MERRA - NASA's Reanalysis Overview & Status

Michele Rienecker, Max Suarez, Ron Gelaro
Julio Bacmeister, Ricardo Todling, Larry Takacs, Emily Liu
Michael Bosilovich, Siegfried Schubert, Gi-Kong Kim
Man-Li Wu, Phil Pegion, Myong-In Lee, Junye Chen, Steve Bloom
&
GMAO

Presentation at NOAA/NCEP/EMC
Dec 5, 2007

GEOS-5 Atmospheric Data Assimilation System

AGCM

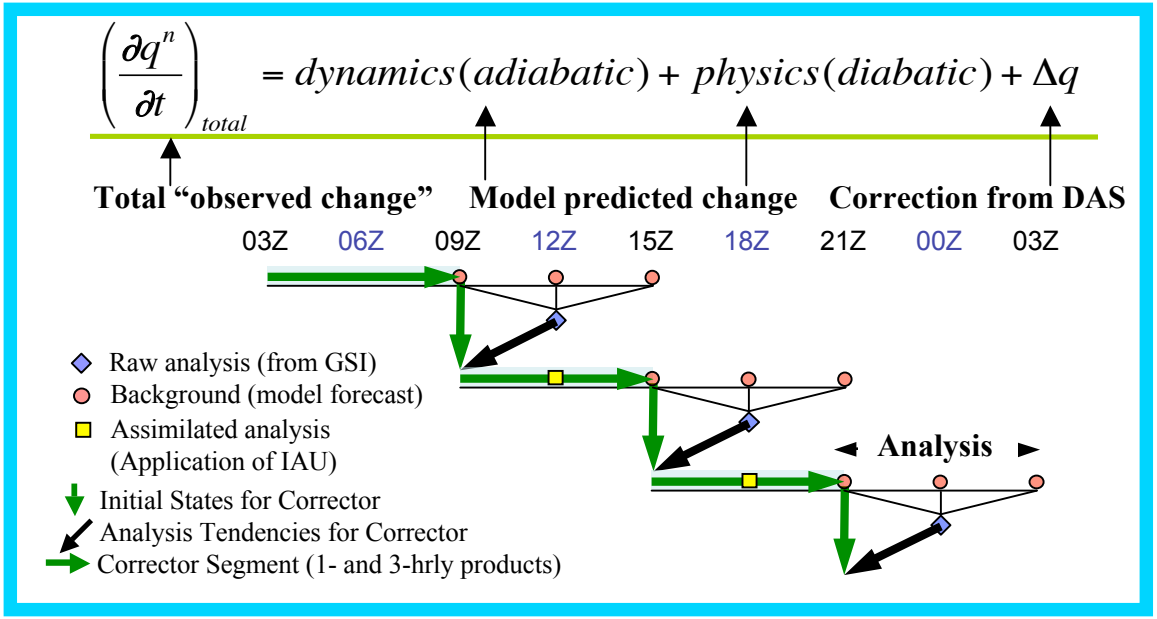
- Finite-volume dynamical core
- Bacmeister moist physics
- Physics integrated under the Earth System Modeling Framework (ESMF)
- Generalized vertical coord to 0.01 hPa
- Catchment land surface model
- Prescribed aerosols
- Interactive ozone
- Prescribed SST, sea-ice

Analysis

- Grid Point Statistical Interpolation (GSI from NCEP)
- Direct assimilation of satellite radiance data using JCSDA Community Radiative Transfer Model (CRTM)
- Variational bias correction for radiances

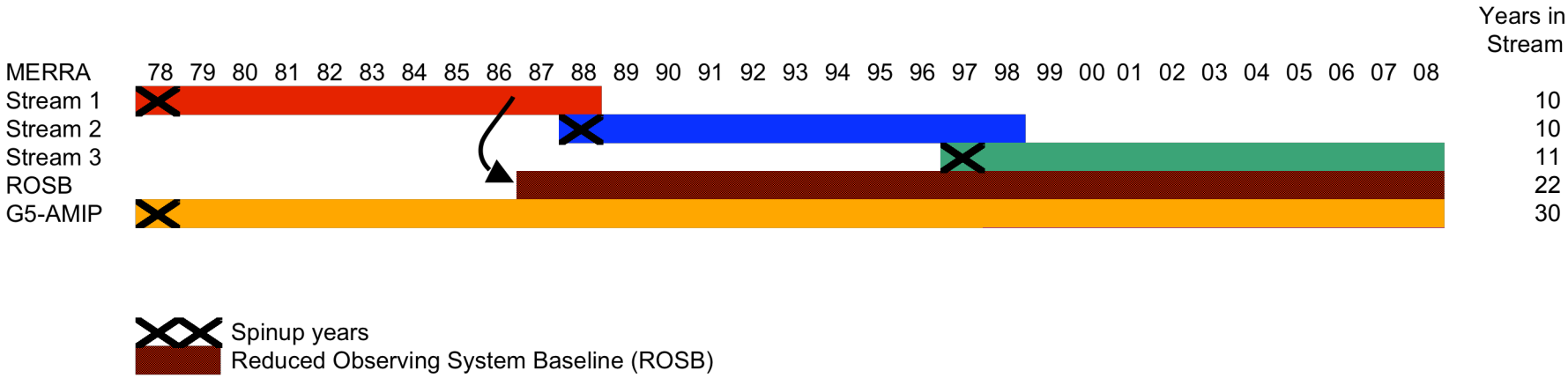
Assimilation

- Apply Incremental Analysis Increments (IAU) to reduce shock of data insertion
- IAU gradually forces the model integration throughout the 6 hour analysis period



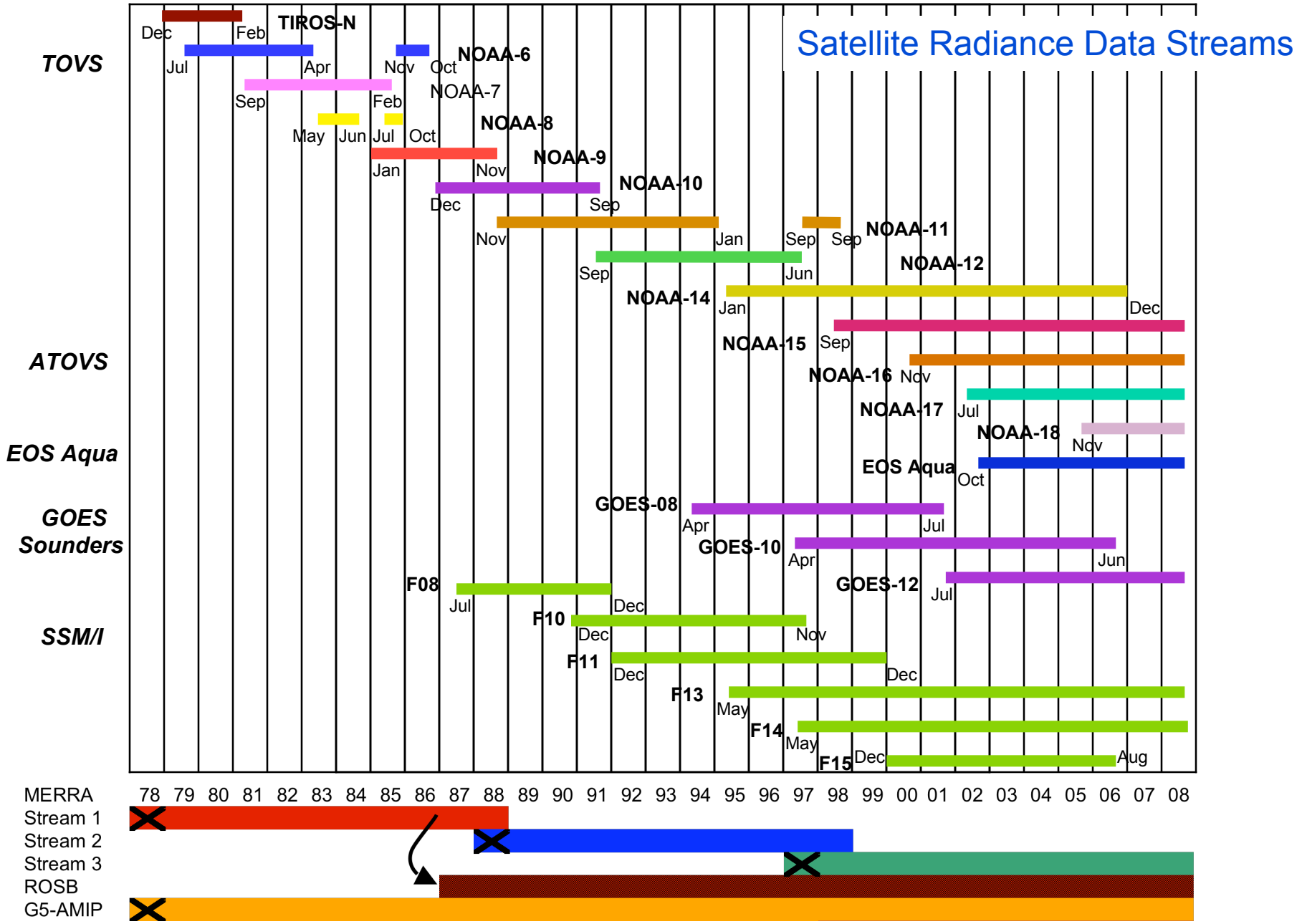
MERRA Production

- 2-year spin up at 2-degree resolution
- 1-year spin up at ½ degree
- Product Streams begin: Jan 1 – 1979, 1989 and 1998



- **Preview/Validation runs:**
  - Jan, Apr, Jul, Oct 2004
  - July-August 1987
  - Jan, Jul 2001
  - Jul 2006

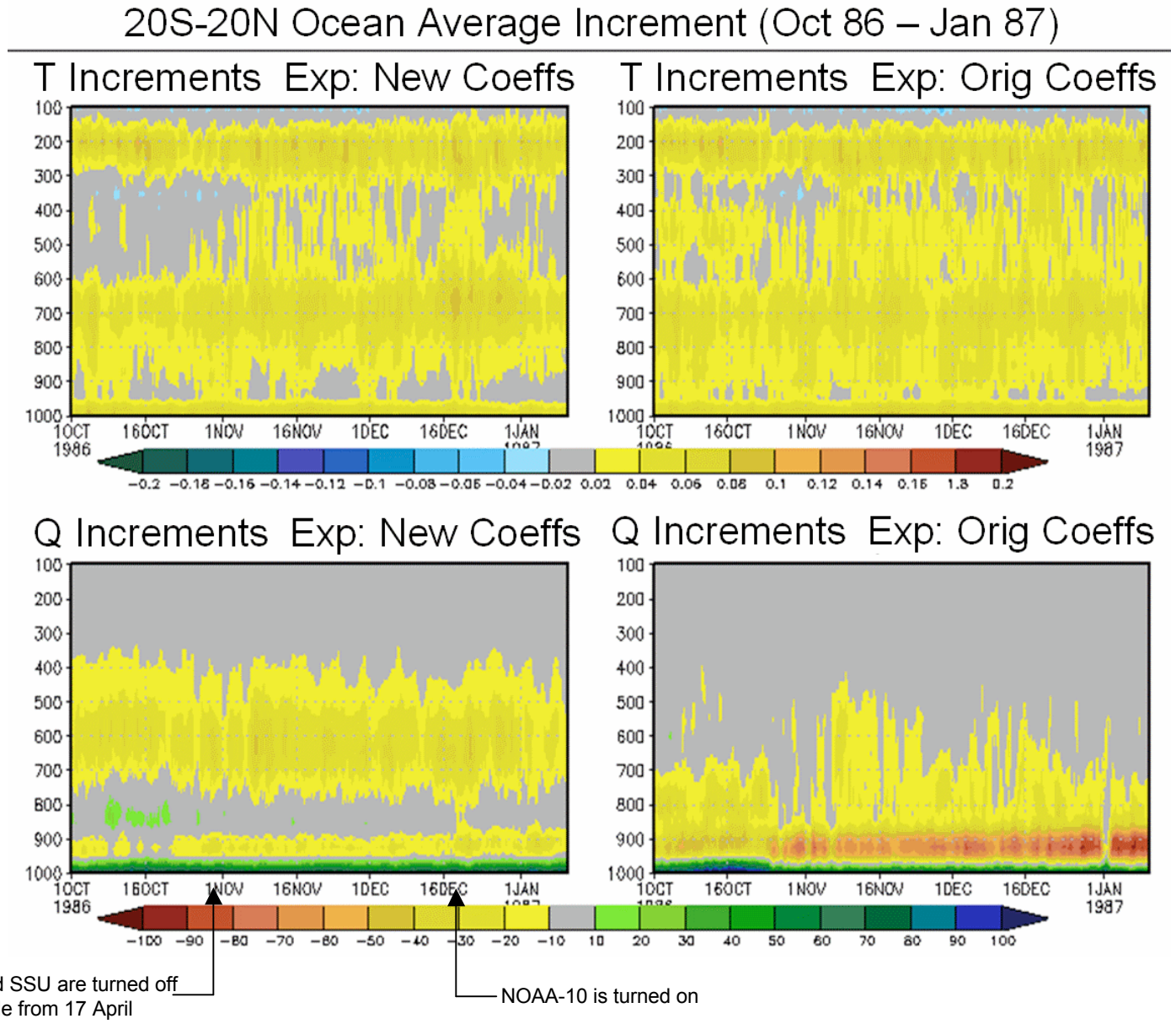
- **2 degree (scout) runs** ⇒ preliminary look at data and spin-up of satellite bias estimates.


Satellite Radiance Data Streams
TOVS
ATOVS
EOS Aqua
GOES Sounders
SSM/I
TIROS-N
Dec
Feb
NOAA-6
Jul
Apr
Nov
Oct
NOAA-7
Sep
Feb
May
Jun
Jul
Oct
NOAA-8
Jan
Nov
NOAA-9
Dec
Sep
NOAA-10
Nov
Jan
Sep
Sep
NOAA-11
Sep
Jun
NOAA-12
NOAA-14
Jan
Dec
NOAA-15
Sep
NOAA-16
Nov
NOAA-17
Jul
NOAA-18
Nov
EOS Aqua
Oct
GOES-08
Apr
Jul
GOES-10
Apr
Jun
GOES-12
Jul
F08
Jul
Dec
F10
Dec
Nov
F11
Dec
Dec
F13
May
F14
May
F15
Dec
Aug
MERRA
Stream 1
Stream 2
Stream 3
ROSB
G5-AMIP
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08

DATA SOURCE/TYPE	PERIOD	DATA SUPPLIER
Conventional Dat a		
Radiosondes	1970 - present	NOAA/NCEP
PIBAL winds	1970 - present	NOAA/NCEP
Wind profiles	1992/5/14 - present	UCAR CDAS
Conventional, ASDAR, and MDCRS aircraft reports	1970 - present	NOAA/NCEP
Dropsondes	1970 - present	NOAA/NCEP
PAOB	1978 - present	NCEP CDAS
GMS, METEOSAT, cloud drift IR and visible winds	1977 – present	NOAA/NCEP
GOES cloud drift winds	1997 – present	NOAA/NCEP
EOS/Terra/MODIS winds	2002/7/01 - present	NOAA/NCEP
EOS/Aqua/MODIS winds	2003/9/01 - present	NOAA/NCEP
Surface land observations	1970 - present	NOAA/NCEP
Surface ship and buoy observations	1977 - present	NOAA/NCEP
SSM/I rain rate	1987/7 - present	NASA/GSFC
SSM/I V6 wind speed	1987/7 - present	RSS
TMI rain rate	1997/12 - present	NASA/GSFC
QuikSCAT surface winds	1999/7 - present	JPL
ERS-1 surface winds	1991/8/5 – 1996/5/21	CERSAT
ERS-2 surface winds	1996/3/19 – 2001/1/17	CERSAT
Satellite Dat a		
TOVS (TIROS N, N-6, N-7, N-8)	1978/10/30 – 1985/01/01	NCAR
(A)TOVS (N-9; N-10 ; N-11; N-12)	1985/01/01 - 1997/07/14	NOAA/NESDIS & NCAR
ATOVS (N-14; N-15; N-16; N-18; N-18)	1995/01/19 - present	NOAA/NESDIS
EOS/Aqua	2002/10 - present	NOAA/NESDIS
SSM/I V6 (F08, F10, F11, F13, F14, F15)	1987/7 - present	RSS
GOES sounder T_B	2001/01 - present	NOAA/NCEP
SBUV2 ozone (Version 8 retrievals)	1978/10 - present	NASA/GSFC/Code 613.3

A special thanks to Jack Woollen for help with the conventional data streams!!!!

