + Fit to observations + other constraints

x = Analysis
x_b = Background
B = Background error covariance
H = Forward model
O = Observations
$E+F$ = Instrument error + Representativeness error

Sample background error structure





Overview (cont)

- Current data assimilation systems have been developed for synoptic scale weather systems
  - Mesoscale applications ported down scale
  - Clouds and precipitation are inherently mesoscale
- There is a lot of mesoscale data which we already have that we cannot use properly
  - Satellite data is thought to be mesoscale
  - “high resolution” refers to
    - Horizontal pixel size
    - Number of channels
- There is a perception that “going to high resolution” will solve our problems
  - Perhaps we don’t know what problems will face us at “high resolution”

Overview (cont)

- For mesoscale data assimilation improved will be techniques necessary before we can use much of the data properly

- A 10+ year problem

In NCEP's opinion: the bottom line is:

- At the mesoscale "you have to get it all right".

Improvements to assimilation techniques (1)

- Background error covariances.
  - Determine structures, smoothing, scales and inter-variable relationships within analysis.
  - Techniques for efficient computation.
  - Techniques for improved estimation.
- Dynamical/Thermodynamical balance.
  - Mass/moisture/momentum – Spin up, Spin down.
  - Gravity waves important.
  - Loss of simple balance implies increased observational requirements.

Improvements to assimilation techniques (2)

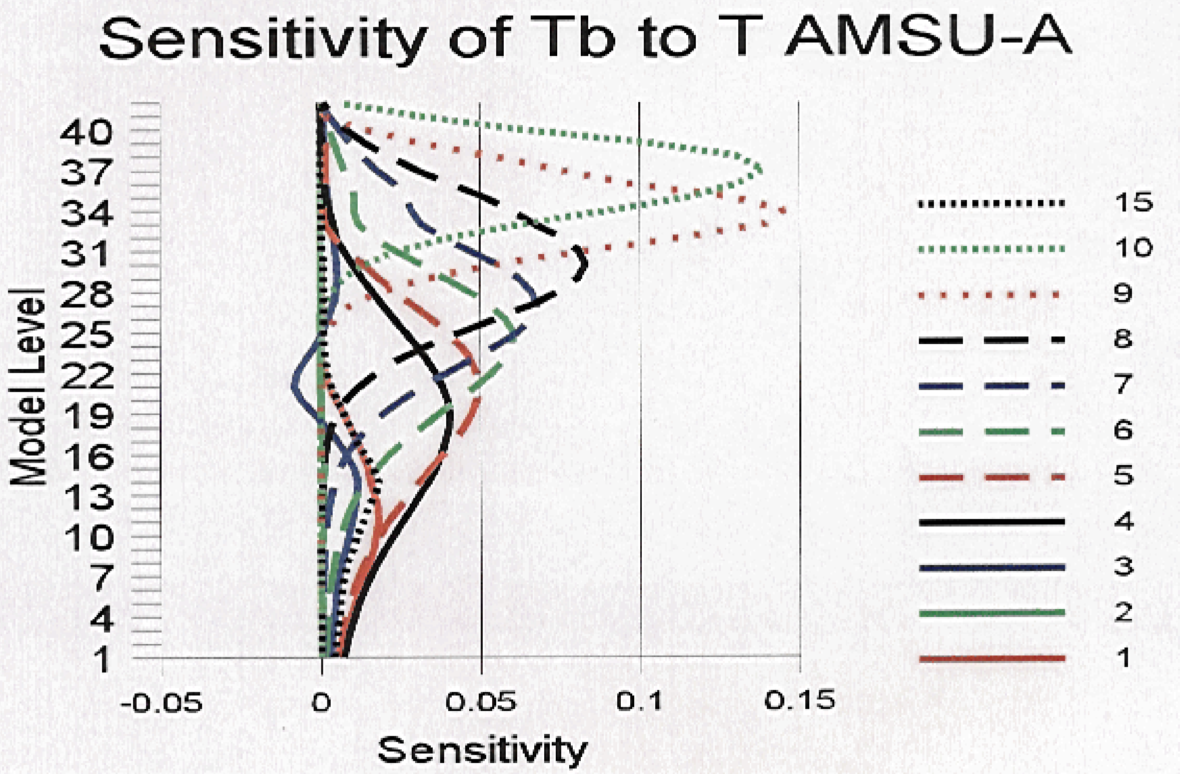
- Additional analysis variables.
  - Clouds/precipitation.
  - Turbulence.
  - Aerosols.
  - Ozone, methane, CO_2, etc.
  - Surface quantities (soil moisture, temperature, etc.).
- Improved forecast models.
  - WRF model.
  - Must include all analysis quantities.
  - Improved model forecast makes assimilation easier.

Improvements to assimilation techniques (3)

- Explicit bias correction of background field.
- Moving misplaced systems without destroying structure.
  - e.g. hurricanes.
- Advanced assimilation techniques.
  - Kalman filtering, others.
  - Boundary control.
  - Applicability over timescales used not clear.
  - Cost?.

Satellite Radiance Observations

- Measure upwelling radiation at top of atmosphere
- Measure deep layers
  - IR not quite as deep as microwave
  - New IR instruments (AIRS, IASI, GIFTS) narrower, but still quite deep layers
  - Deep layers generally implies large horizontal scale



Sensitivity of Tb to T AMSU-A
Model Level
40
37
34
31
28
25
22
19
16
13
10
7
4
1
-0.05
0
0.05
0.1
0.15
Sensitivity
15
10
9
8
7
6
5
4
3
2
1

Satellite data use

- Key to using data is to have good characterization of *K* – forward model. If unknowns in *K*(x,z) – either in formulation of *K* or in unknown variables (z) are too large data cannot be reliably used.
  - If situations where data cannot be reliably used they must be removed by the quality control. For example, currently we cannot use radiances containing cloud signal – thus we attempt to not use these observations.
- Note that errors in formulation or unknown variables generally produce correlated errors. This is a major source

Satellite data requirements

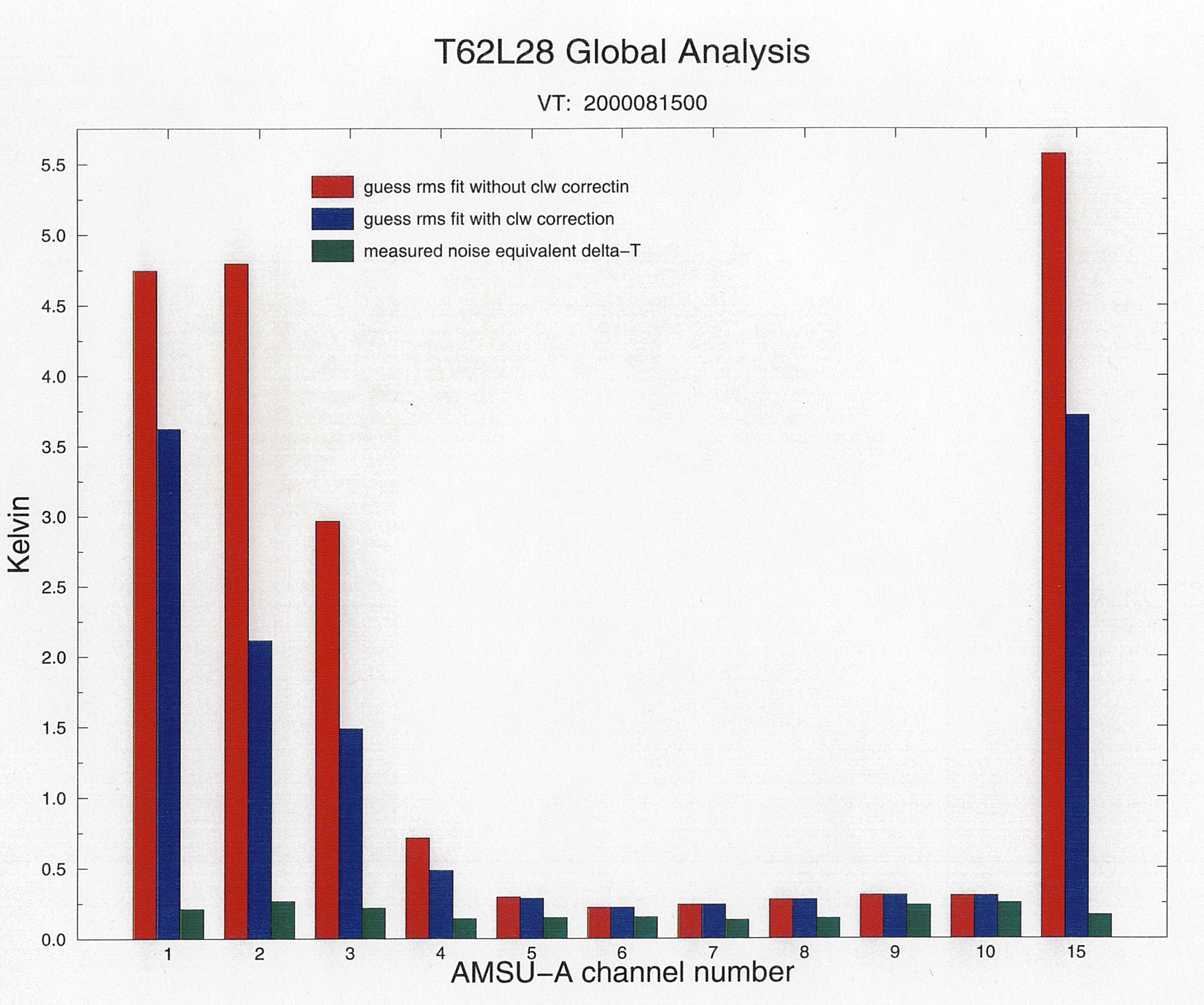
- Requirements for operational use of observations
  - Accurate forward model (and adjoint) available
  - Available in real time in acceptable format
  - Assurance of stable data source
  - Quality control procedures defined (conservative)
  - Observational errors defined (and bias removed if necessary)
  - Evaluation and testing to ensure

Satellite Radiance Observations

- Radiative transfer
- Quality Control
- Bias correction
- Monitoring
- Impact

Satellite Radiance Observations Radiative transfer

- Need fast radiative transfer function (and tangent linear, adjoint and Jacobian) to use observations (LBL codes much too slow)
  - Reflected and emitted radiation from surface (emissivity, temperature, polarization, etc.)
  - Atmospheric transmittances dependent on moisture, temperature, ozone, clouds, aerosols, CO2, methane, ...
  - Cosmic background radiation (important for microwave)
  - View geometry (local zenith angle, view angle (polarization))


T62L28 Global Analysis
VT: 2000081500
guess rms fit without clw correctin
guess rms fit with clw correction
measured noise equivalent delta−T
Kelvin
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
1
2
3
4
5
6
7
8
9
10
15
AMSU−A channel number

Joint Center for Satellite Data Assimilation

Stephen J. Lord (NCEP/EMC)
Fuzhong Weng (NESDIS/ORA)
L.P. Riishojgaard (NASA/DAO)

JCSDA Ocean Data Assimilation Workshop

June 16, 2003

Mission

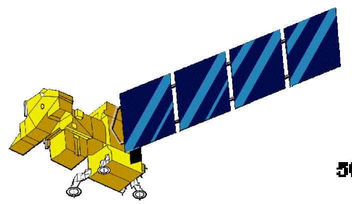
The mission of the Joint Center for Satellite Data Assimilation is to accelerate and improve the quantitative use of research and operational satellite data in weather and climate prediction models.

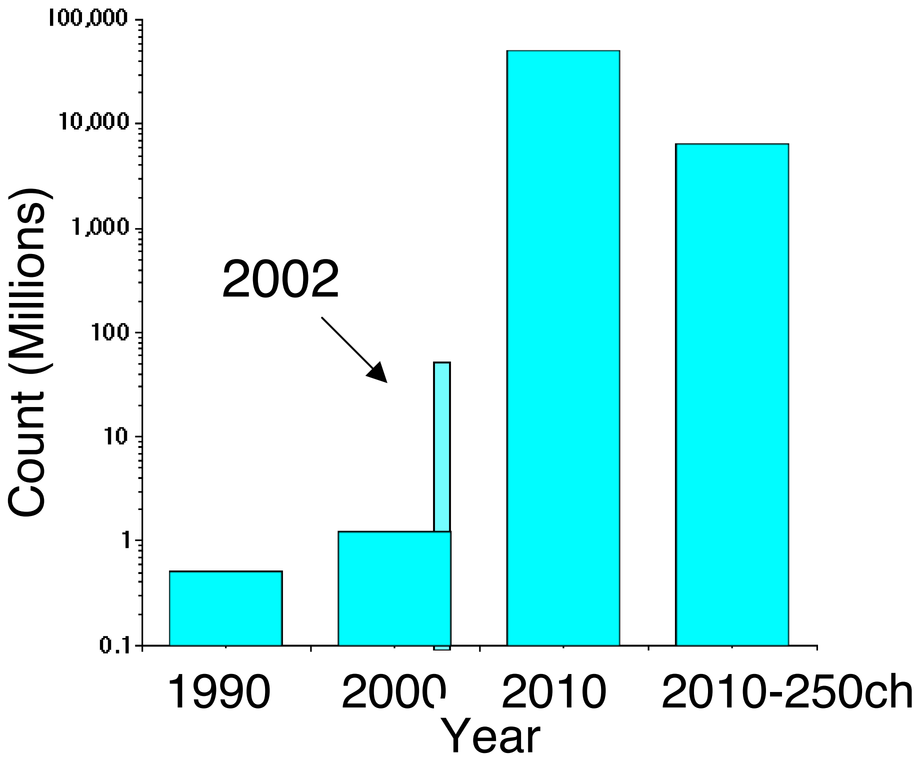
Goals

- Reduce from two years to one year the average time for operational implementation of new satellite technology
- Increase use of current satellite data in Weather and Climate Forecast Systems
- Assess the impacts of satellite data on Weather and Climate predictions

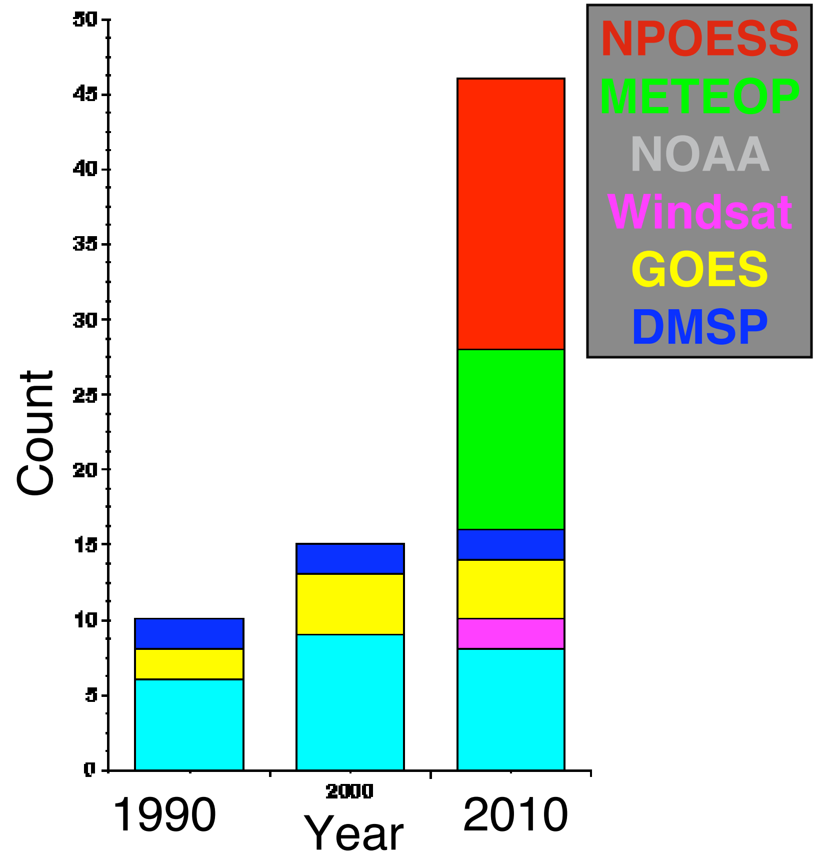
5-Order Magnitude Increase in Satellite Data Over 10 Years