Assimilation increments to assess satellite transitions
(CRTM coefficients; satellite bias estimation)



Overview

- Monthly-Mean Tropospheric Circulation
  - Zonal means (U, T, Q)
  - Eddy Transports
  - Interannual variations
- The Kinetic Energy and Moisture Budgets
- Clouds and Radiation
  - TOA Rad vs CERES
  - Cloud liquid water vs SSM/I
  - PBL height
- Precipitation Variability
  - Mean and Interannual Variability
  - Mississippi River Basin - comparison with gauge data
  - TPW vs SSM/I
- Climate Variability
  - Monsoons
  - North American Low Level Jet
  - Diurnal Cycle of Precipitation
- Product Distribution

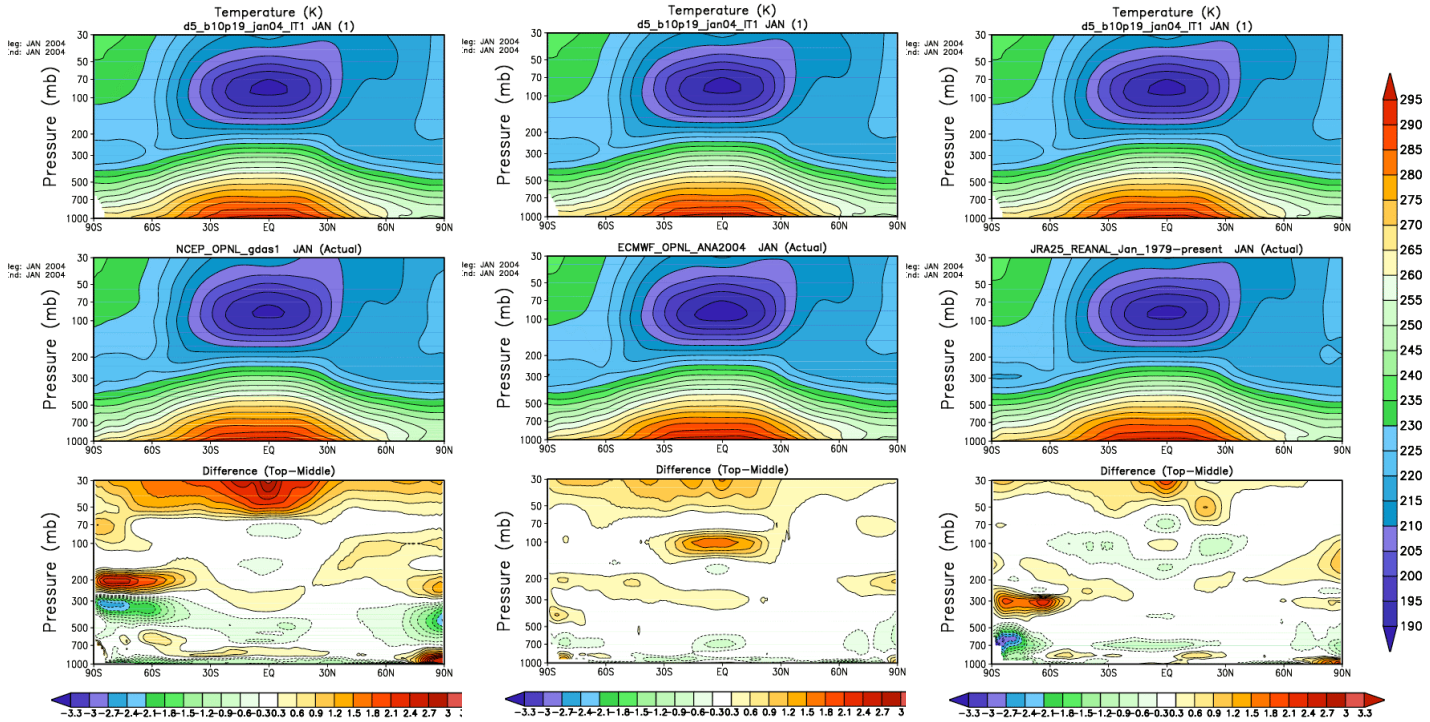
Zonal Mean Temperature
Jan 2004

NCEP OPS | EC OPS | JRA-25

GEOS-5

Other

Δ



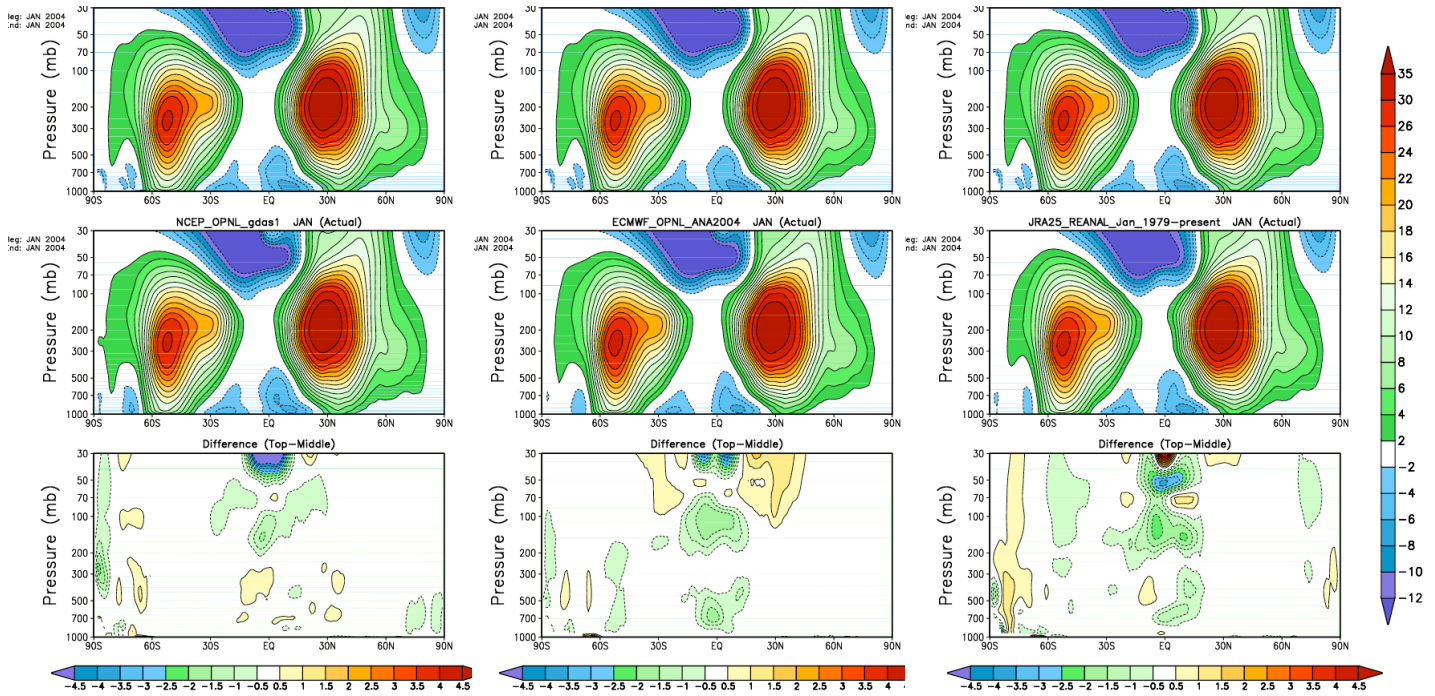
Zonal Mean u-wind
Jan 2004

NCEP OPS | EC OPS | JRA-25

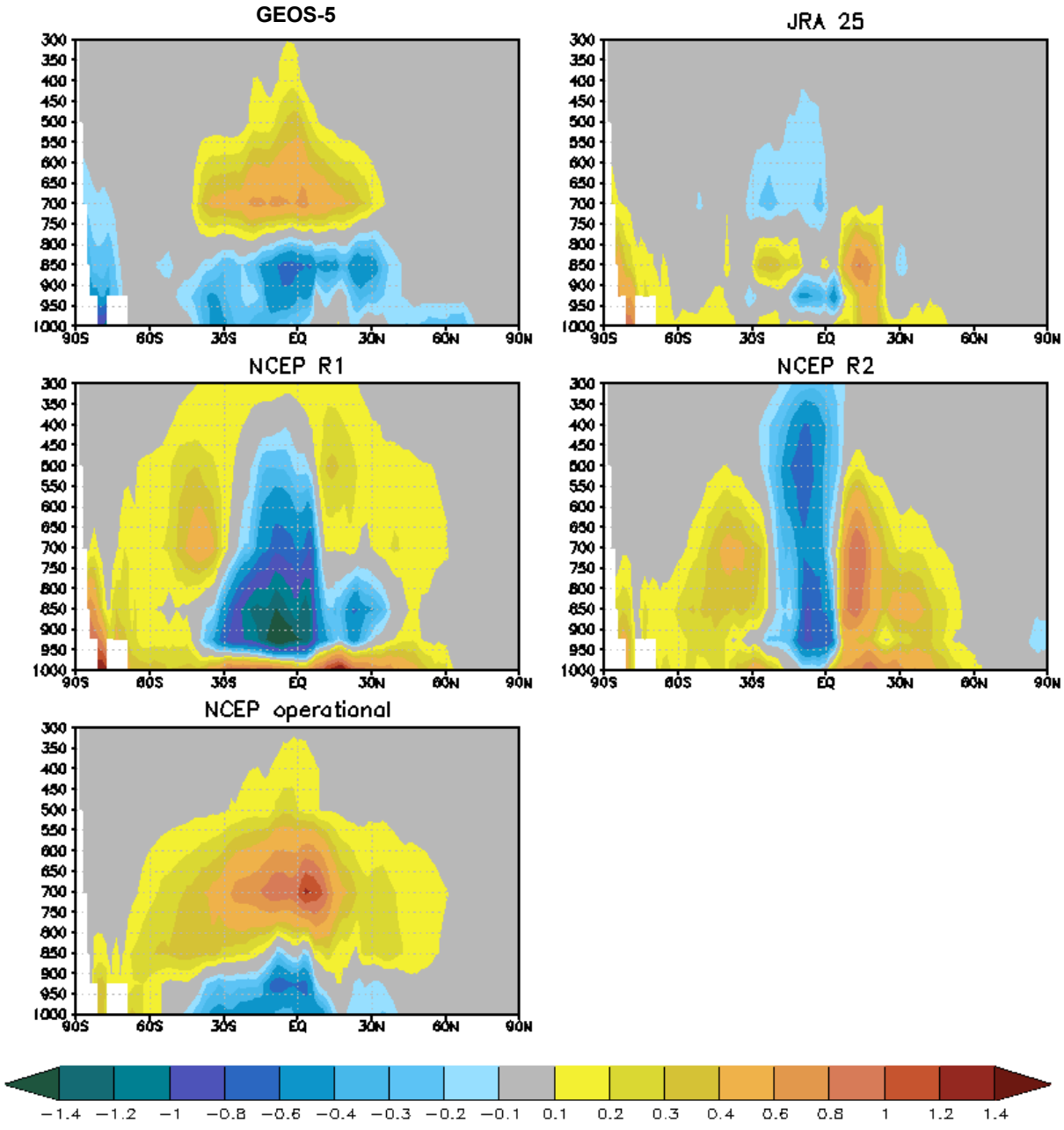
GEOS-5

Other

Δ



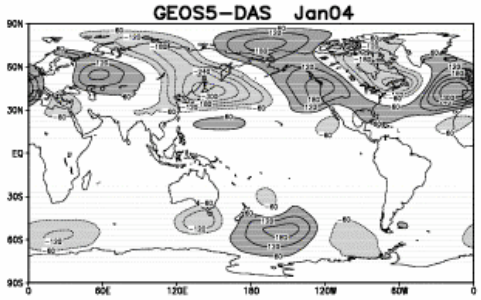
Jan. 2004 Specific Humidity – ECOPS (g/kg)

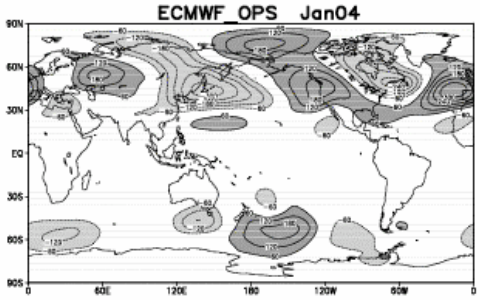


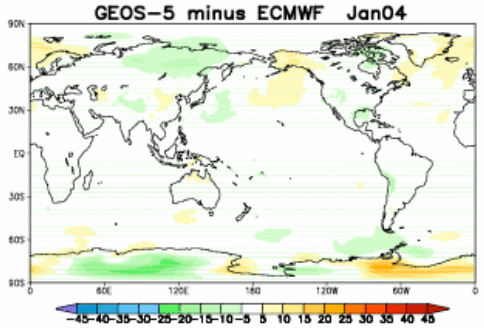
300 MB Eddy Height vs EC OPS

GEOS-5 | EC OPS | G5 - EC

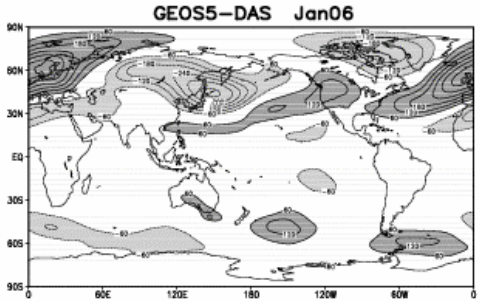
Jan 04 (neutral)

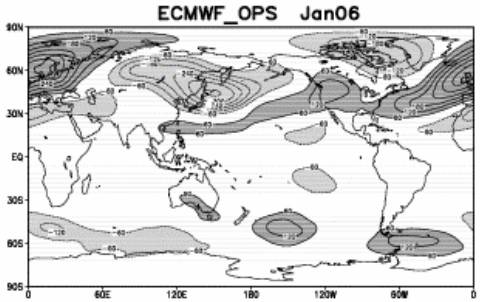


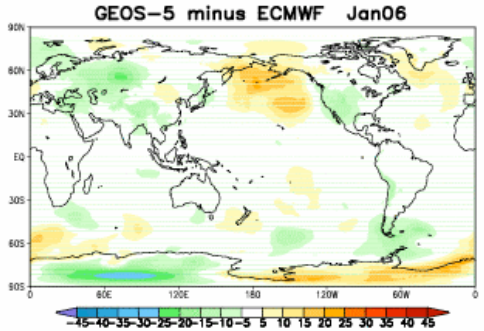




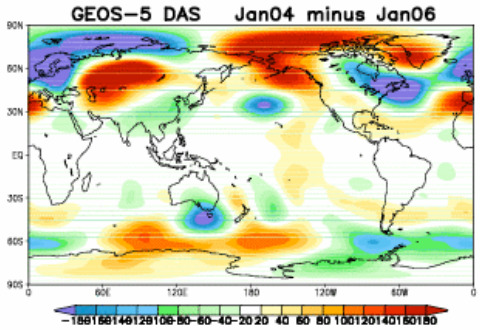
Jan 06 (weak La Nina)