Daily Upper Air Observation Count





Satellite Instruments by Platform



JCSDA Partners

JOINT CENTER FOR SATELLITE DATA ASSIMILATION

PARTNERS

NASA/Goddard

Global Modeling & Assimilation Office

NOAA/NCEP

Environmental Modeling Center

NOAA/OAR

Office of Weather and Air Quality

US Navy

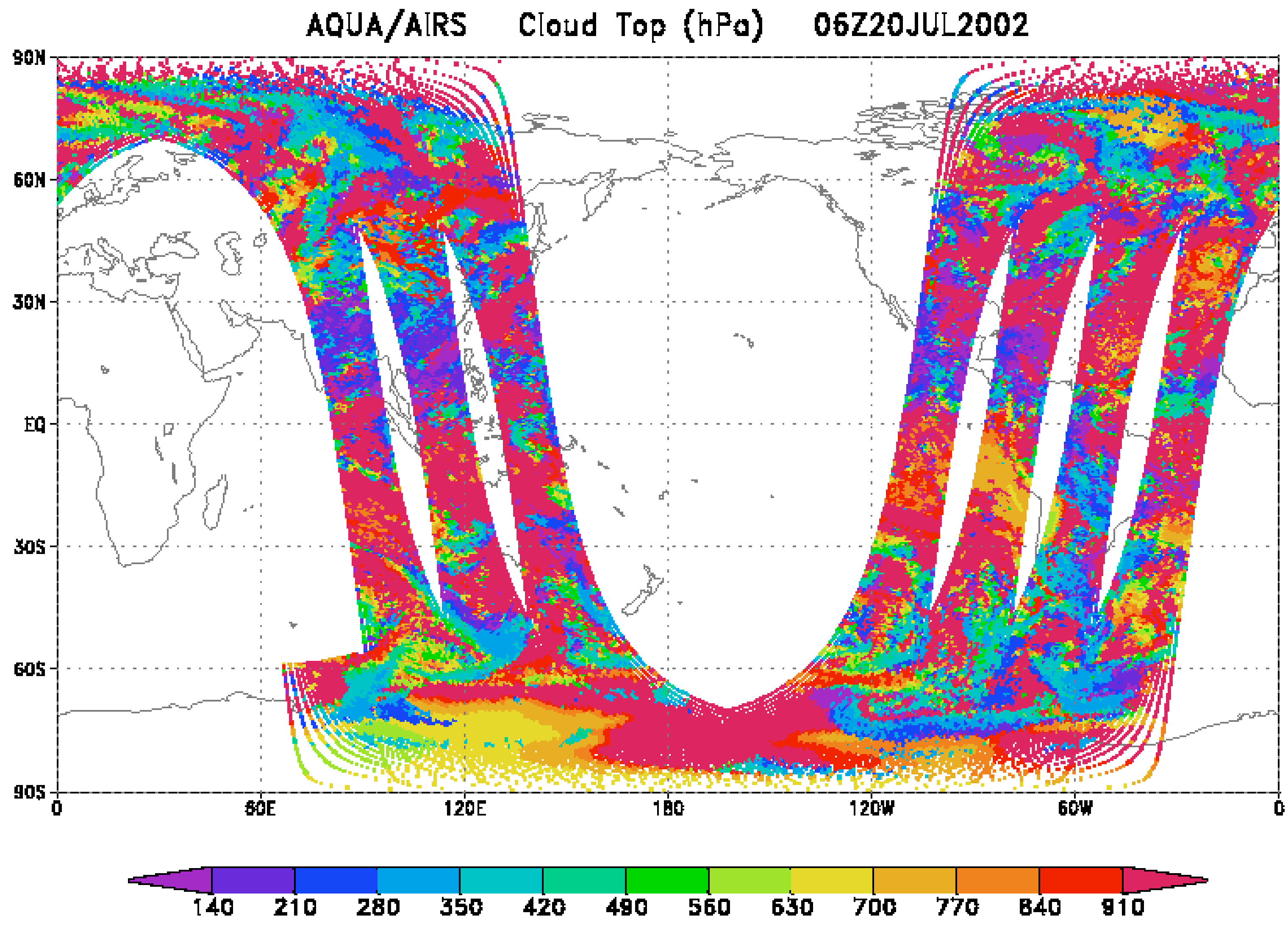
Oceanographer of the Navy, Office of Naval Research (NRL)

NOAA/NESDIS

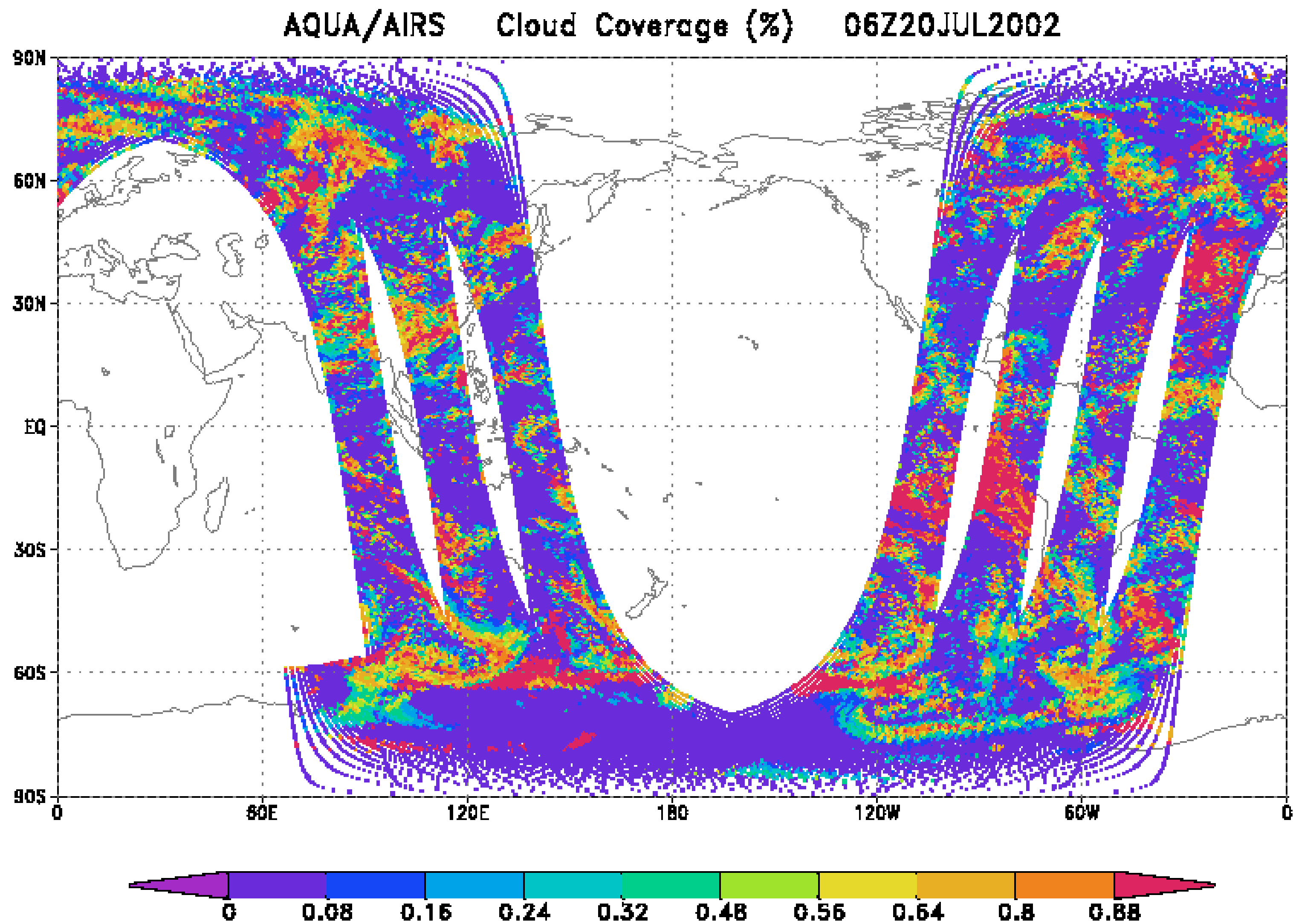
Office of Research & Applications

US Air Force

AF Director of Weather
AF Weather Agency



AQUA/AIRS Cloud Top (hPa) 06Z20JUL2002
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
140
210
280
350
420
490
560
630
700
770
840
910

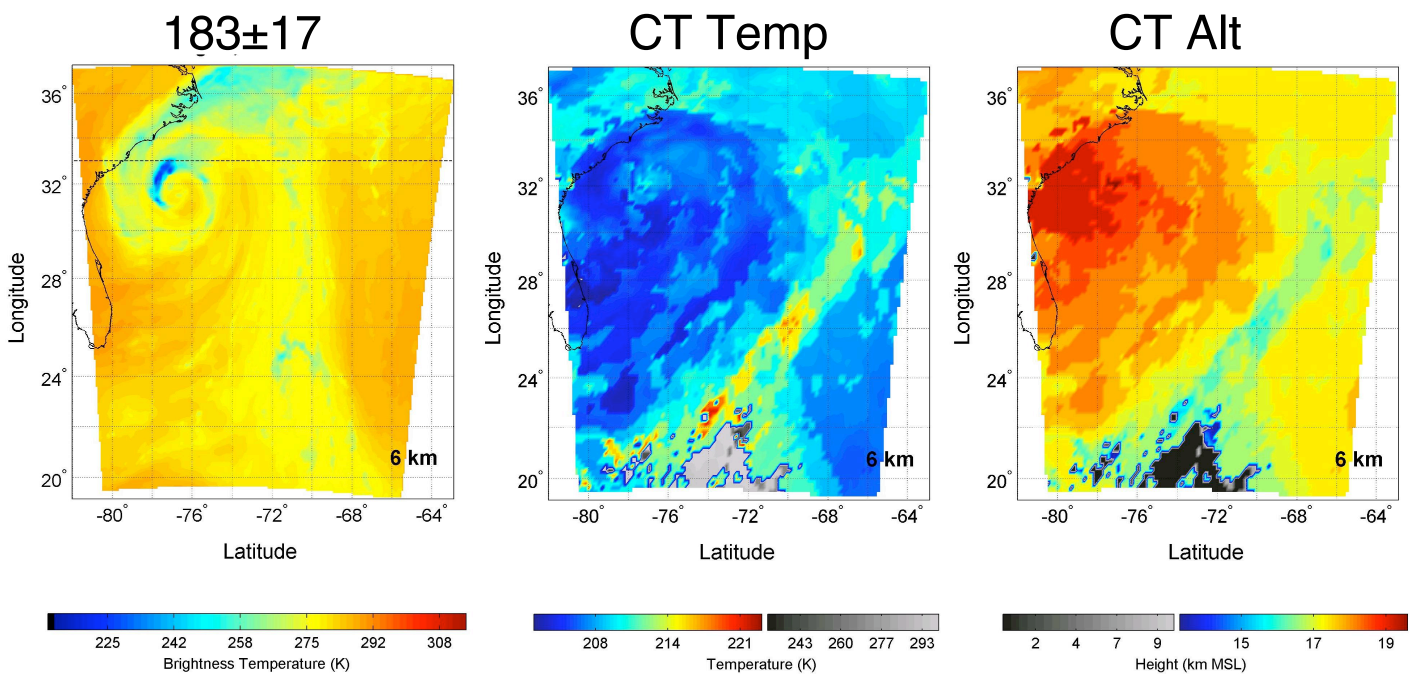


AQUA/AIRS Cloud Coverage (%) 06Z20JUL2002
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
0.08
0.16
0.24
0.32
0.48
0.56
0.64
0.8
0.88

24-Hr Simulation of AMSU 183 GHz T_B

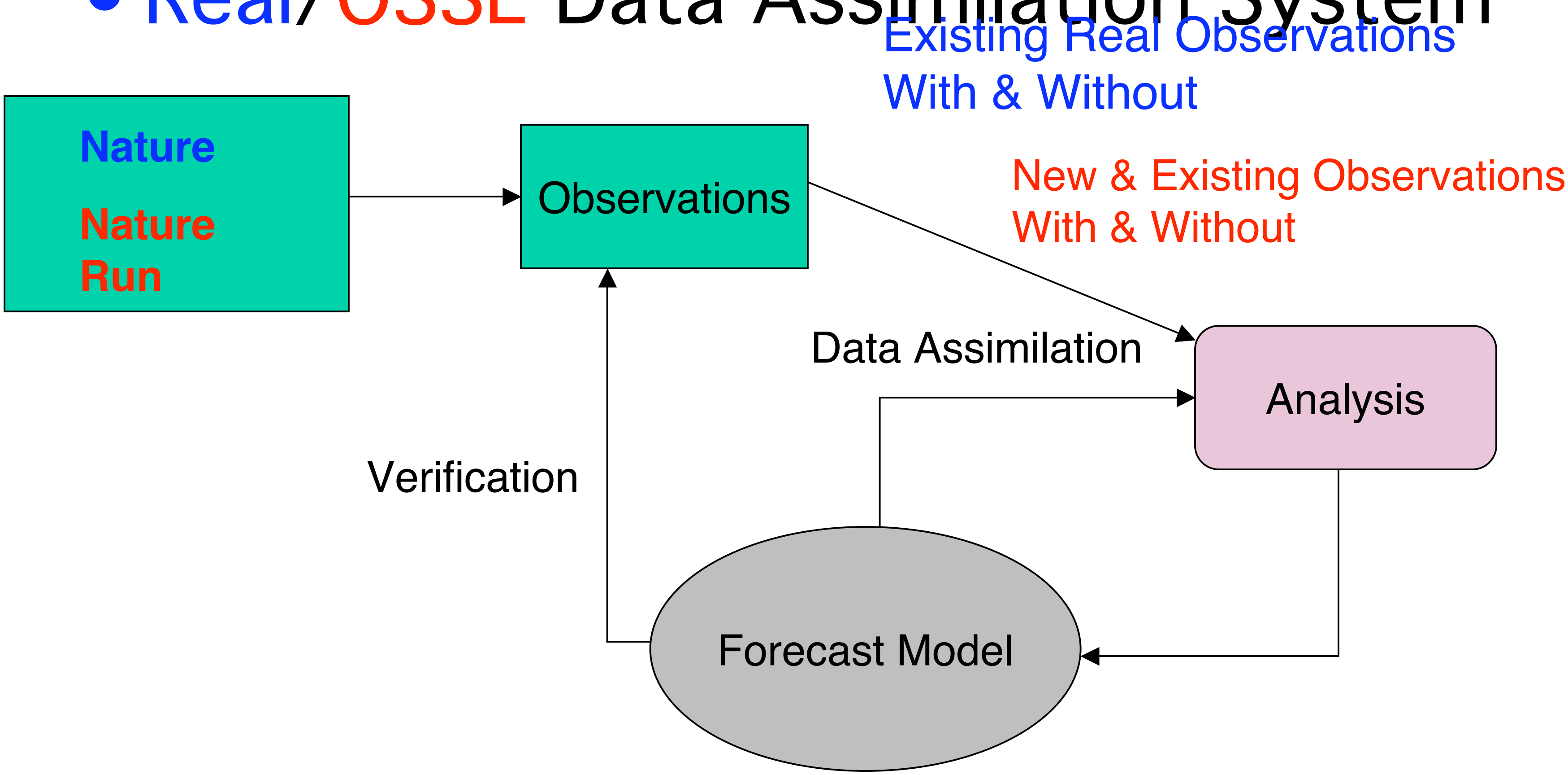
Hurricane Bonnie   August 26, 1998   0300 UTC

- Microwave response is more representative of sub-cloud hydrometeor structure than cloud-top temperature (e.g., GOES IR).
- Strong T_B contrast associated with precipitation structure expected at 183 GHz, somewhat weaker but important at other AMSU bands.
- Significant precipitation evolution occurs on ~15-30 minute time scales – 3-hour time steps show large changes in rainband structure.



Introduction to OSSEs
Basic Concepts

- Real/OSSE Data Assimilation System



Introduction to OSSEs
Basic Concepts (cont)

- In OSSEs
  - “Nature Run” is proxy for Real Nature
    - Free run of forecast model
      - Realistic phenomenology and variability vs. Nature
    - As independent as possible from Data Assimilation system model
      - Correlated biases introduce optimism
      - Construction of observations from Nature Run should also be independent
  - Truth is known
    - Verification vs truth can reveal characteristics of data assimilation system
  - New observations can be simulated

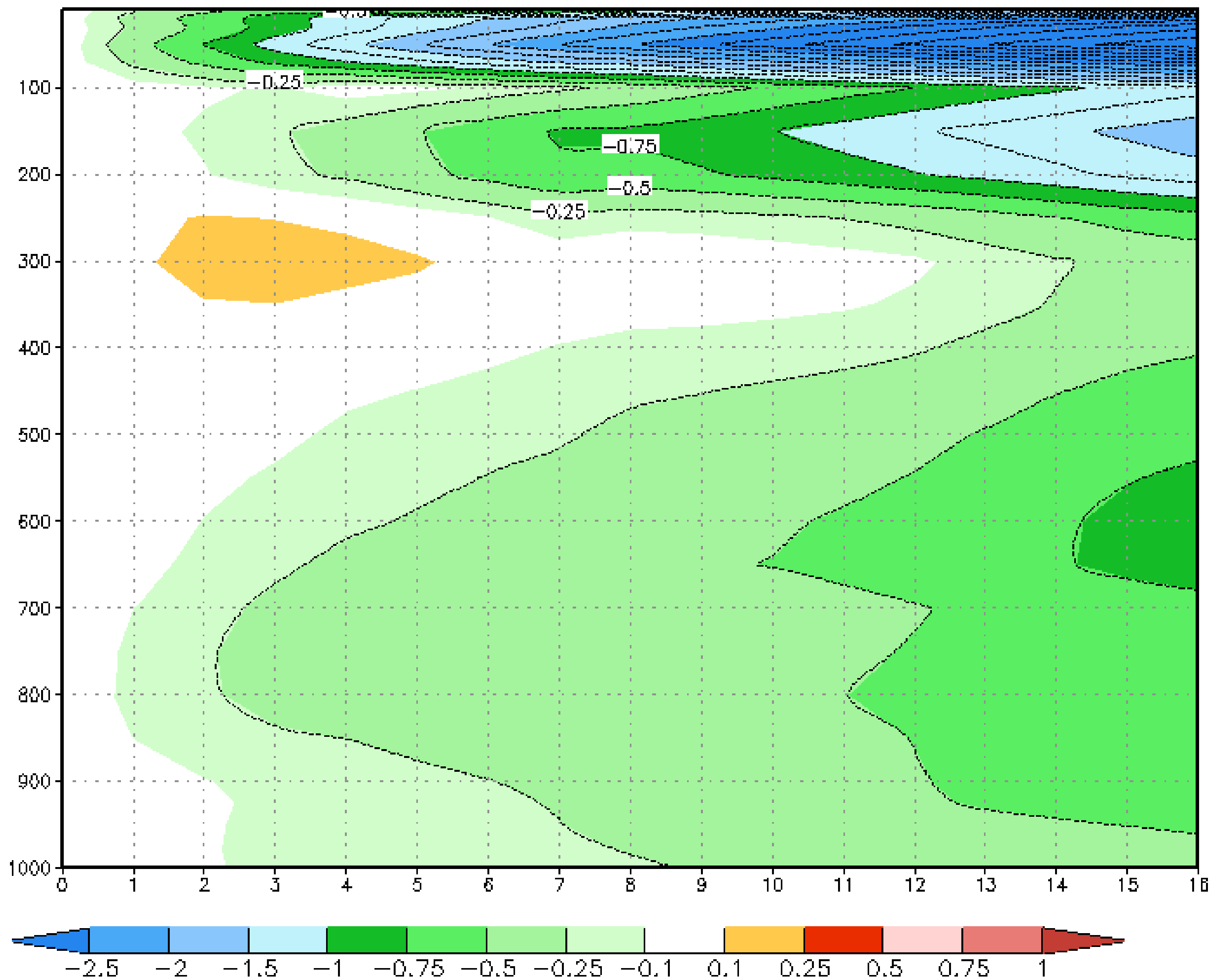
Introduction to OSSEs Basic Concepts (cont)