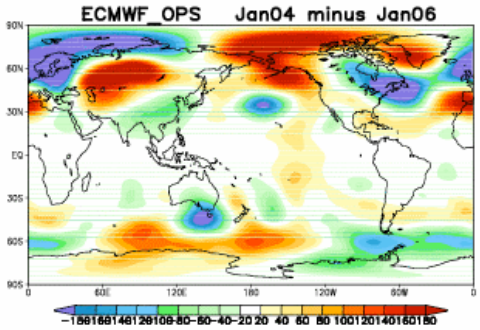


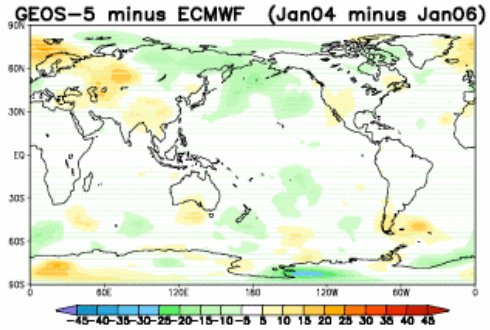




04 - 06



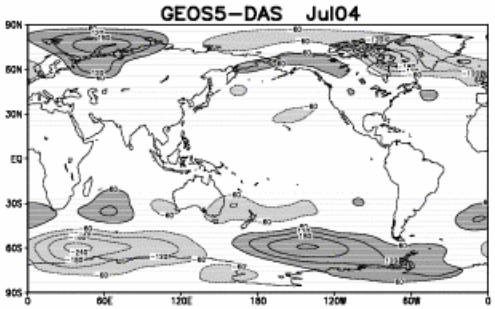


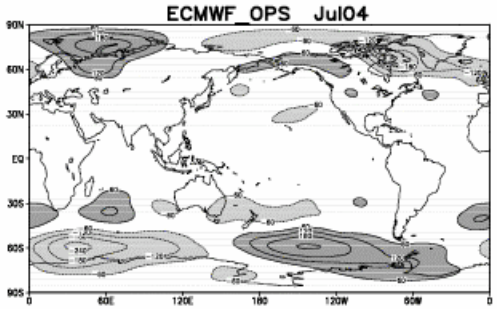


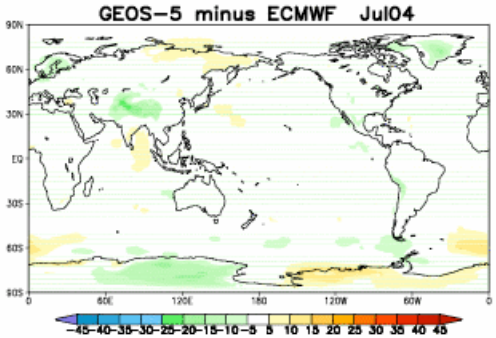
300 MB Eddy Height vs EC OPS

GEOS-5 | EC OPS | G5 - EC

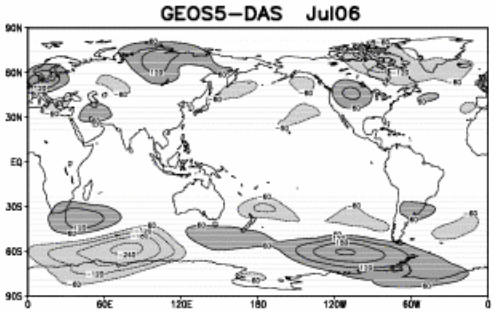
Jul 04

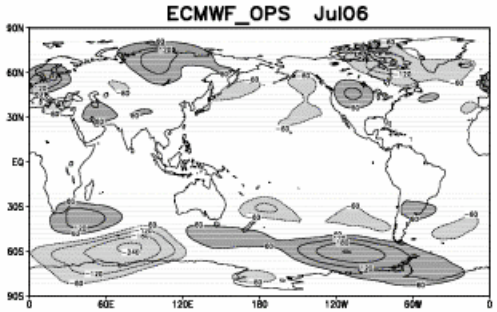


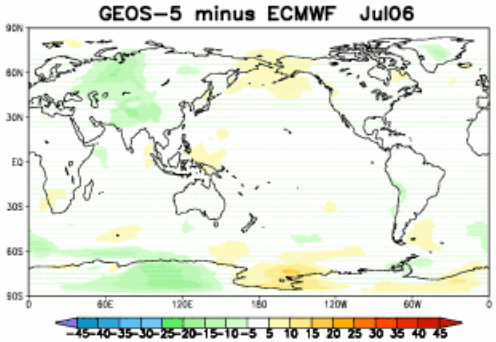




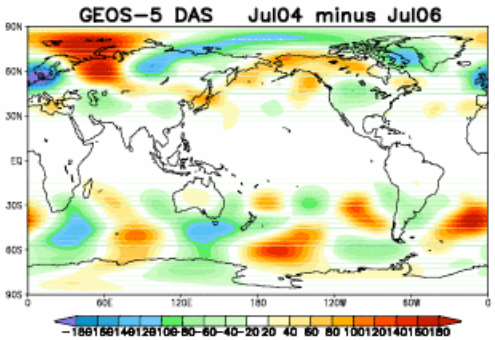
Jul 06

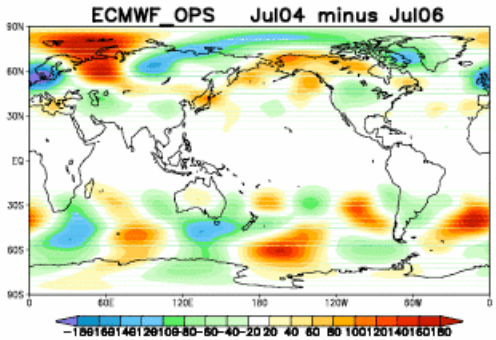


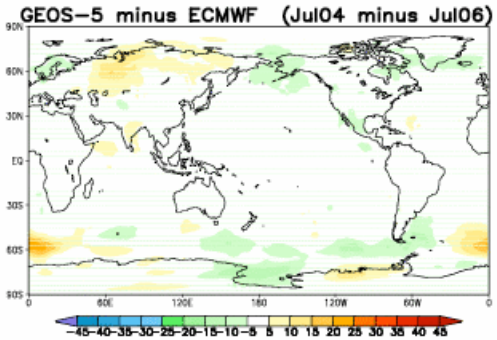




04 - 06



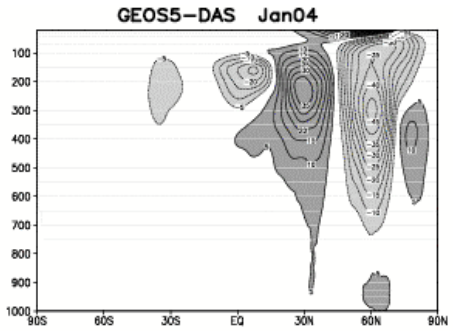


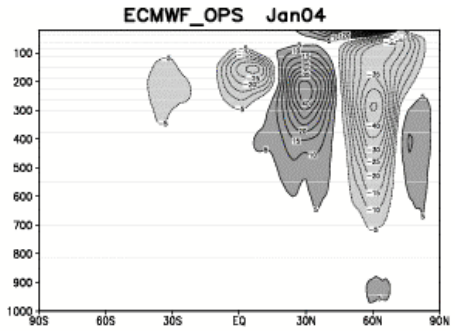


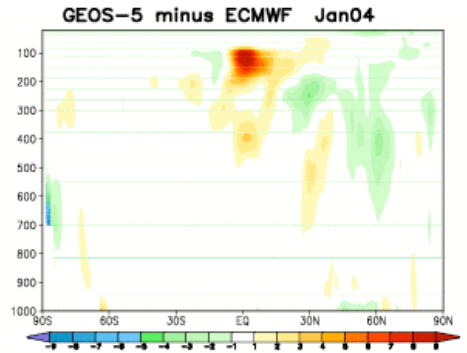
U*V* vs EC OPS

GEOS-5 | EC OPS | G5 - EC

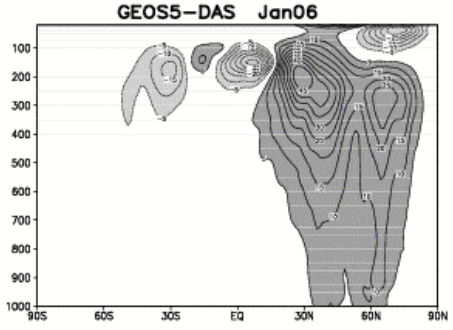
Jan 04 (neutral)

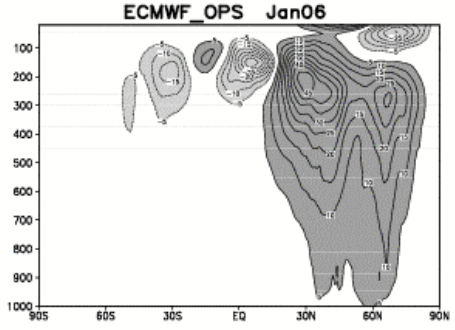


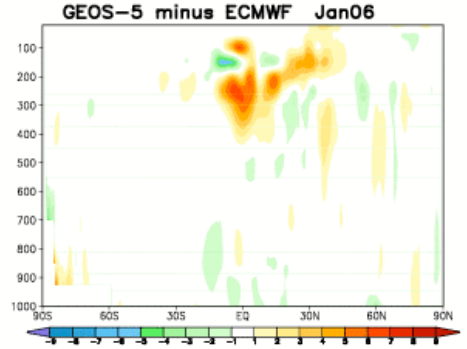




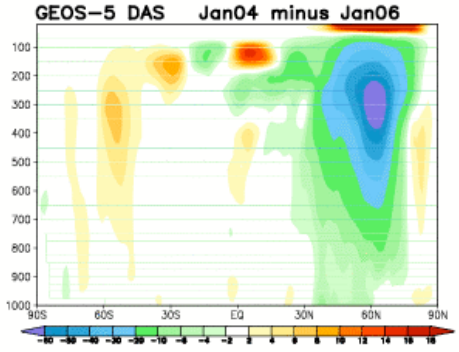
Jan 06 (weak La Nina)

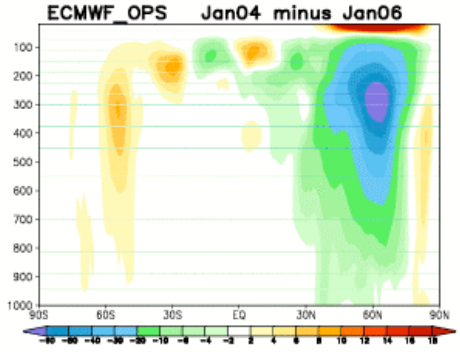


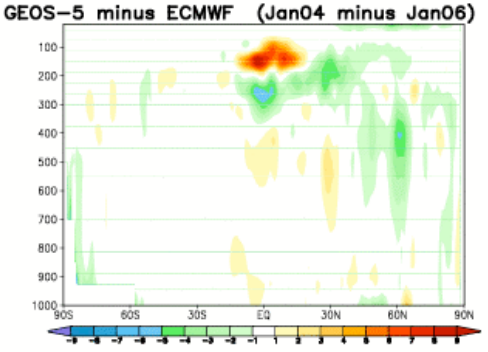




04 - 06







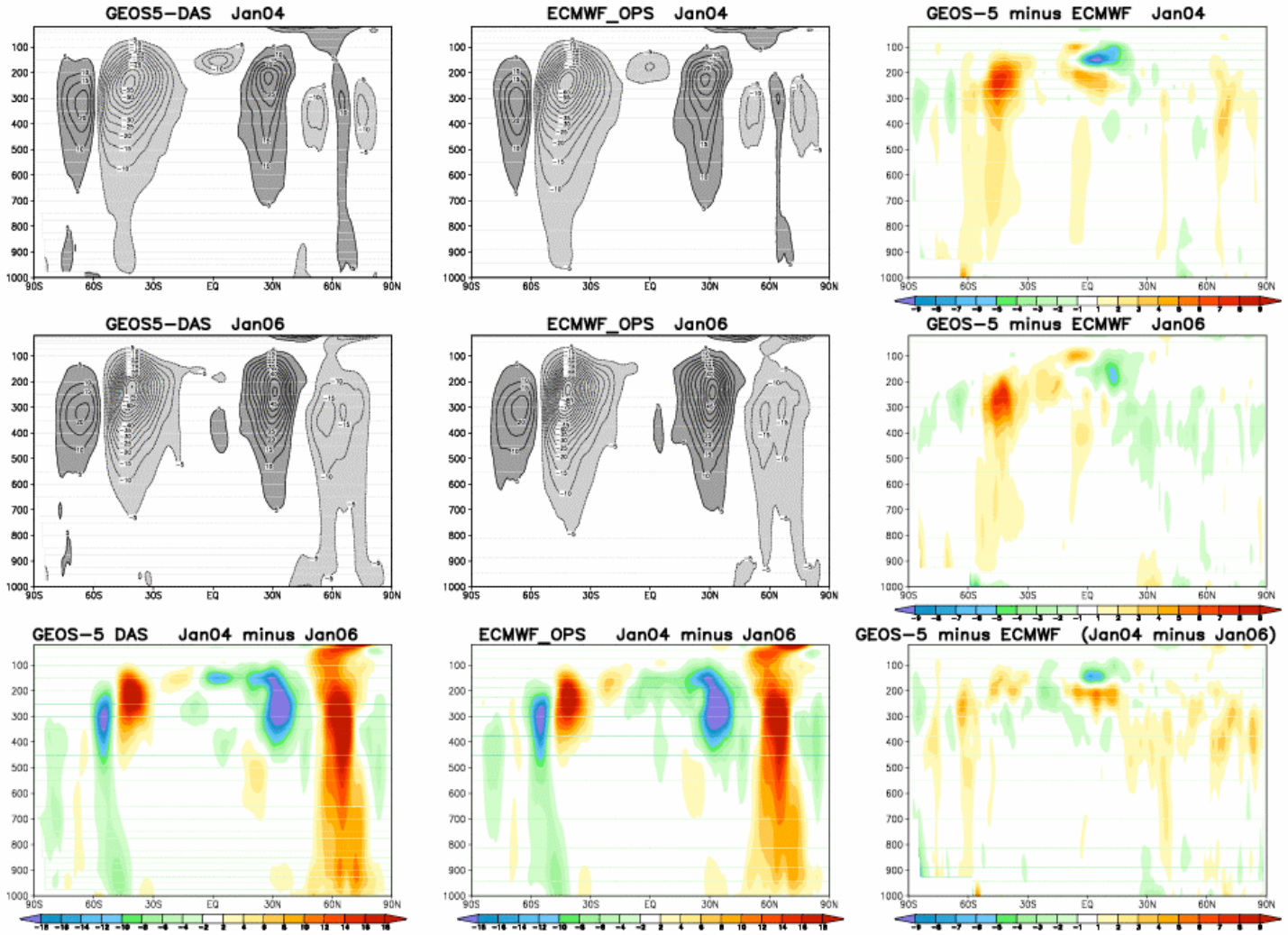
U´V´ vs EC OPS

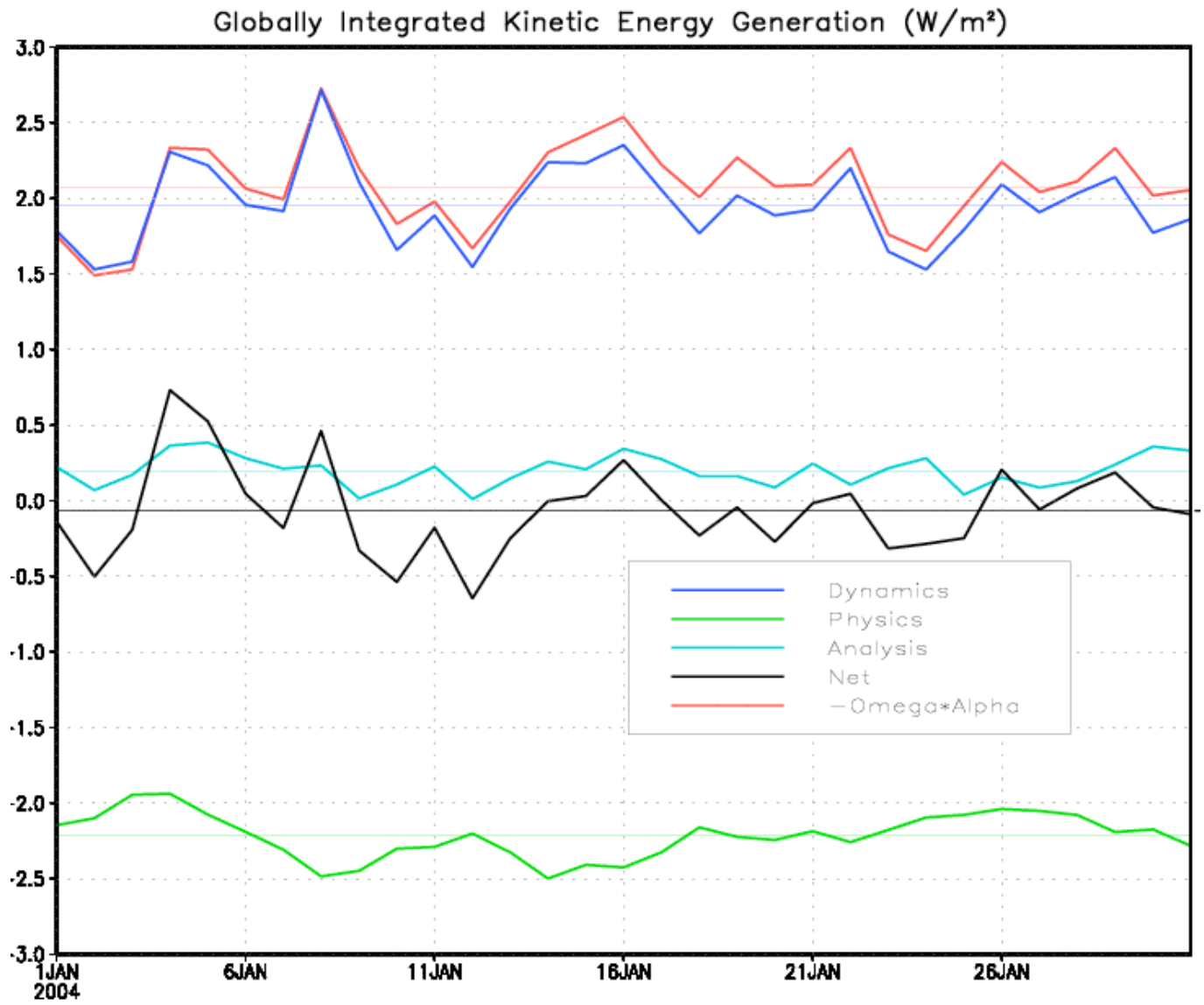
GEOS-5 | EC OPS | G5 - EC

Jan 04 (neutral)

Jan 06 (weak La Nina)

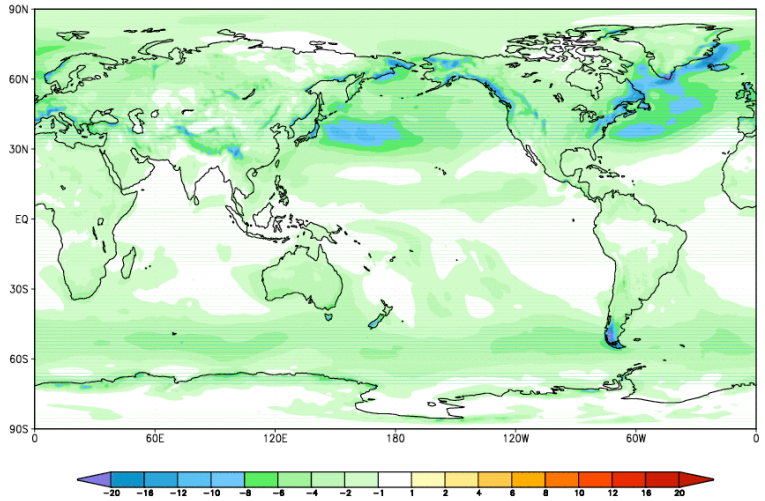
04 - 06



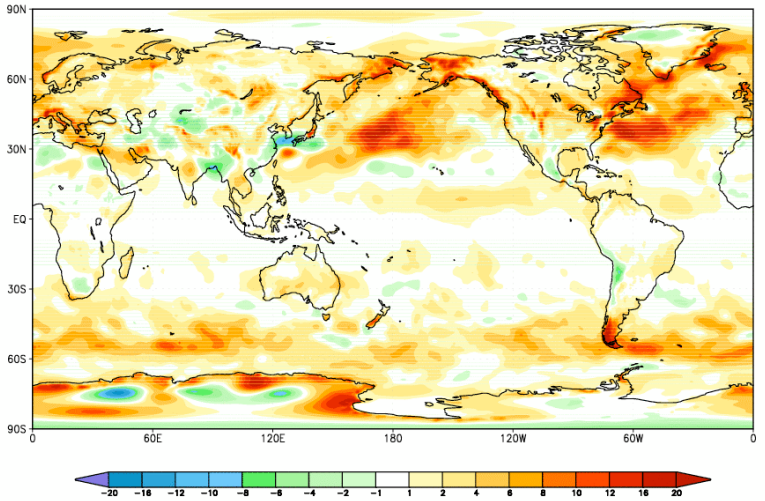

Globally Integrated Kinetic Energy Generation (W/m²)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
1JAN
2004
6JAN
11JAN
16JAN
21JAN
26JAN
Dynamics
Physics
Analysis
Net
−Omega*Alpha

KE BUDGET
JAN 2004

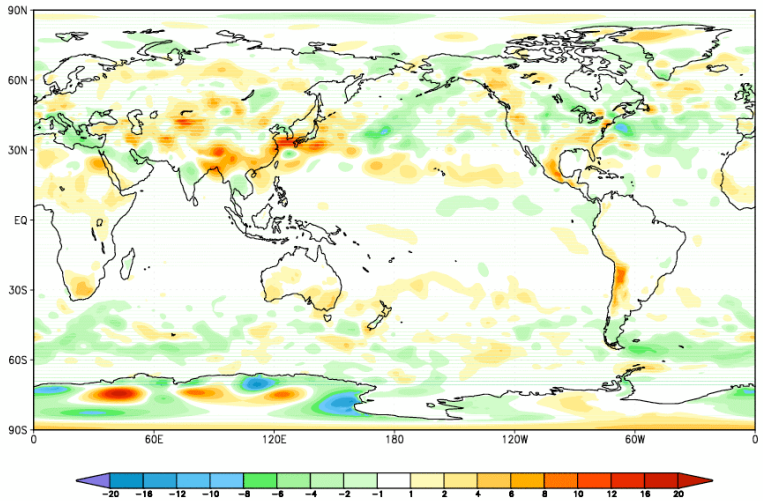
Physics
-2.21 W/m^2



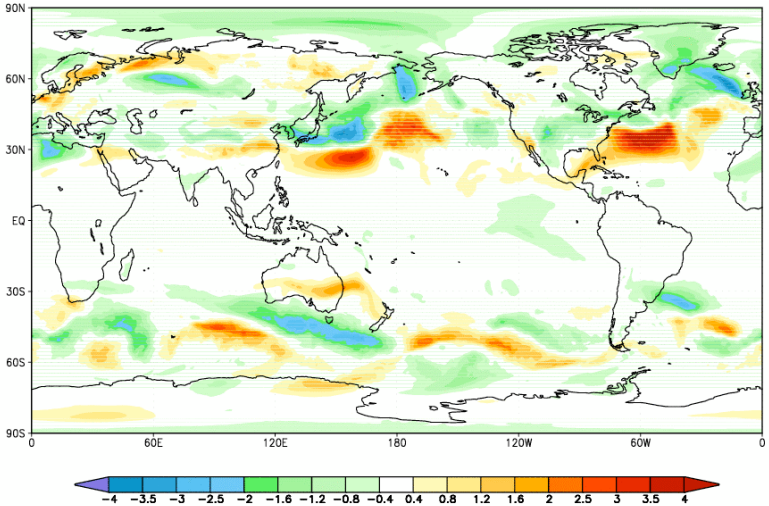
Dynamics
1.95 W / m^2



Analysis
0.20 W / m^2



Change
-0.06 W / m^2



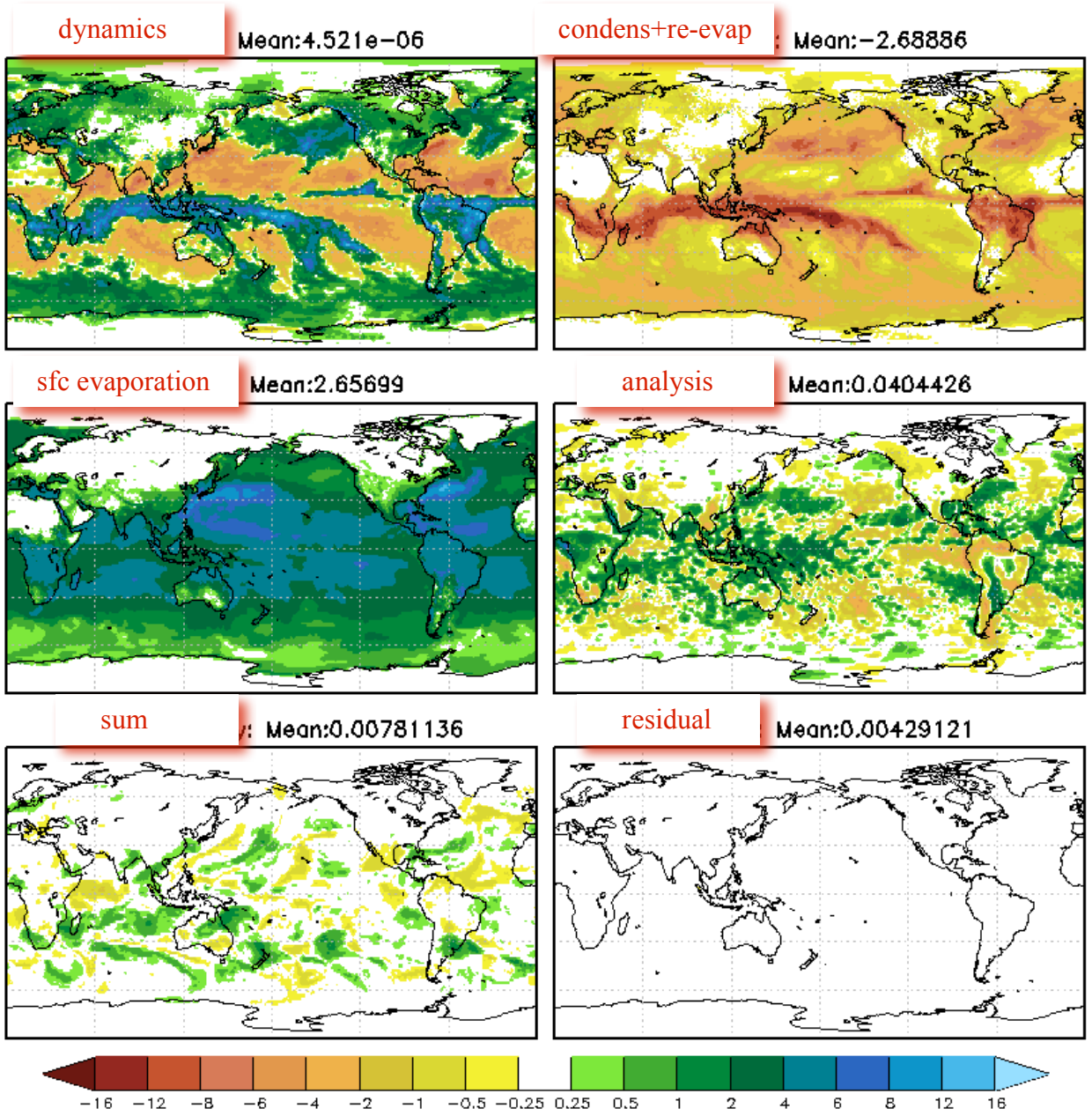
Water Vapor Budget for Jan 2004

sum =

dynamics + (condensation + re-evaporation) + surface evaporation + analysis

residual =

$(q_{end} - q_{begin})$ - sum

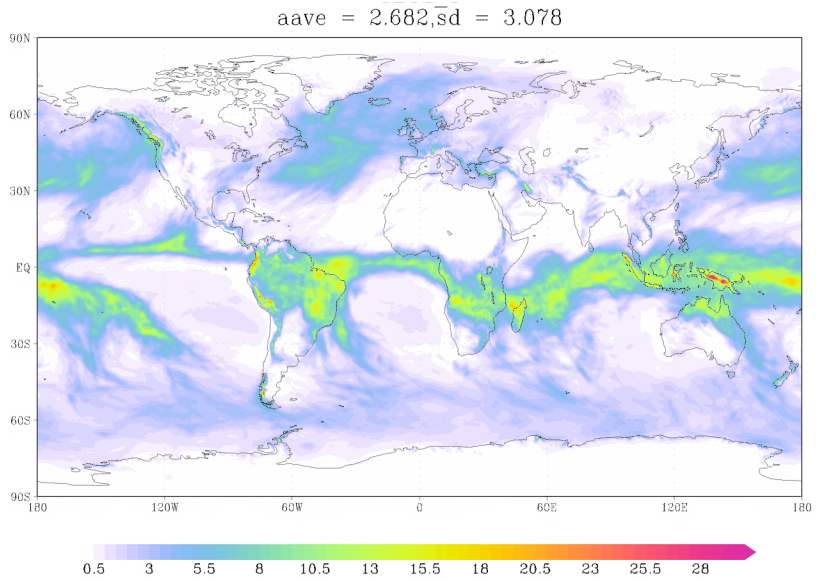


Precipitation
TPW

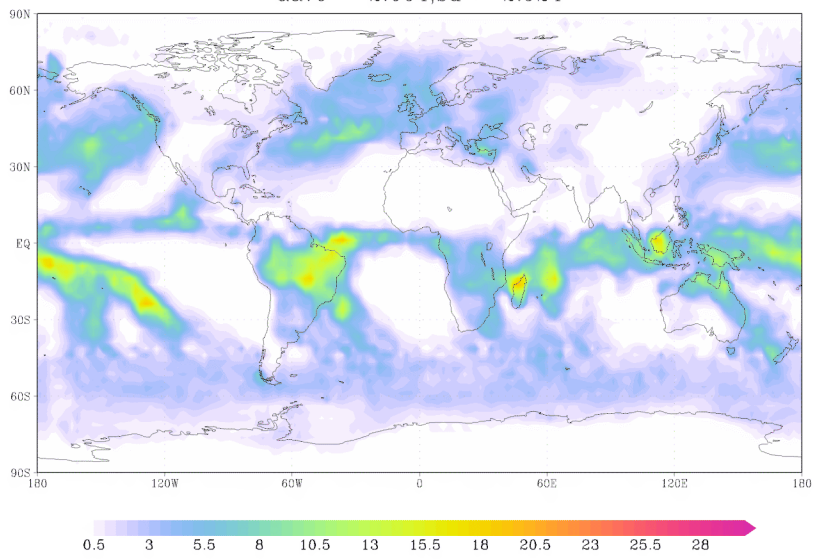
Precipitation (mm/day)

January 2004

GEOS-5

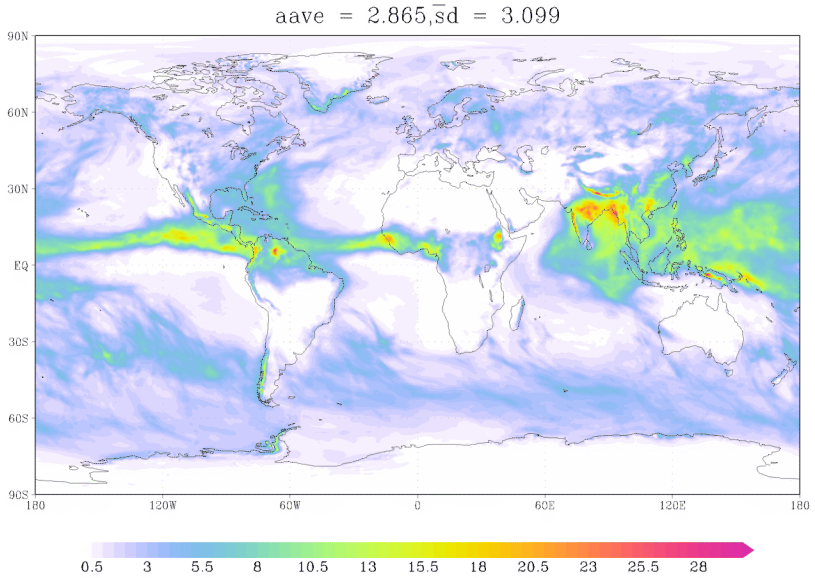


GPCP

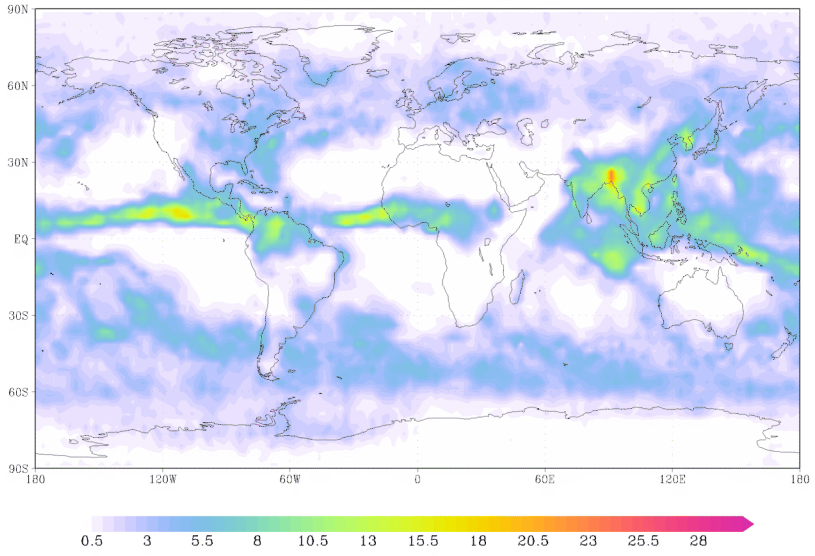


July 2004

GEOS-5

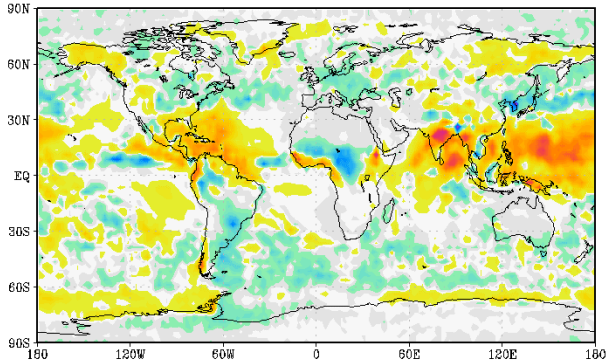


GPCP

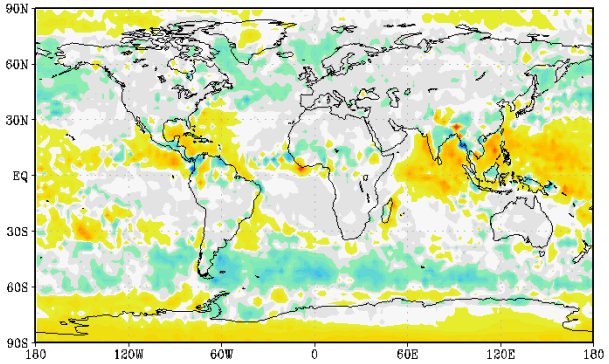


Precipitation c.f. GPCP (mm/day)
July 2004

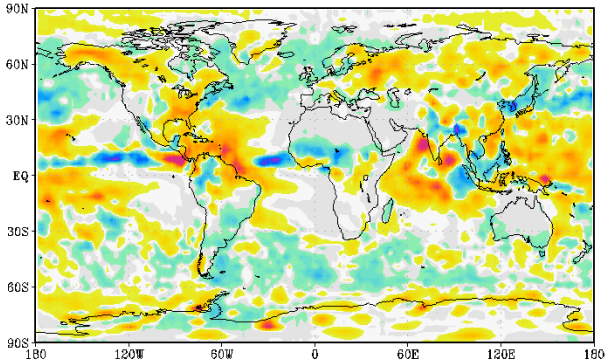
GEOS_5 – GPCP
aave = 0.324,sd = 1.661



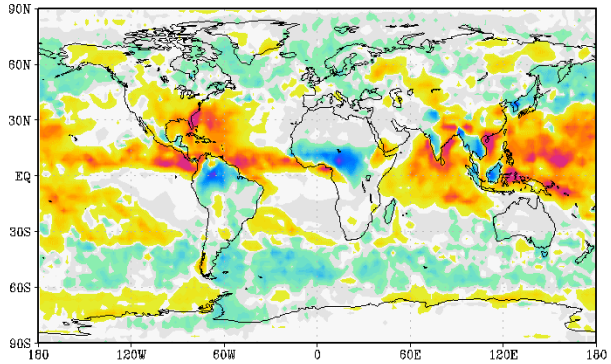
CMAP – GPCP
aave = 0.118,sd = 1.112



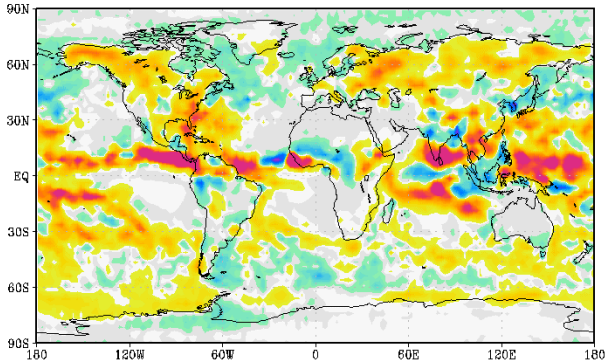
NCEP-R1 – GPCP
aave = 0.345,sd = 1.976



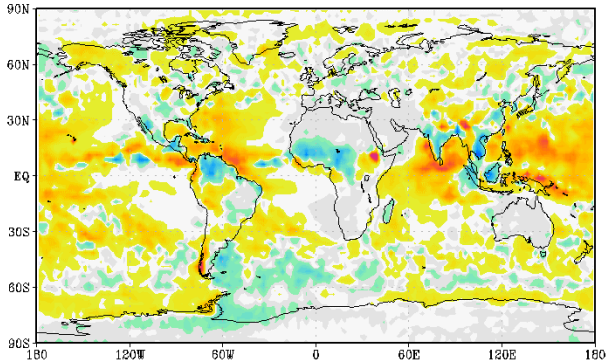
JRA-25 – GPCP
aave = 0.706,sd = 2.423



NCEP-R2 – GPCP
aave = 0.898,sd = 3.022



ECMWF_EC-OPS – GPCP
aave = 0.611,sd = 1.564

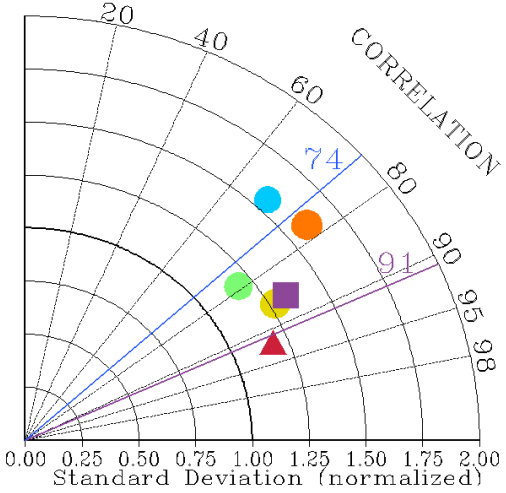


200407 Precip, Reanalysis v. GPCP: Spatial Relationships

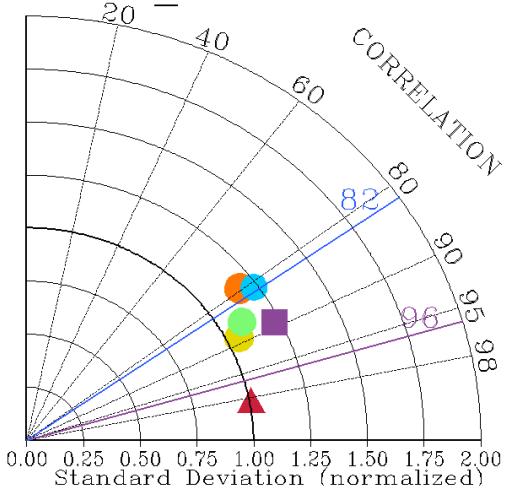
■ GEOS_5
● NCEP−R2
● NCEP−R1
● ECMWF_EC−OPS
● JRA−25
▲ CMAP