- Simulated observations should
  - Exhibit same system impact as real observations
  - Contain same kinds of errors as real observations (e.g., representativeness)
    - Nature Run is truncated spectrally in space & time
    - Real Nature is not truncated
  - Be produced by different instrument models than used in data assimilation system (e.g., radiances)
- For application to advanced observing systems
  - The Data Assimilation System should be leading edge but well tested
  - OSSEs should be run periodically leading up to

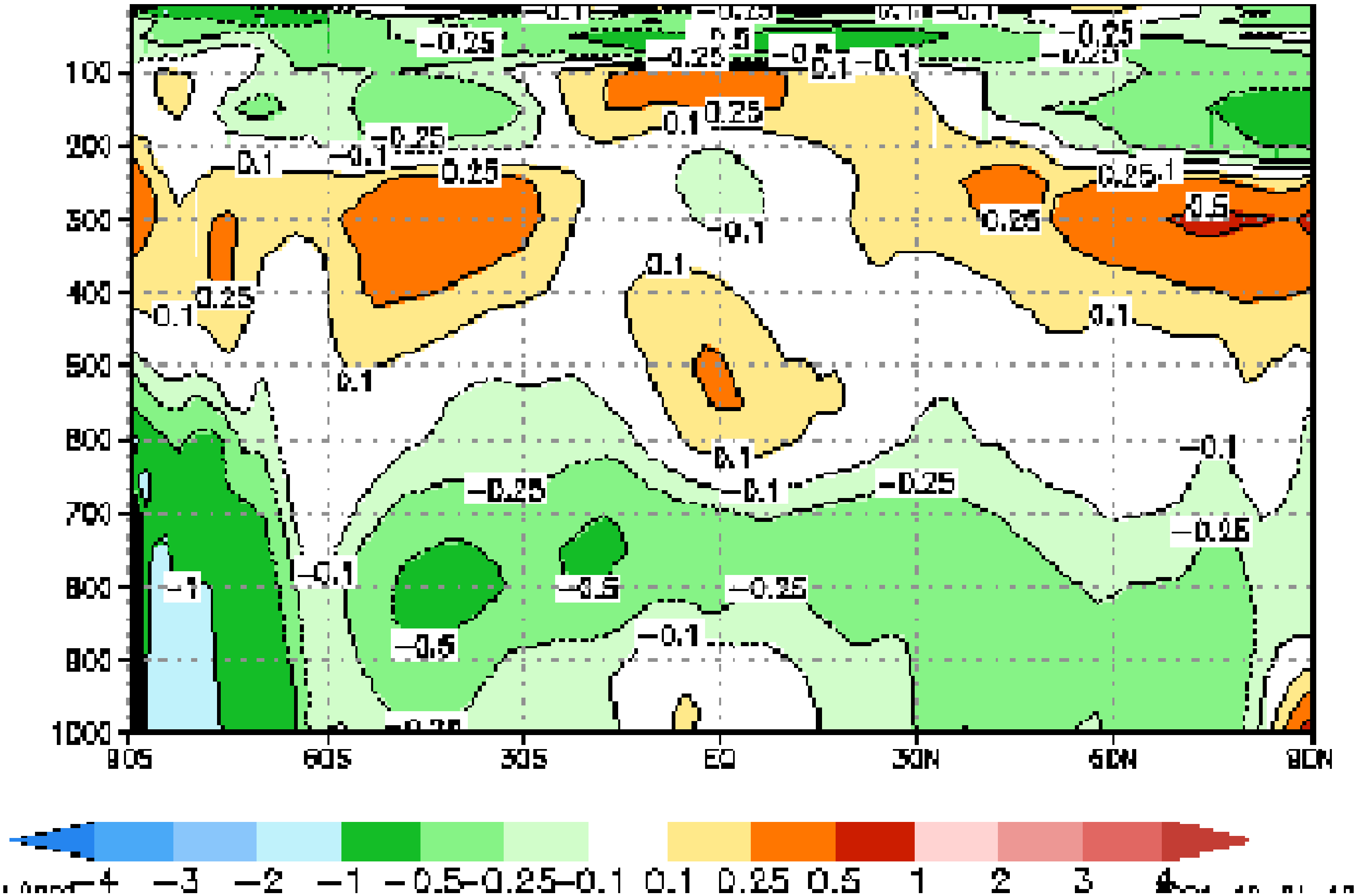
Super-parameterization (SP) Approach

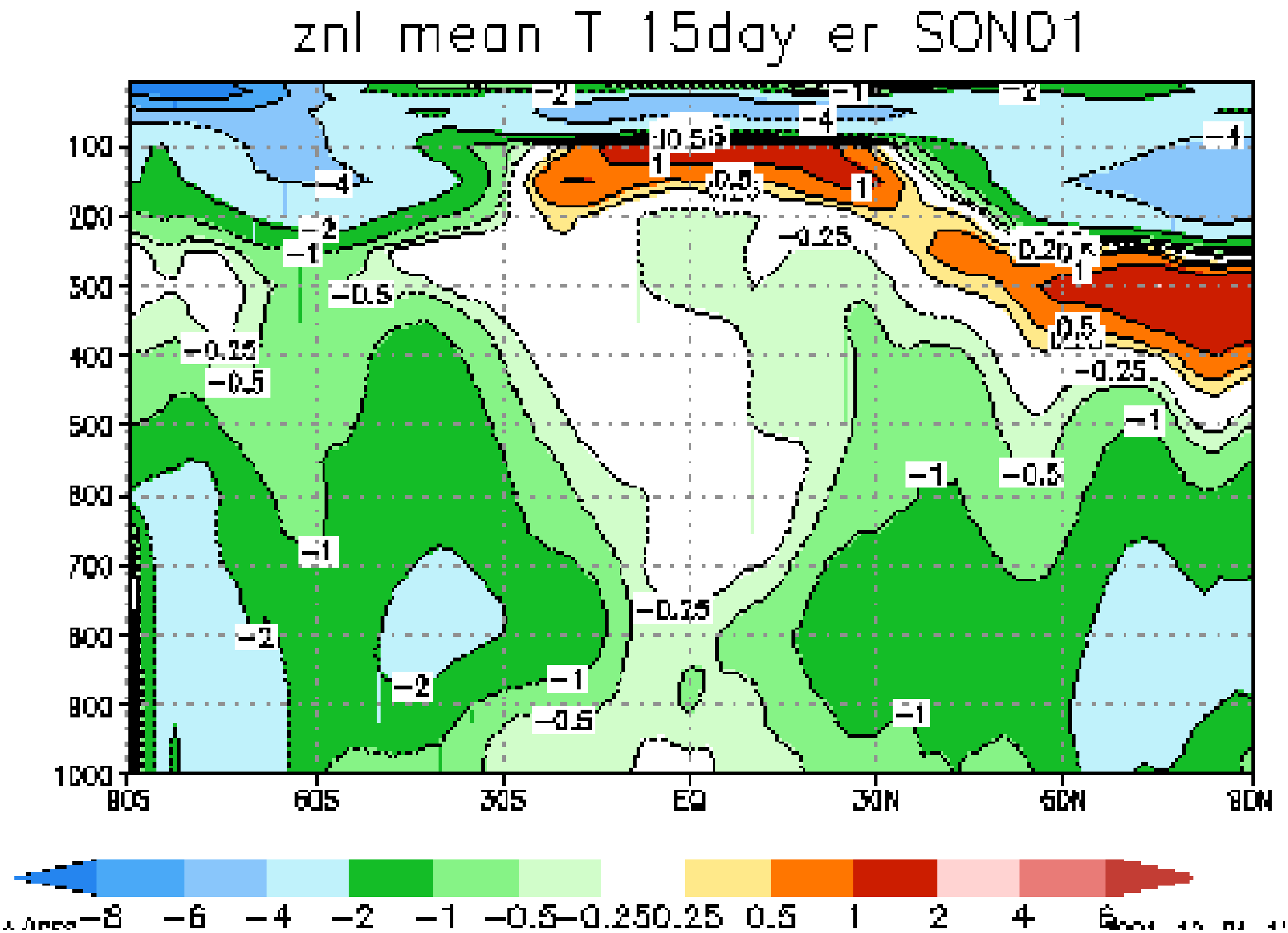
- Assertion
  - Using Cloud System Resolving Model (CSRM) will produce a simulated model climate closer to Nature than current parameterizations
  - Some temperature drift results follow
  - Some results on NCEP's coupled climate runs follow
- The SP approach will provide data for many types of studies
  - Observing System Simulation Experiments