v. GPCP

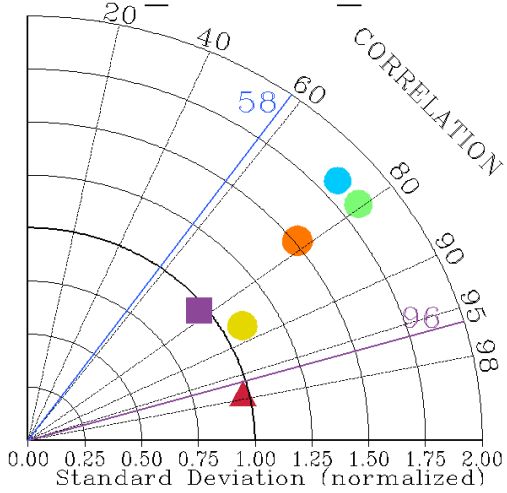
Global



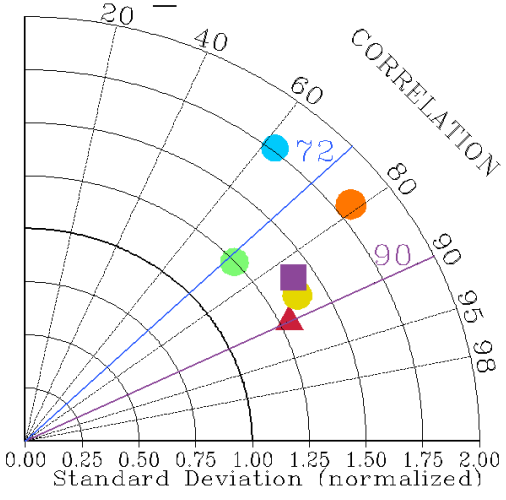
Global_Land



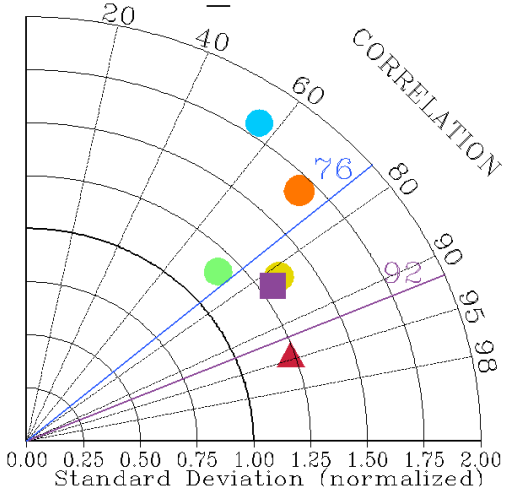
North_America_Land



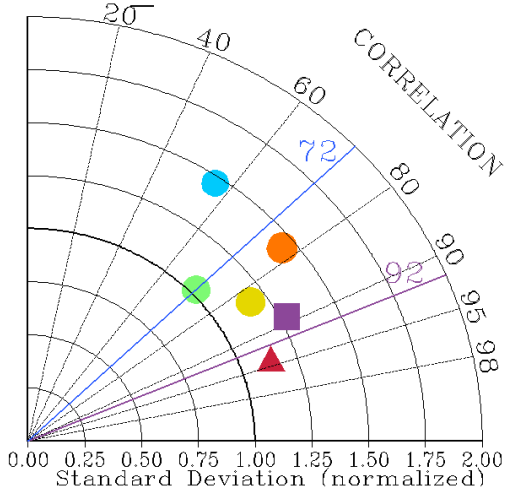
Global_Ocean



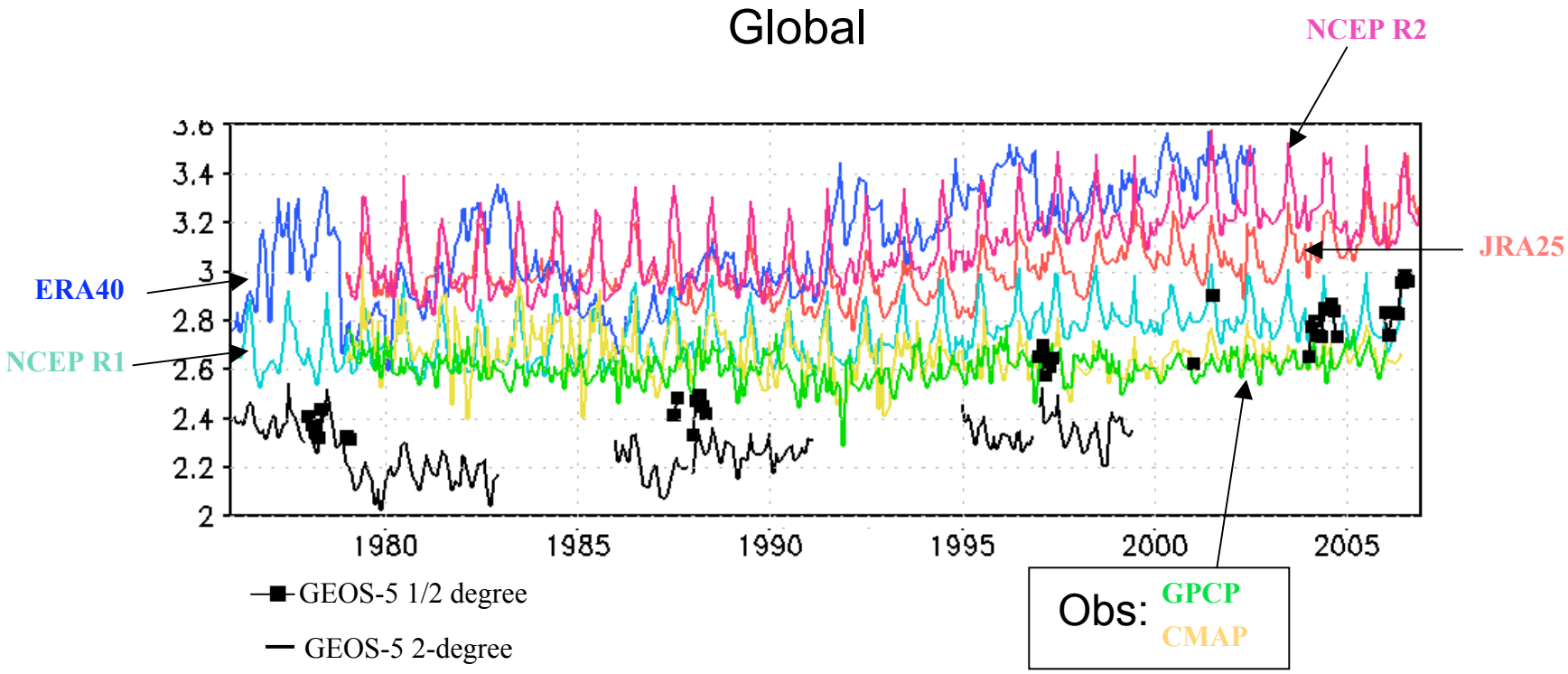
15S−15N_Latitude



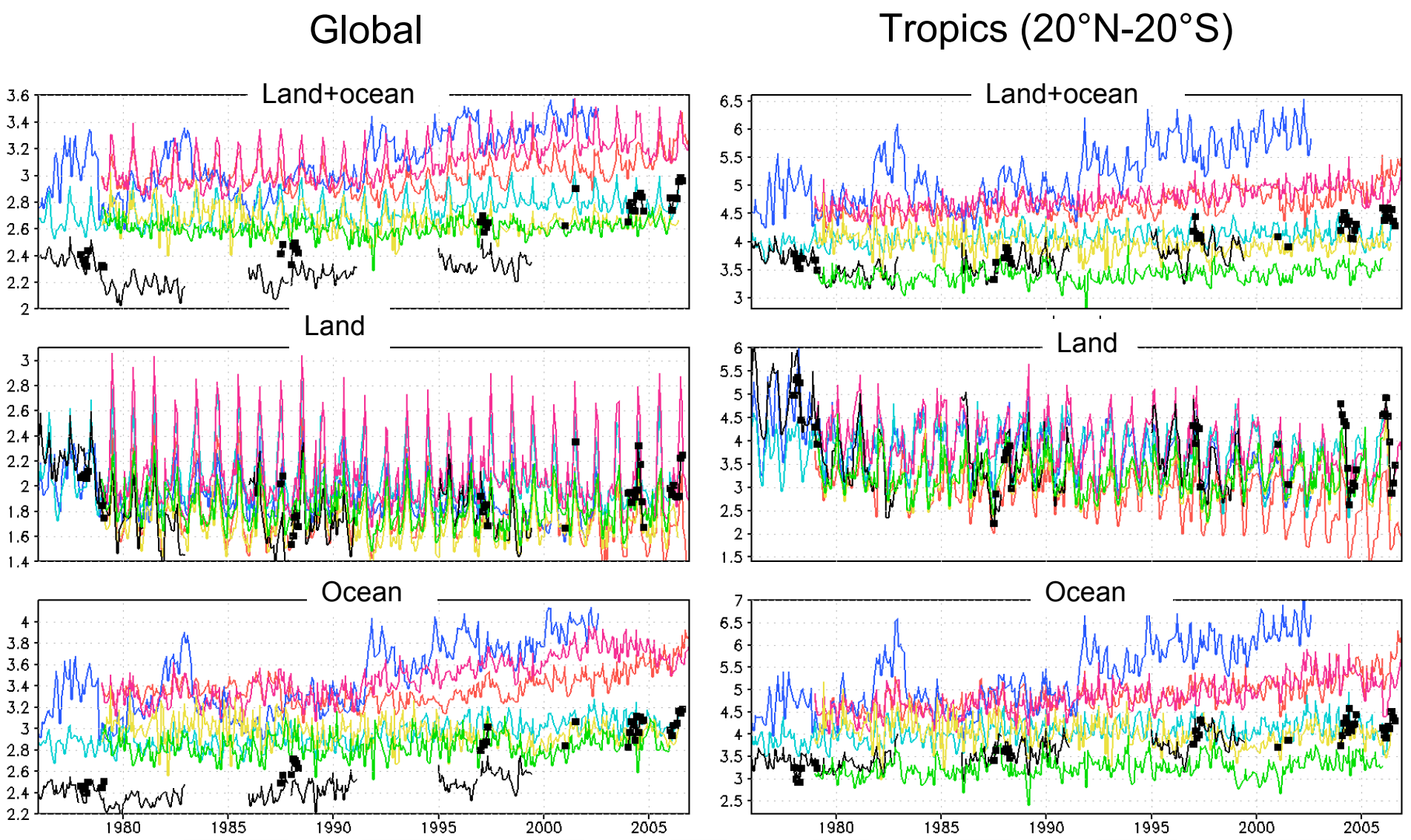
India_Monsoon



Area Averaged Precipitation (mm/day)



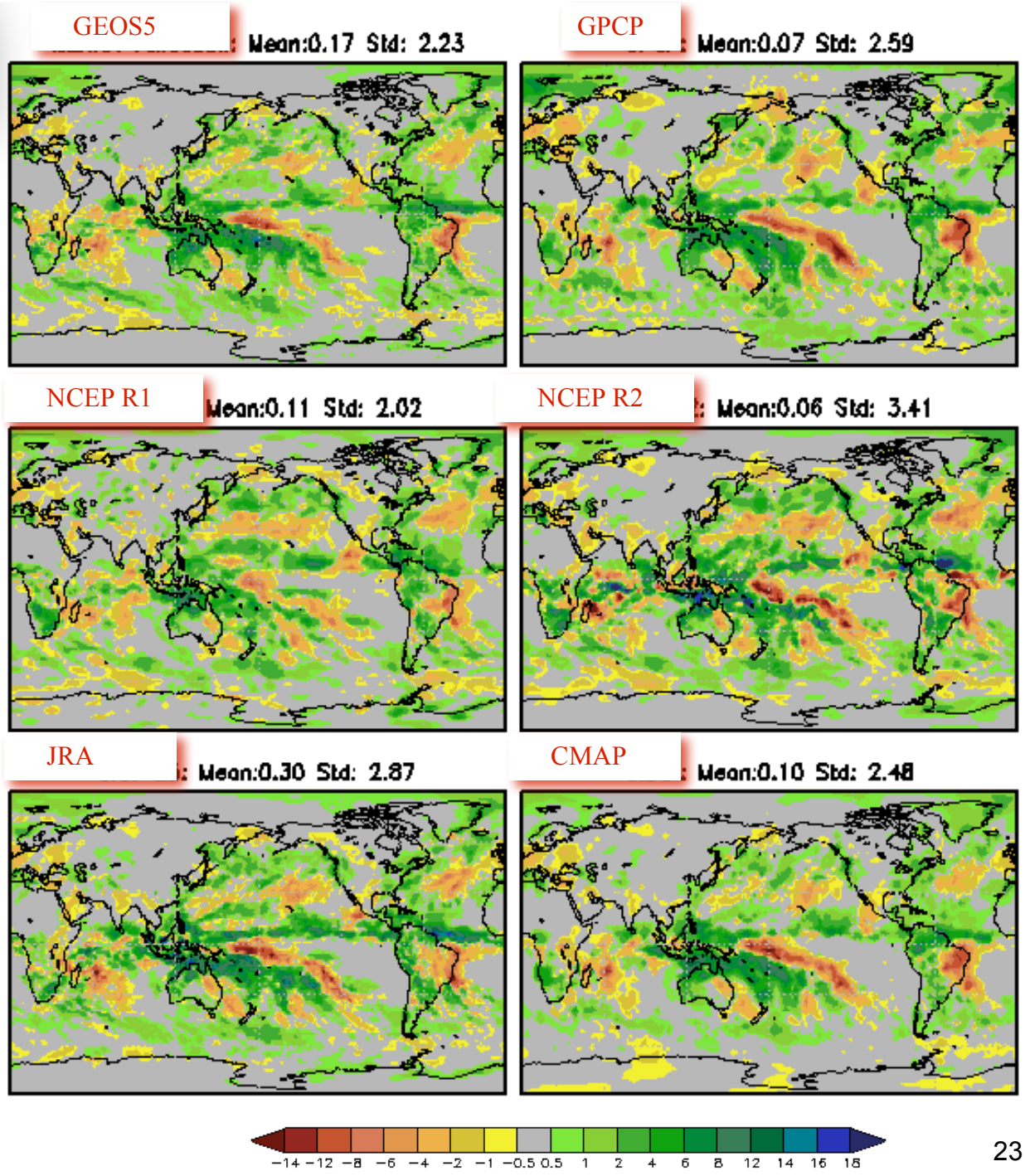
Area Averaged Precipitation (mm/day)