gbl mean T Oct03op 0-16dy



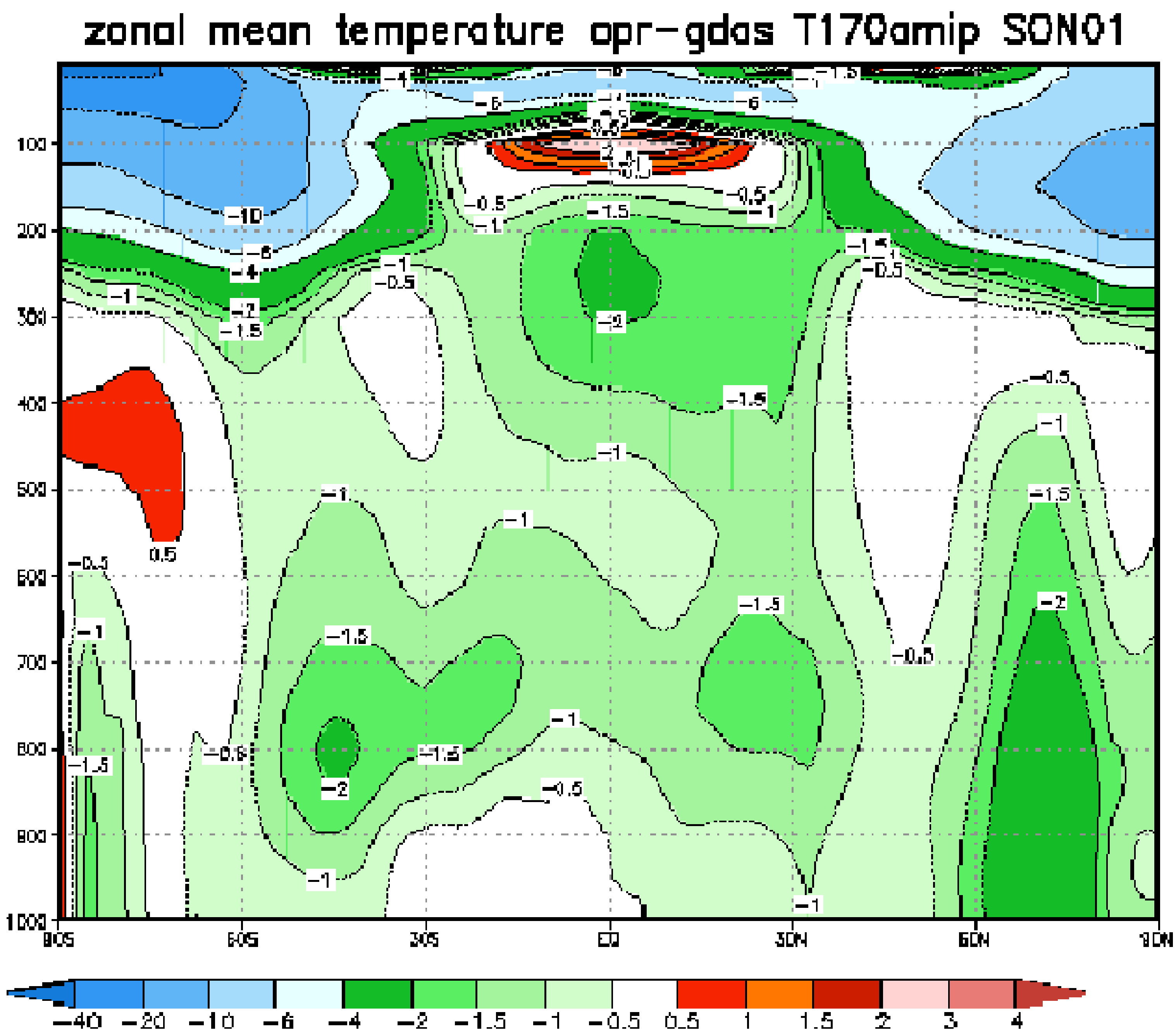
znl mean T 1day er SON01





znl mean T 15day er SON01
100
200
300
400
500
600
700
800
900
1000
80S
60S
30S
EQ
30N
60N
80N
−8 −6 −4 −2 −1 −0.5 −0.25 0.25 0.5 1 2 4 6

Temperature Drift 3 month mean after 11.5 month A



E

M

C

Hindcast Skill in the New Coupled NCEP Ocean-Atmosphere Model

Suranjana Saha, Wanqiu Wang, Hua-Lu Pan

and the NCEP/EMC Climate and Weather Modeling Branch

Environmental Modeling Center, NCEP/NWS/NOAA

Special Acknowledgements : Sudhir Nadiga, Jiande Wang, Qin Zhang, Shrinivas Moorthi, Huug van den Dool

Introduction

A new global coupled atmosphere-ocean model has recently been developed at NCEP/EMC.

Components

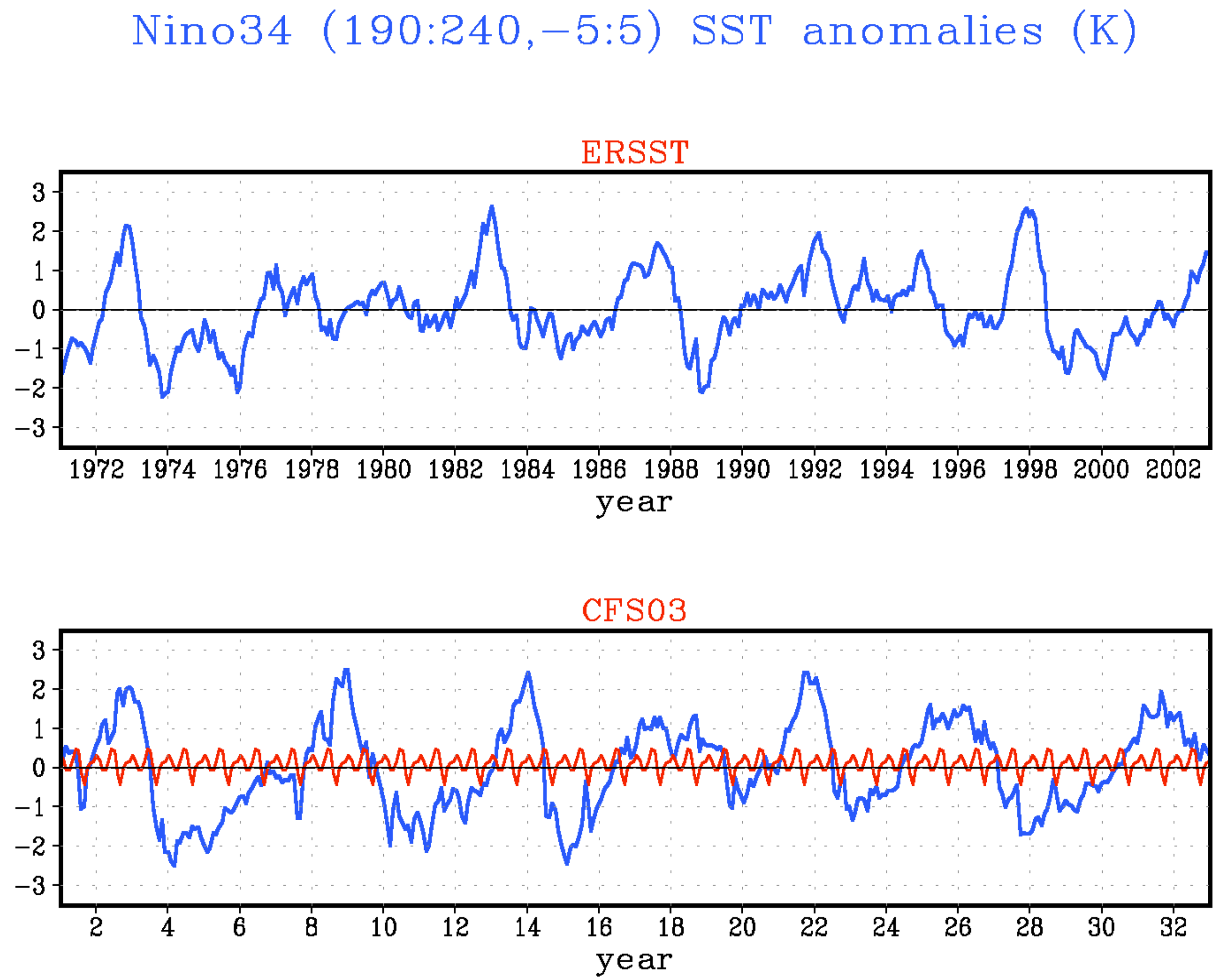
a) the T62/64-layer version of the current NCEP atmospheric GFS (Global Forecast System) model and

b) the 40-level GFDL Modular Ocean Model (version 3)