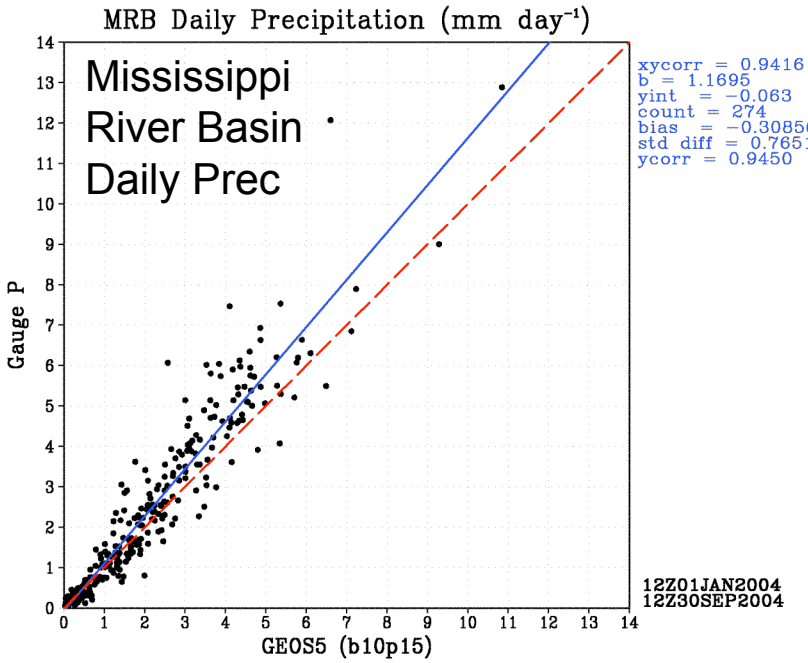


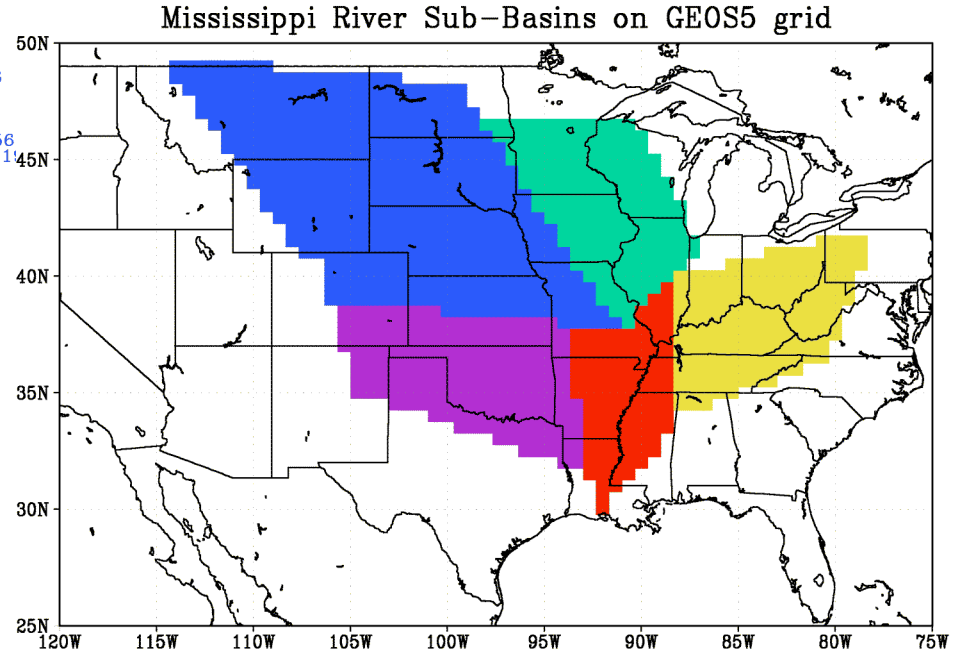
Precipitation (mm/day)
Jan 2006 - Jan 2004

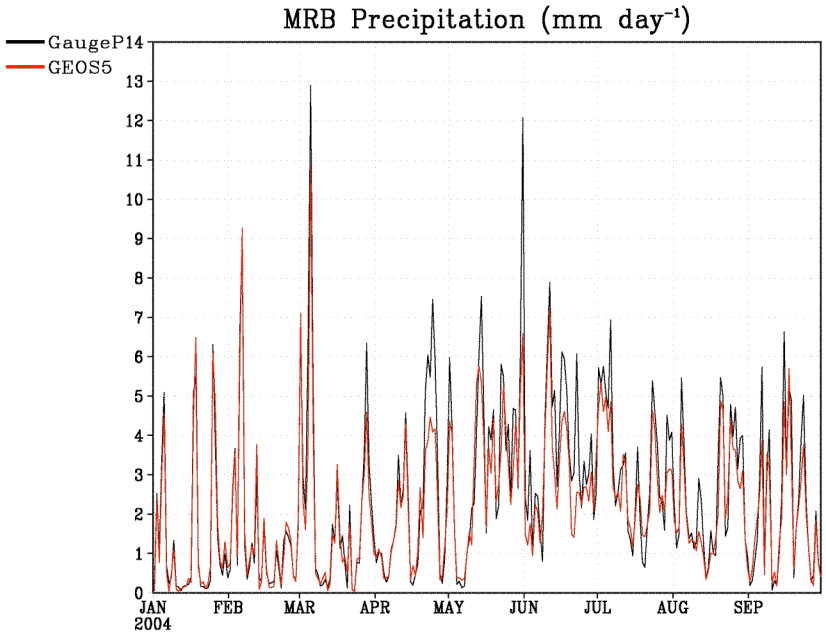
Jan 06: weak La Nina

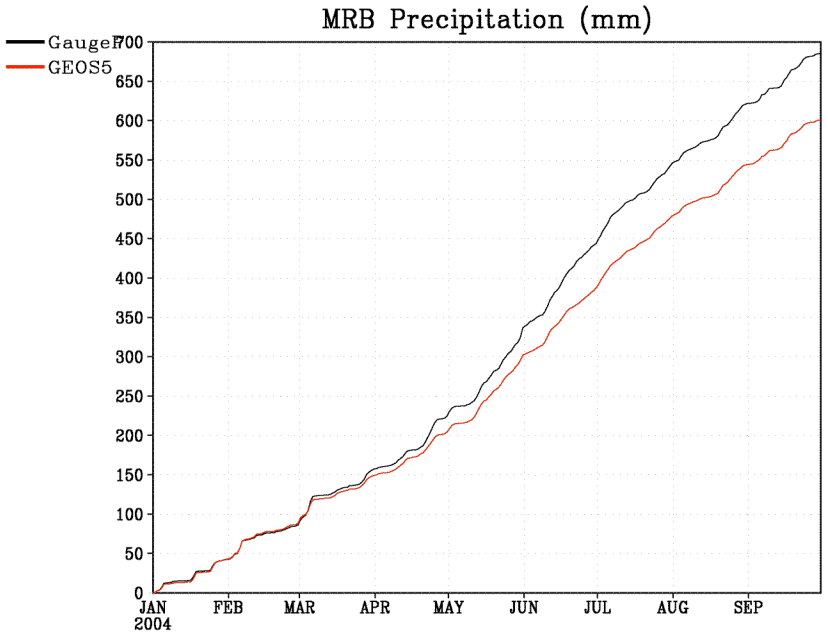
Jan 04: near neutral



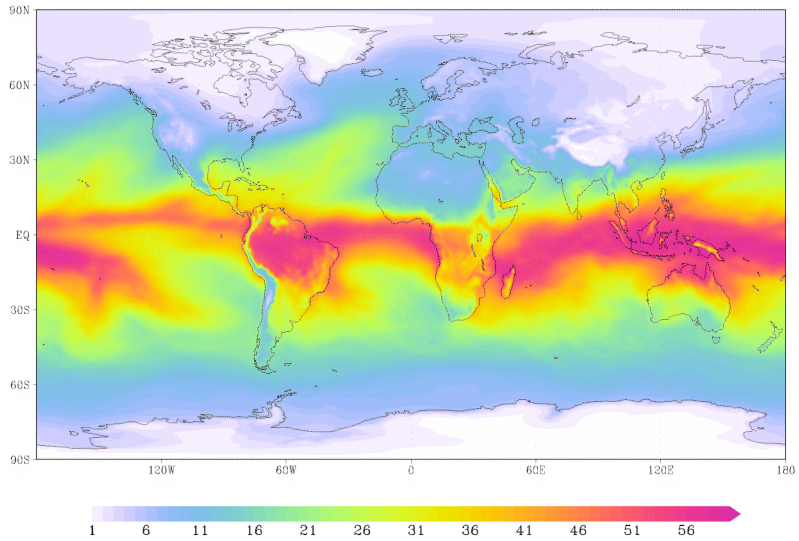

MRB Daily Precipitation (mm day⁻¹)
Mississippi
River Basin
Daily Prec
xycorr = 0.9416
b = 1.1695
yint = −0.063
count = 274
bias = −0.30856
std diff = 0.7651
ycorr = 0.9450
12Z01JAN2004
12Z30SEP2004
Gauge P
GEOS5 (b10p15)


Mississippi River Sub−Basins on GEOS5 grid
50N
45N
40N
35N
30N
25N
120W
115W
110W
105W
100W
95W
90W
85W
80W
75W

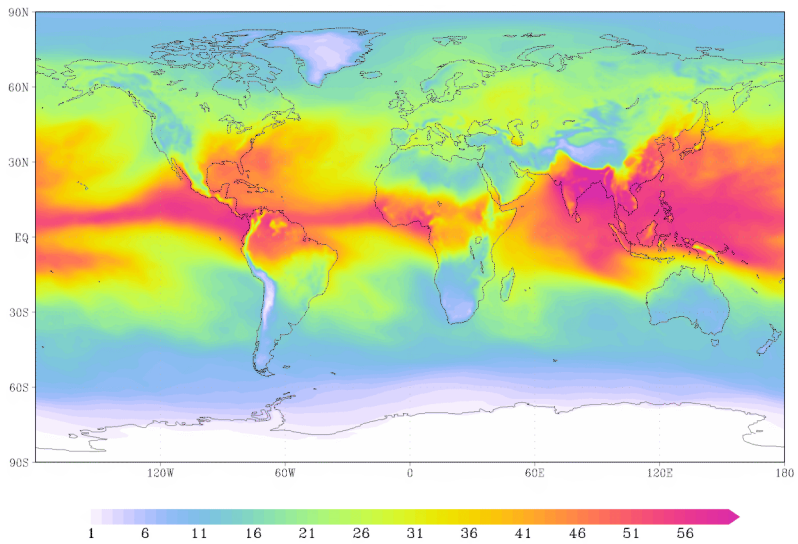

MRB Precipitation (mm day⁻¹)
GaugeP14
GEOS5
JAN
2004
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP


MRB Precipitation (mm)
GaugeP
GEOS5
JAN
2004
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

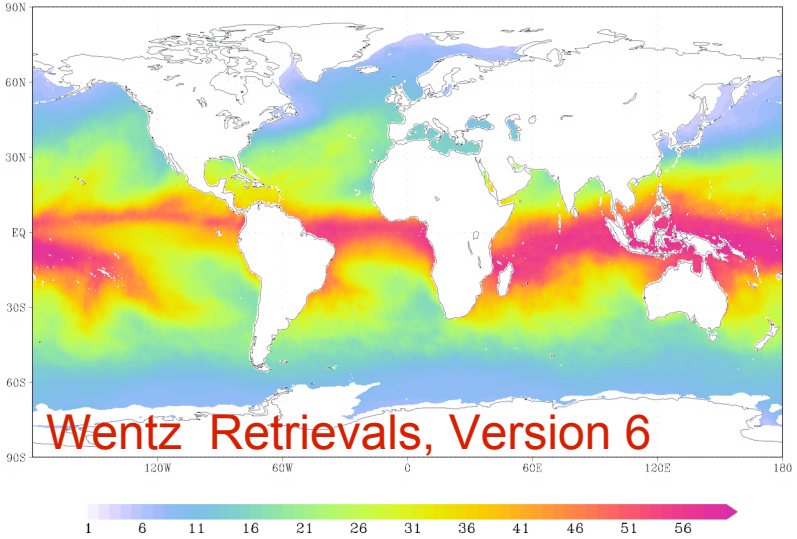
GEOS5 TPW Jan 2004



GEOS5 TPW Jul 2004

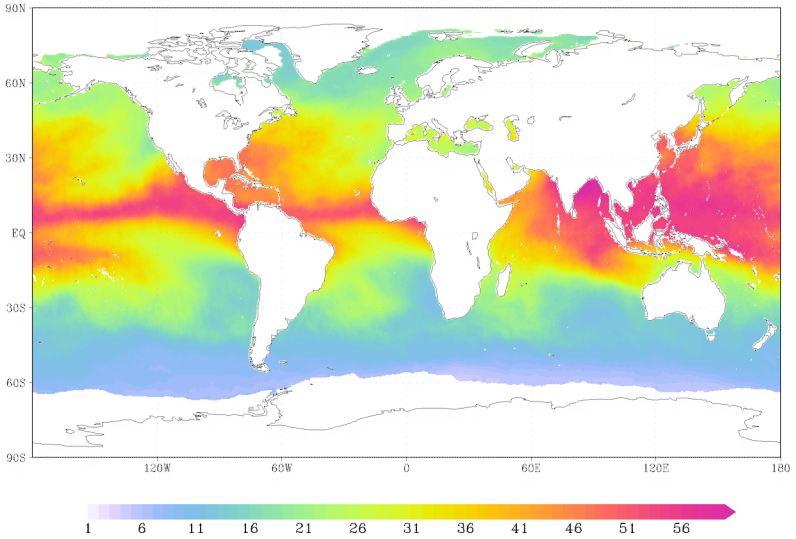


SSMI TPW Jan 2004

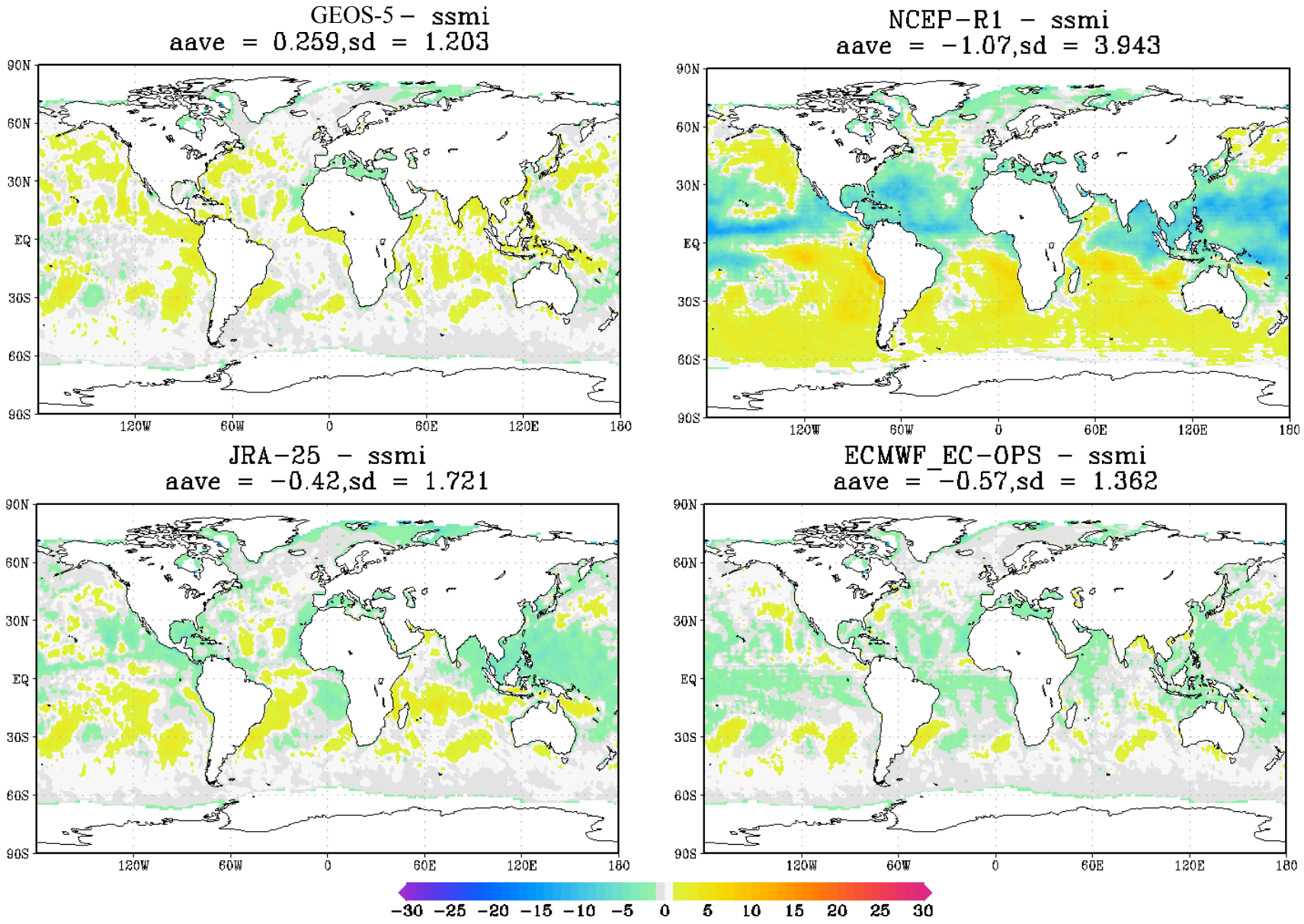


Wentz Retrievals, Version 6

SSMI TPW Jul 2004

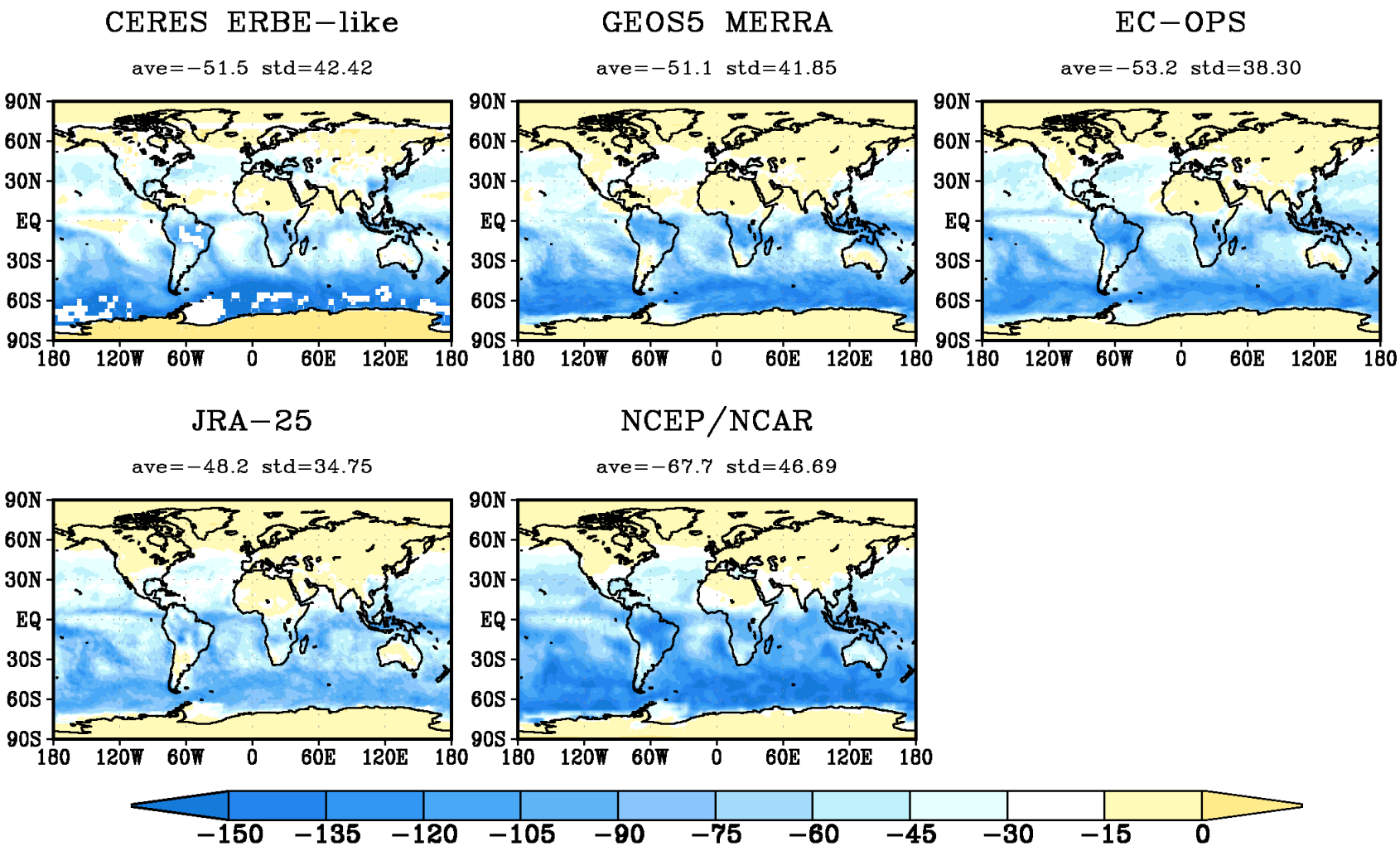


TPW - SSM/I
Jul 2004

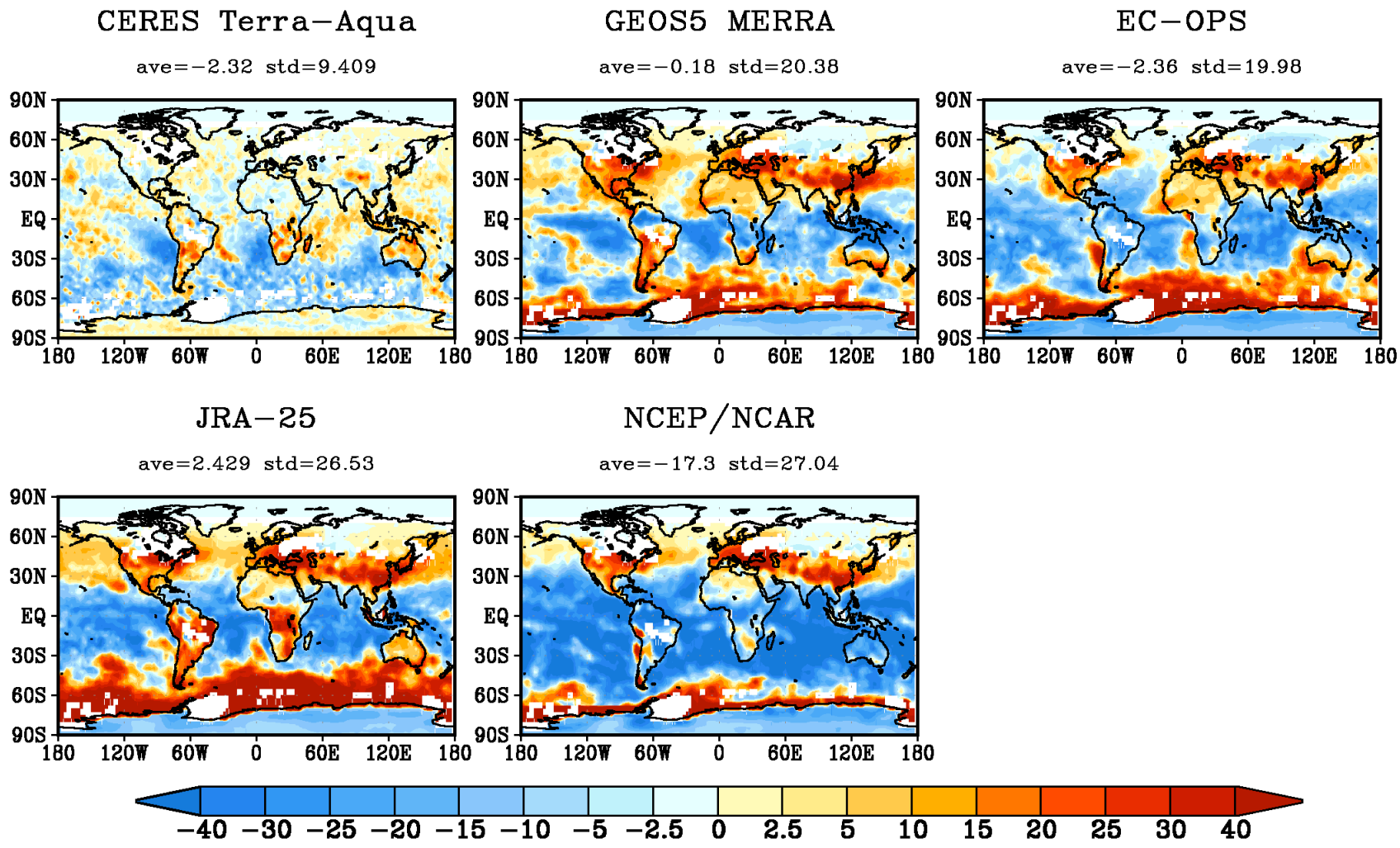


Clouds and Radiation

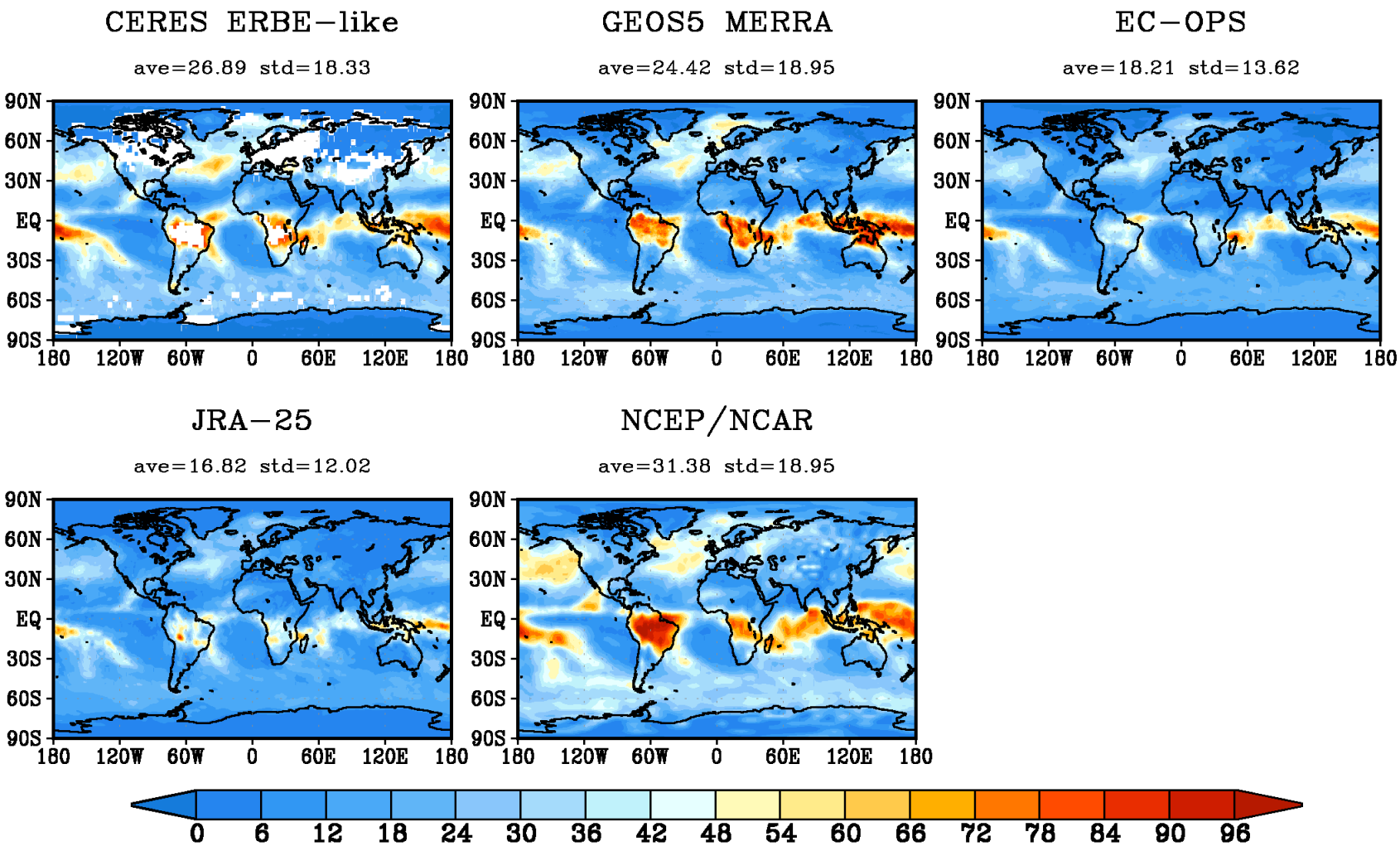
Jan 2004 TOA SW CLDFCN (W/m^2)

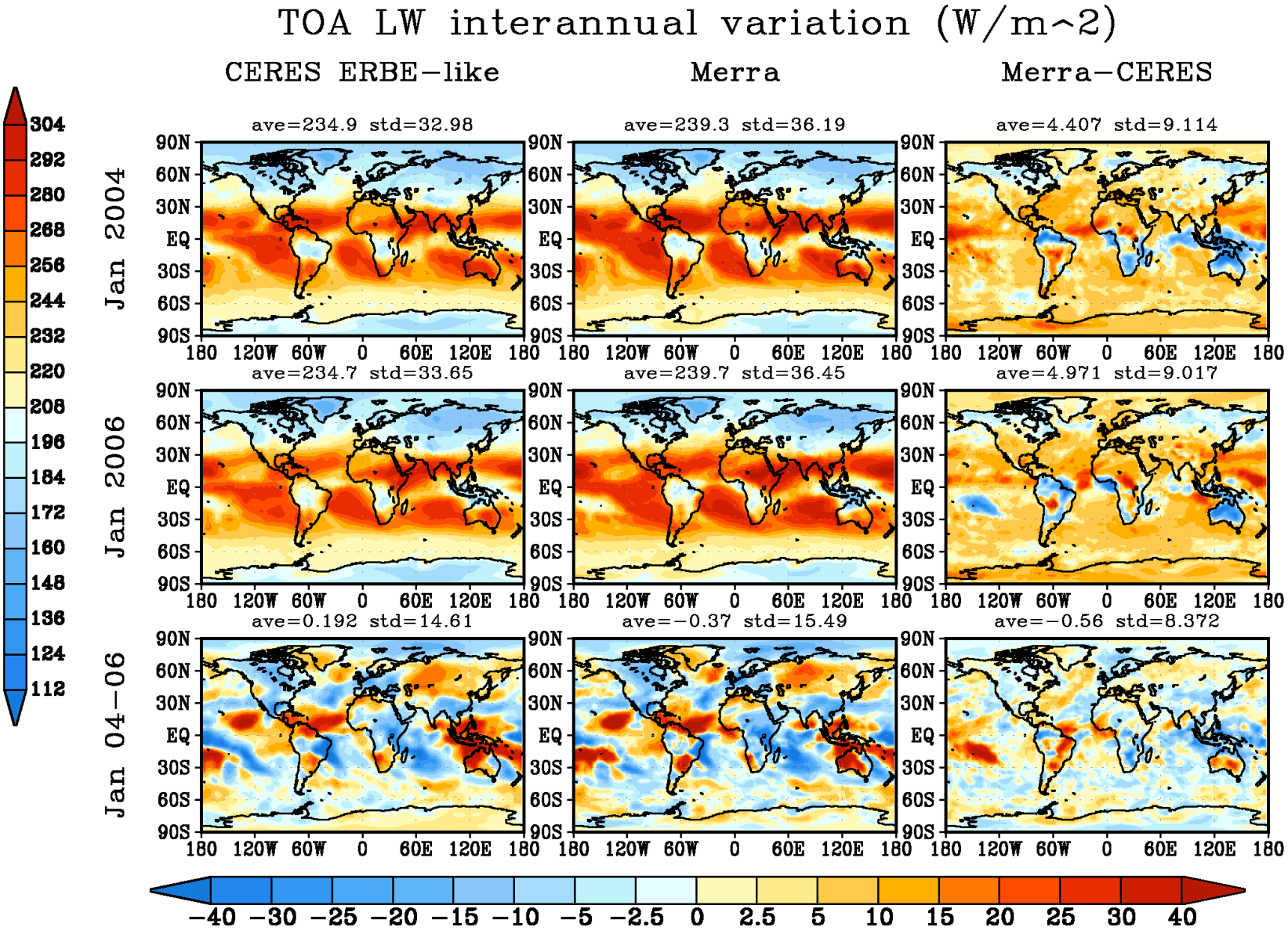


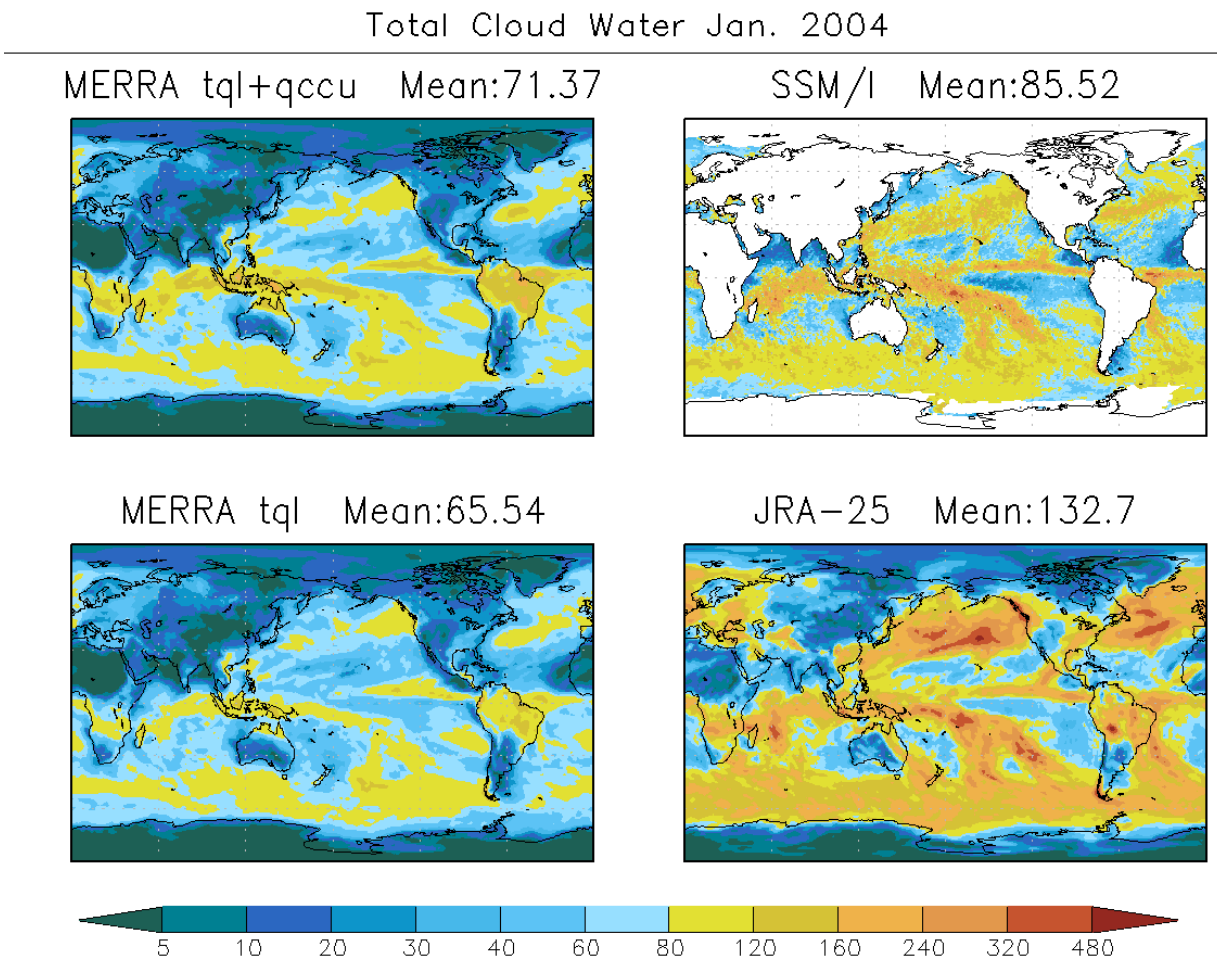
Jan 2004 TOA SW CLDFCN diff from CERES ERBE-like (W/m^2)



Jan 2004 TOA LW CLDFCN (W/m^2)




TOA LW interannual variation (W/m^2)
CERES ERBE-like
Merra
Merra-CERES
ave=234.9 std=32.98
ave=239.3 std=36.19
ave=4.407 std=9.114
ave=234.7 std=33.65
ave=239.7 std=36.45
ave=4.971 std=9.017
ave=0.192 std=14.61
ave=-0.37 std=15.49
ave=-0.56 std=8.372
Jan 2004
Jan 2006
Jan 04-06
304
292
280
268
256
244
232
220
208
196
184
172
160
148
136
124
112
90N
60N
30N
EQ
30S
60S
90S
180 120W 60W 0 60E 120E 180
-40 -30 -25 -20 -15 -10 -5 -2.5 0 2.5 5 10 15 20 25 30 40



GEOS-5 cloud liquid water path, compares well with SSMI estimates

JRA is too high.