Note:

Direct coupling with no flux correction

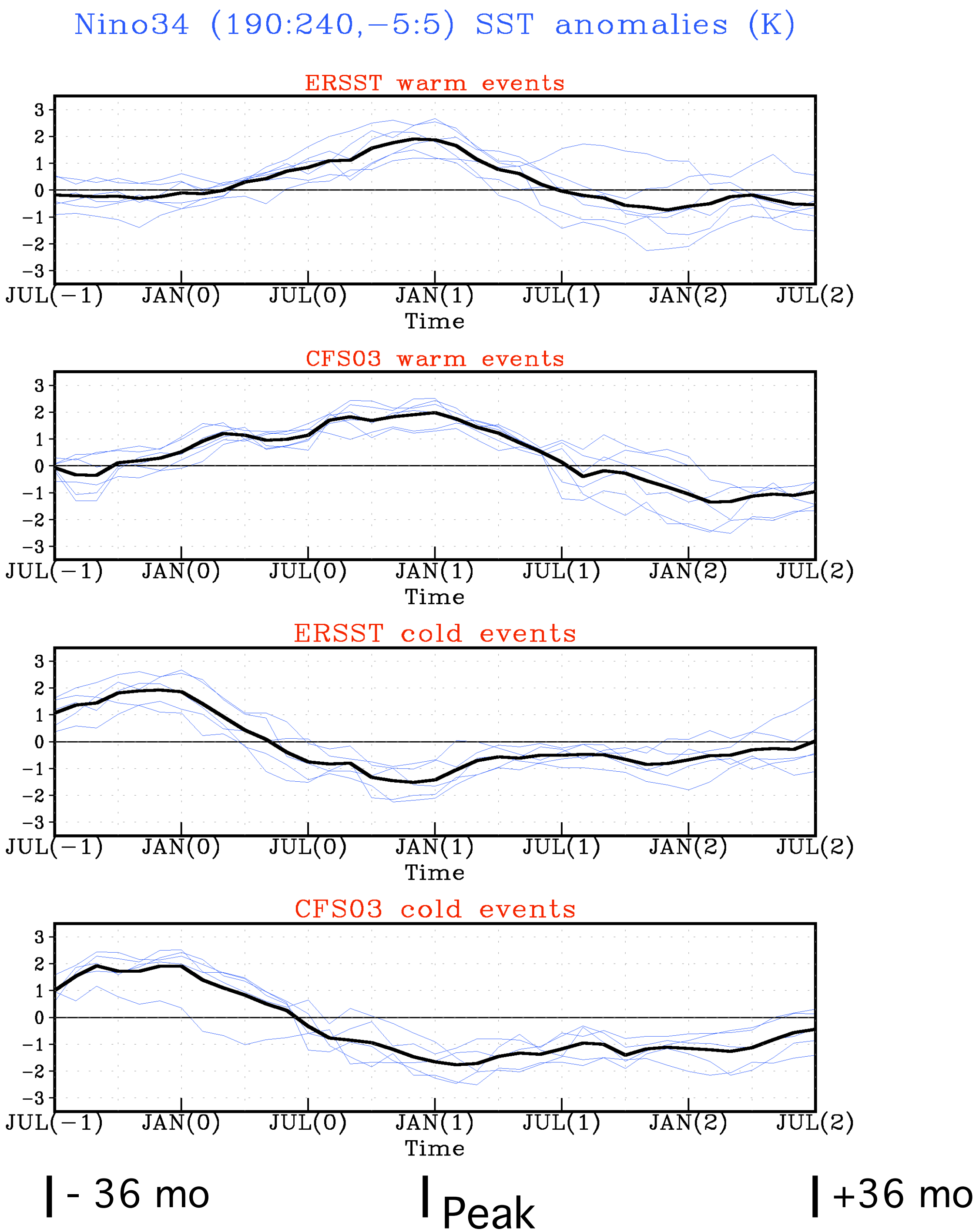
This model will replace the current operational NCEP



Observed

Coupled

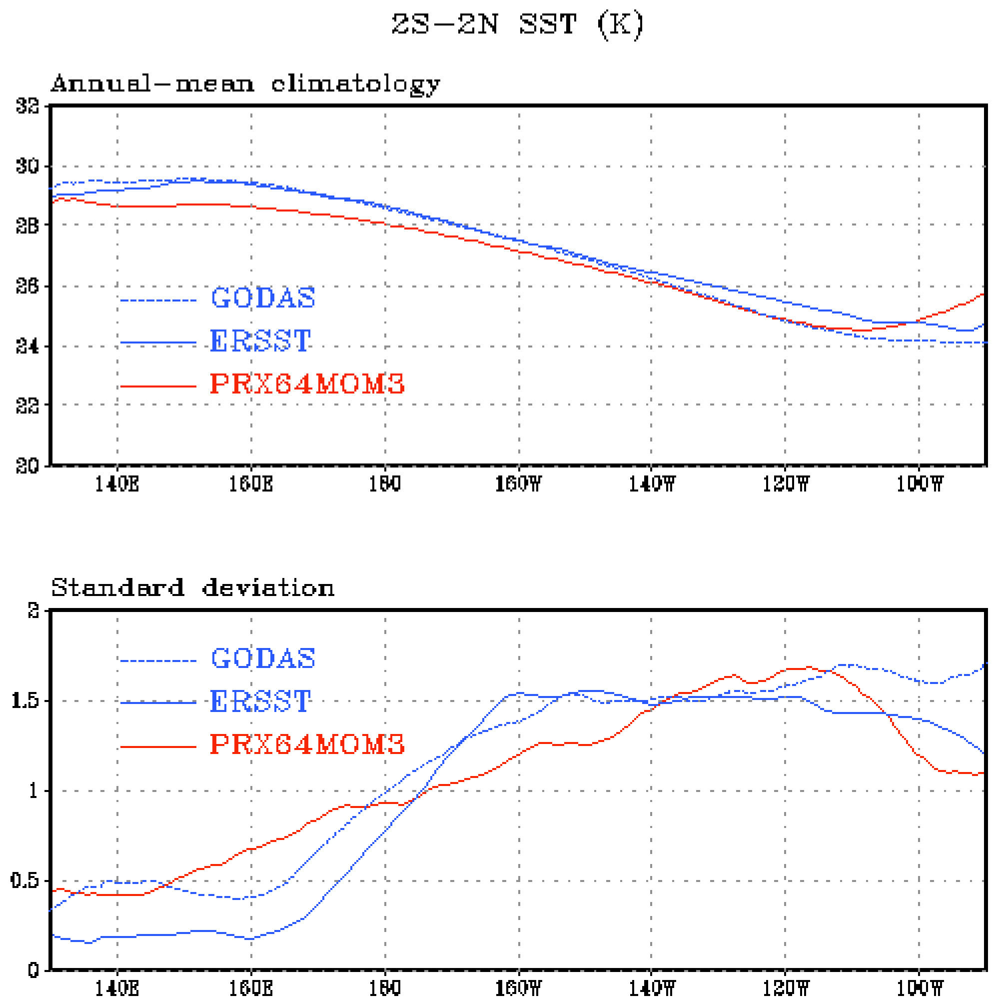
Red: monthly bia



Composite Warm and Cold Events

- Events exceed ERSST variance by
  - 1.0 SD (warm)
  - 0.75 SD (cold)
- Heavy black line is mean

SST Climatology on Equator



Red: coupled model

Hindcast Skill Assessment

- 5-member ensemble over 22 years from 1981-2002

- January and April initial conditions
  - Other months to follow

- 9 month runs

- Initial atmospheric states 0000 GMT 19, 20, 21, 22, and 23 for each month
  - Reanalysis-2 archive

.

- Initial ocean states NCEP GODAS (Global Ocean Data Assimilation System) 0000 GMT 21st of each month
  - Same for all runs
  - GODAS operational September 2003

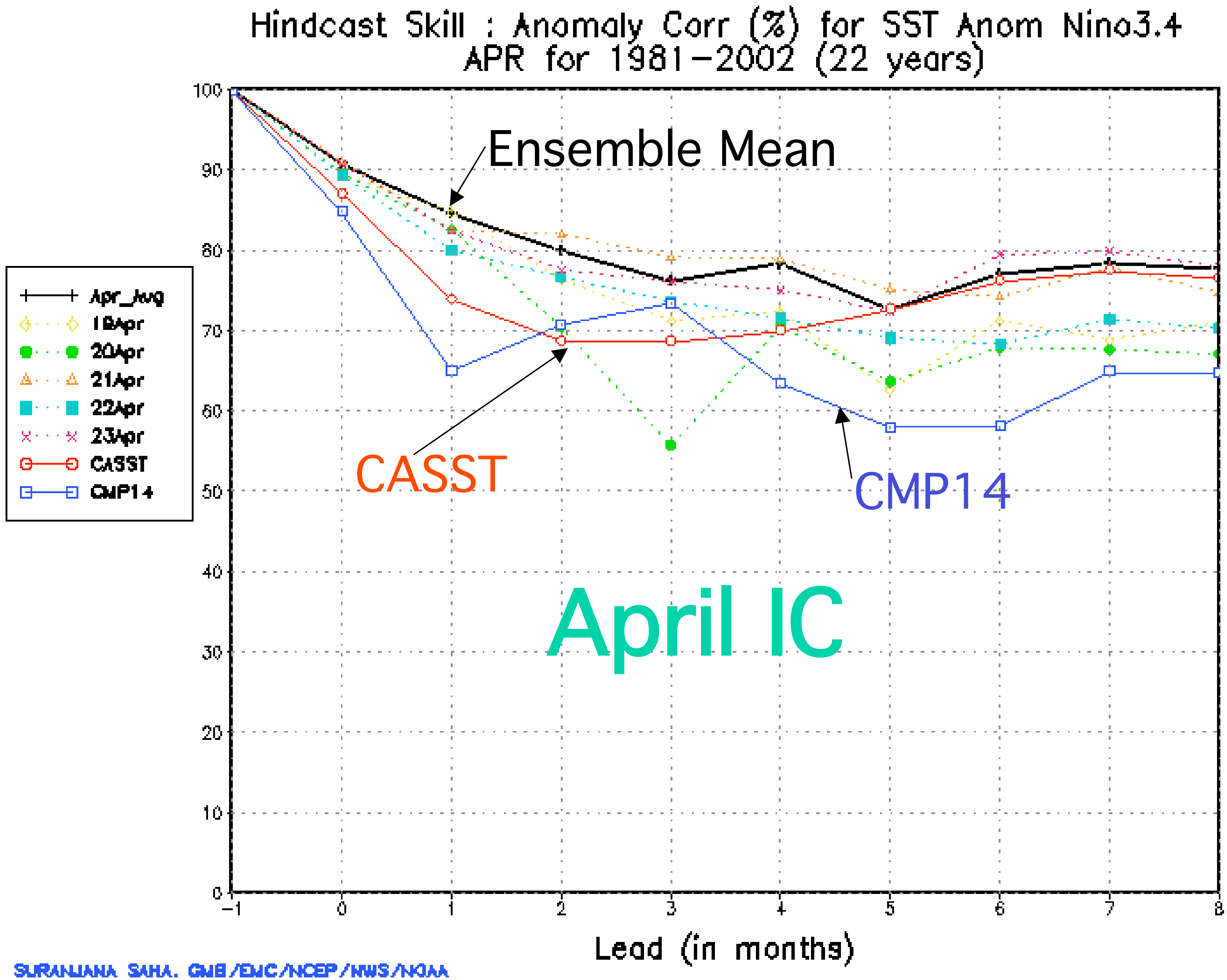
Hindcast Skill Assessment (cont)

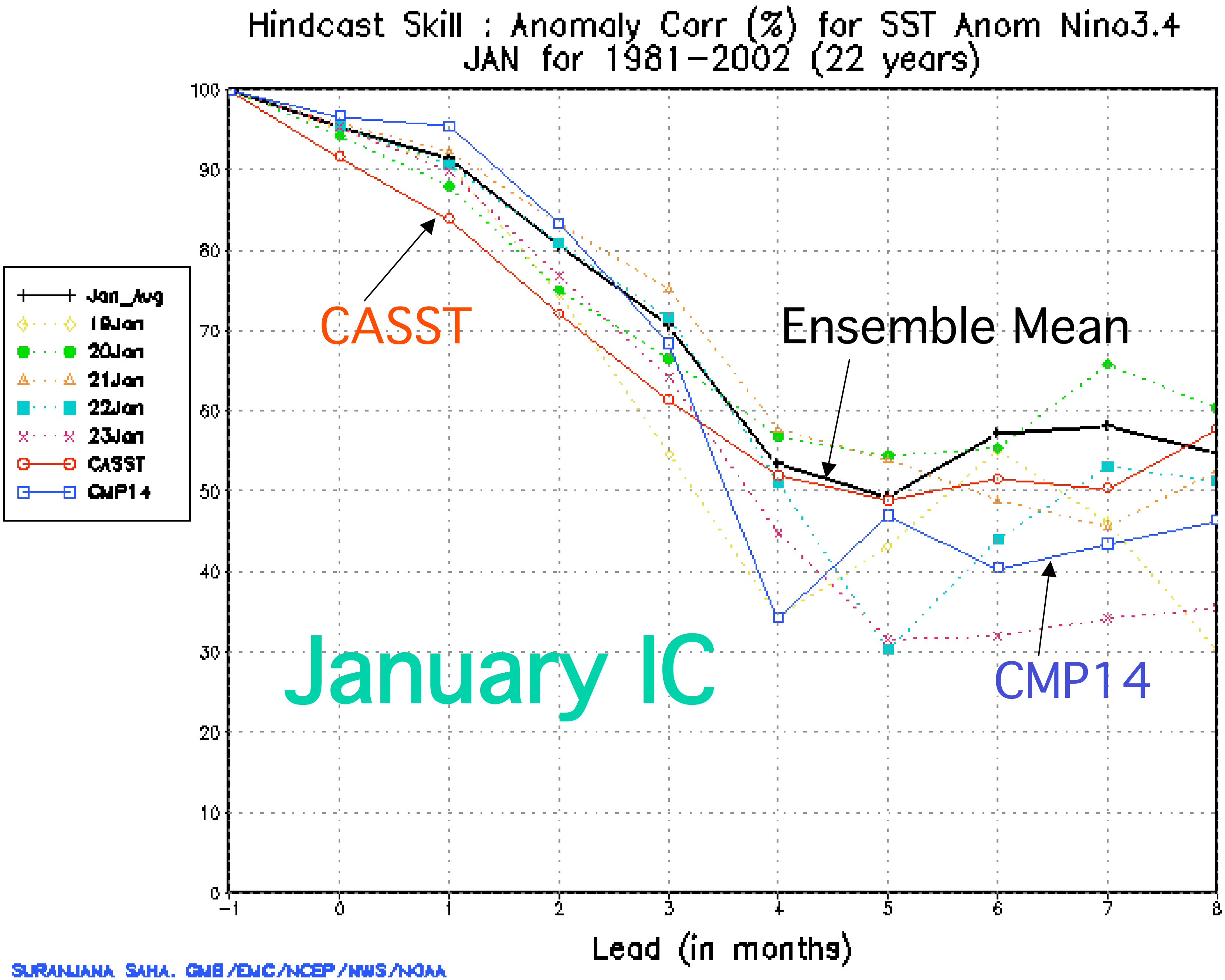
- So far 220 runs have been made

- Hindcast skill
  - Estimated after doing a bias correction for each year
  - Uses model climatology based on the other years

- Anomaly correlation skill score for Nino 3.4 region SST prediction

- Skill maps
  - Global SST
  - U.S. temperature and precipitation.


Hindcast Skill : Anomaly Corr (%) for SST Anom Nino3.4
APR for 1981-2002 (22 years)
Ensemble Mean
CASST
CMP14
April IC
Apr_Aug
19Apr
20Apr
21Apr
22Apr
23Apr
CASST
CMP14
100
90
80
70
60
50
40
30
20
10
0
-1
0
1
2
3
4
5
6
7
8
Lead (in months)
SURANJANA SAHA. GMB/EMC/NCEP/NWS/NOAA



Hindcast Skill : Anomaly Corr (%) for SST Anom Nino3.4
JAN for 1981-2002 (22 years)
Jan_Avg
19Jan
20Jan
21Jan
22Jan
23Jan
CASST
CMP14
CASST
Ensemble Mean
January IC
CMP14
Lead (in months)
SURANJANA SAHA. GMB/EMC/NCEP/NWS/NOAA

Proposal for NCEP Participation

1. Test any potential improvements to "classical" parameterizations with NCEP models
2. Introduce CSRM into NCEP global model
3. Run Parameterized model (NCEP-P) and SP model NCEP-SP for at least one year with AMIP forcing
4. Provide output samples appropriate for diagnosing parameterized and SP diabatics
5. Provide output samples appropriate for OSSE simulated observations
6. Coordinate data assimilation activities (if