Comparison with observations is complicated.

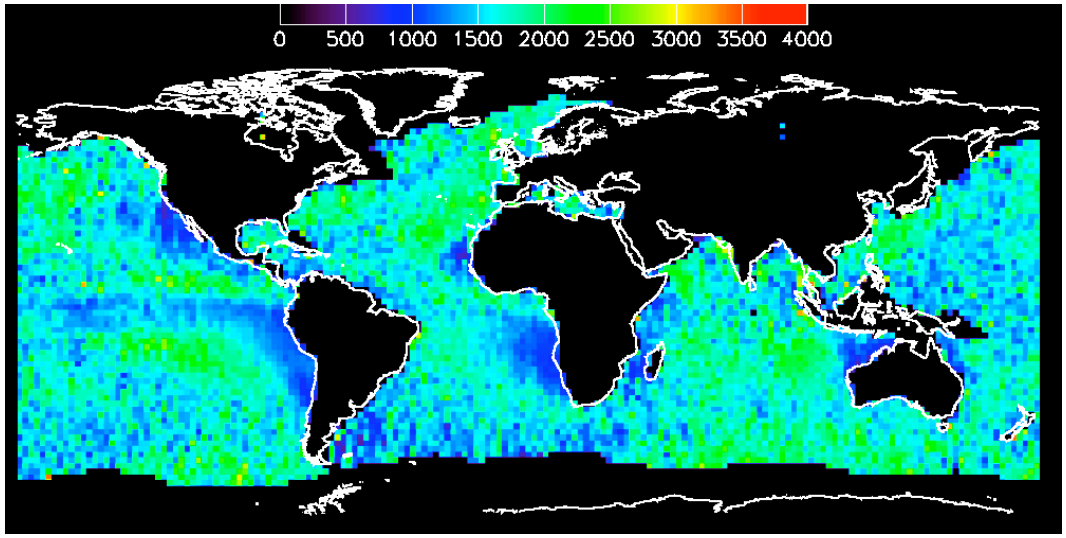
SSMI LWP contains contributions from convective and precipitating liquid

"True", i.e., radiatively active, model LWP does not contain convective (or precipitating) condensate.

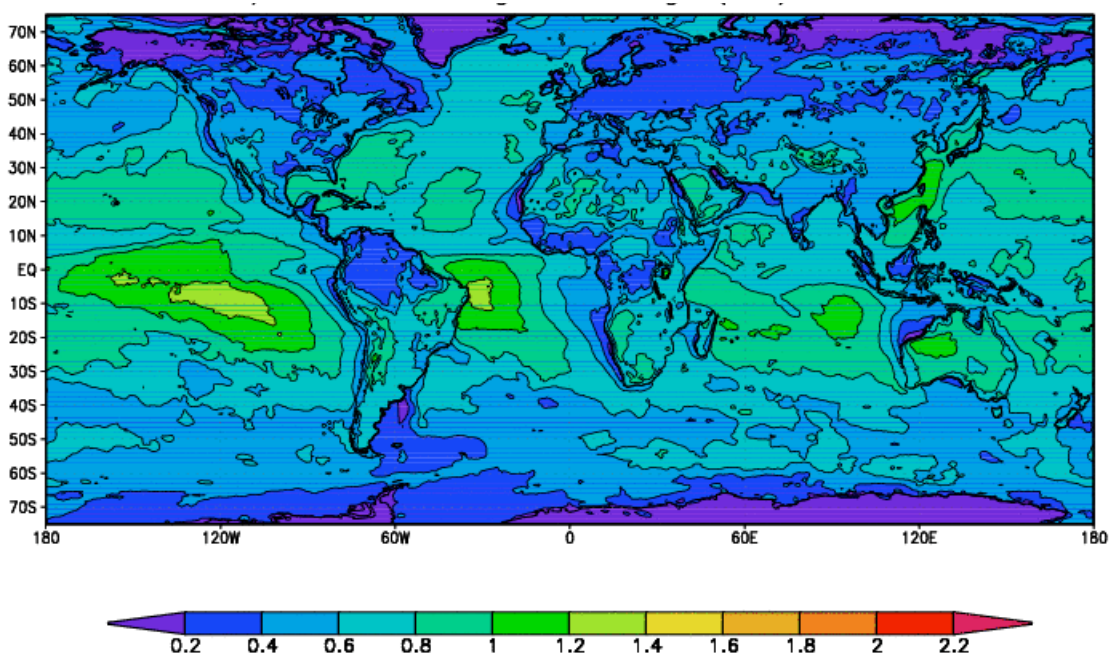
Convective contribution to LWP can be estimated from MERRA output.

PBL STRUCTURE

GLAS
INVERSION
HEIGHT (m)
Oct 2003



GEOS-5
PBL
HEIGHT (km)
Oct 2004

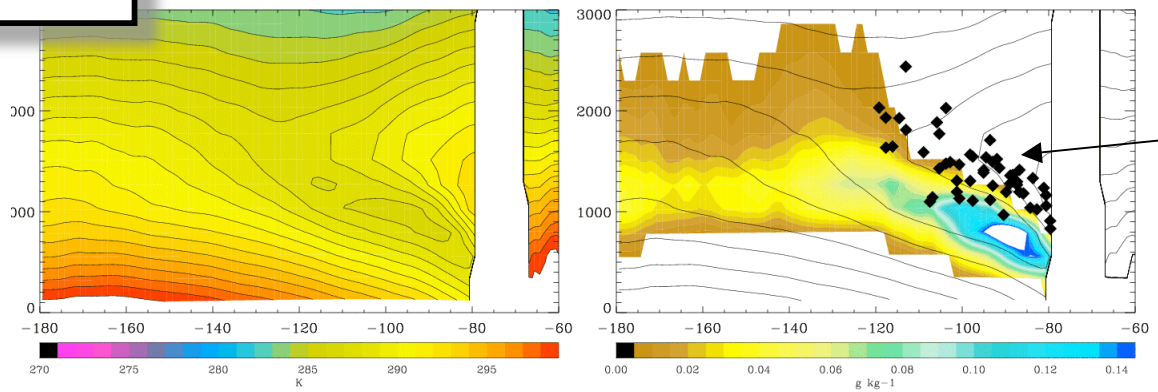


Marine Stratus Deck Off Peru

T

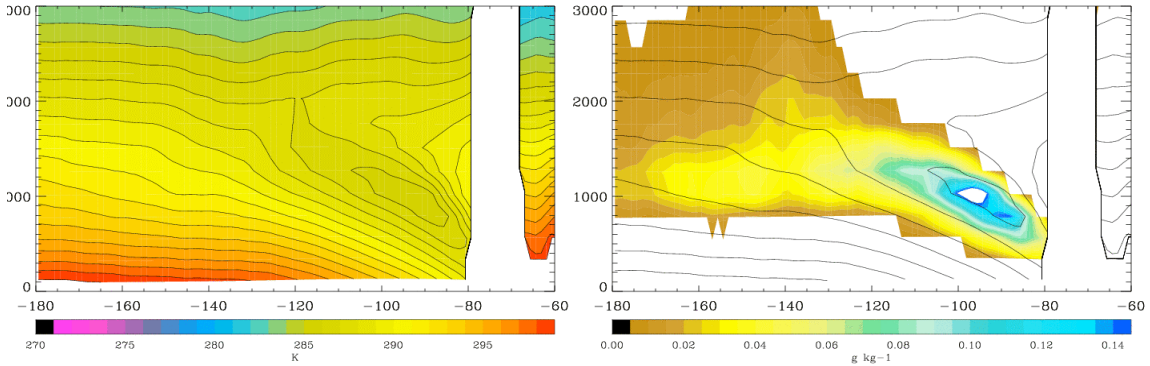
q_L

Jul 06

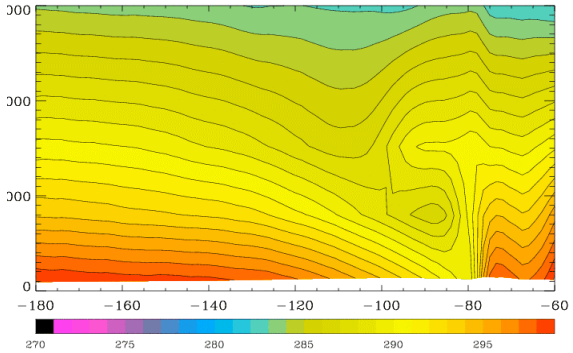


CLOUDSAT Cloud Tops

Jul 04



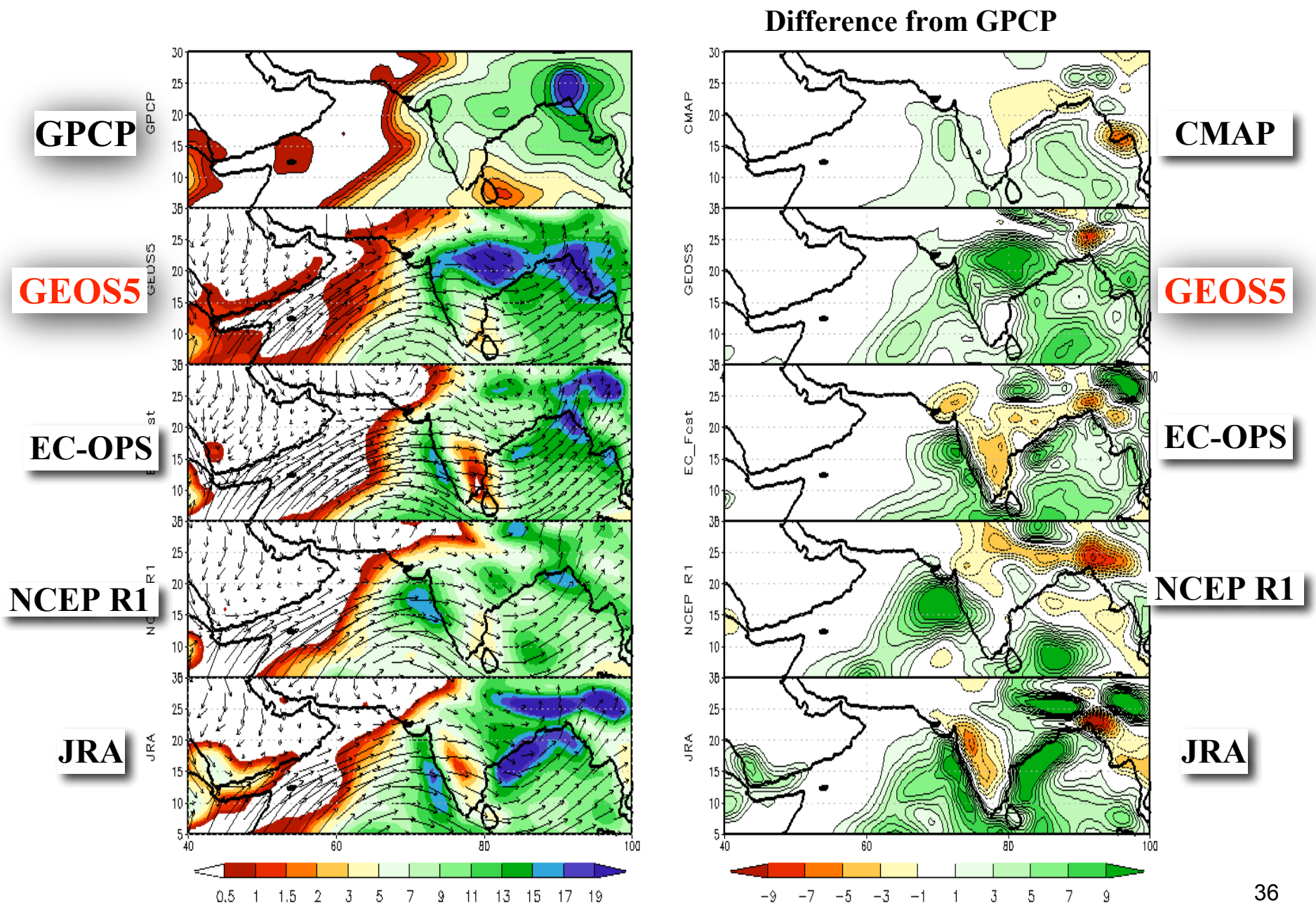
Jul 04
EC OPS



Climate Variability

- Interannual Variability - shown earlier
- Seasonal Variations
  - Indian Summer Monsoon
  - North American Monsoon
- Diurnal Cycle
  - Tropical Precipitation
  - North American Precipitation
  - North American Low Level Jet (LLJ)

Monthly Mean Precipitation over India July 2004 (mm/day)



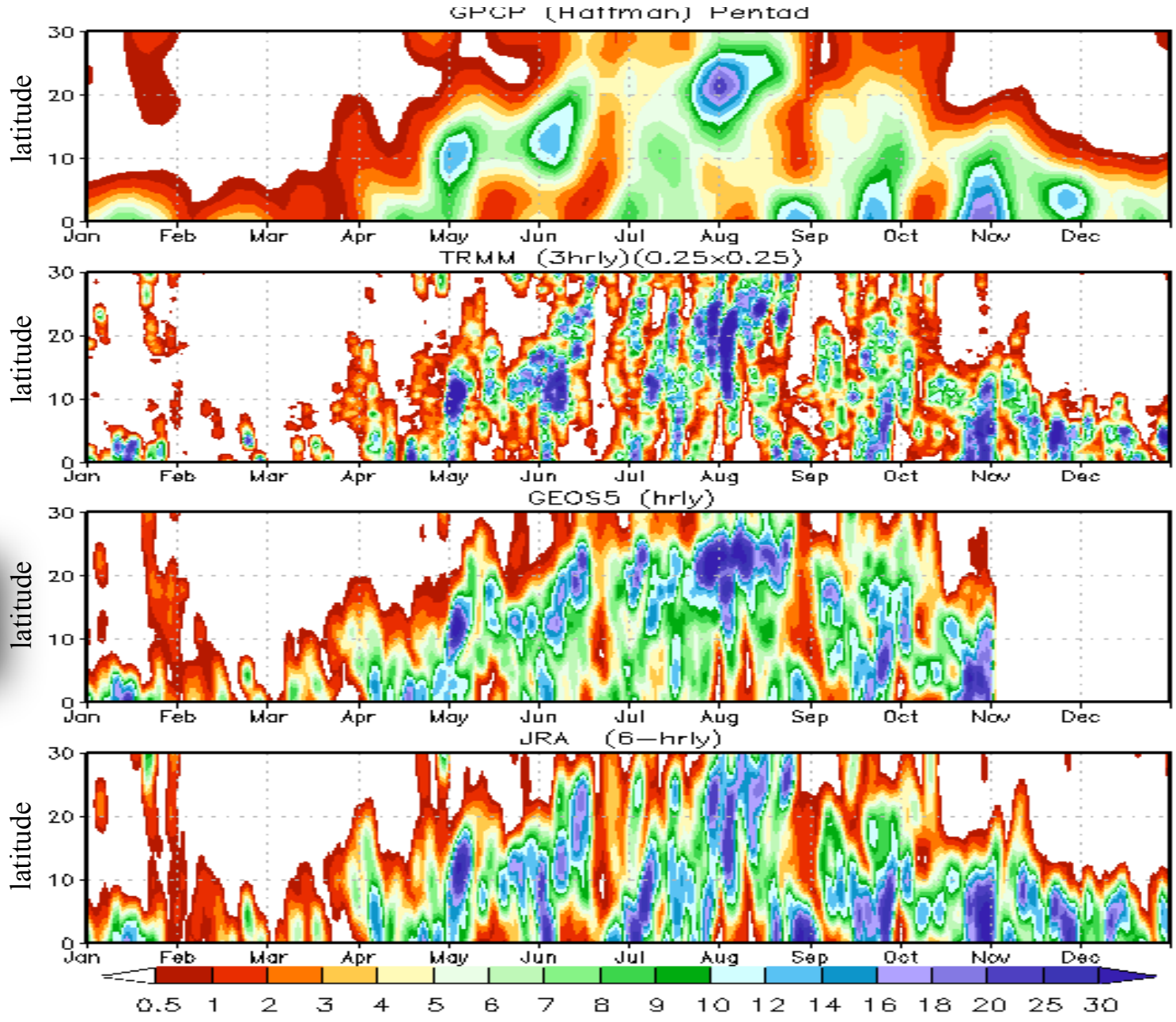
Latitude-time Cross Section of Precipitation over India 2004 (72.5E-80E)

GPCP (Pentad)

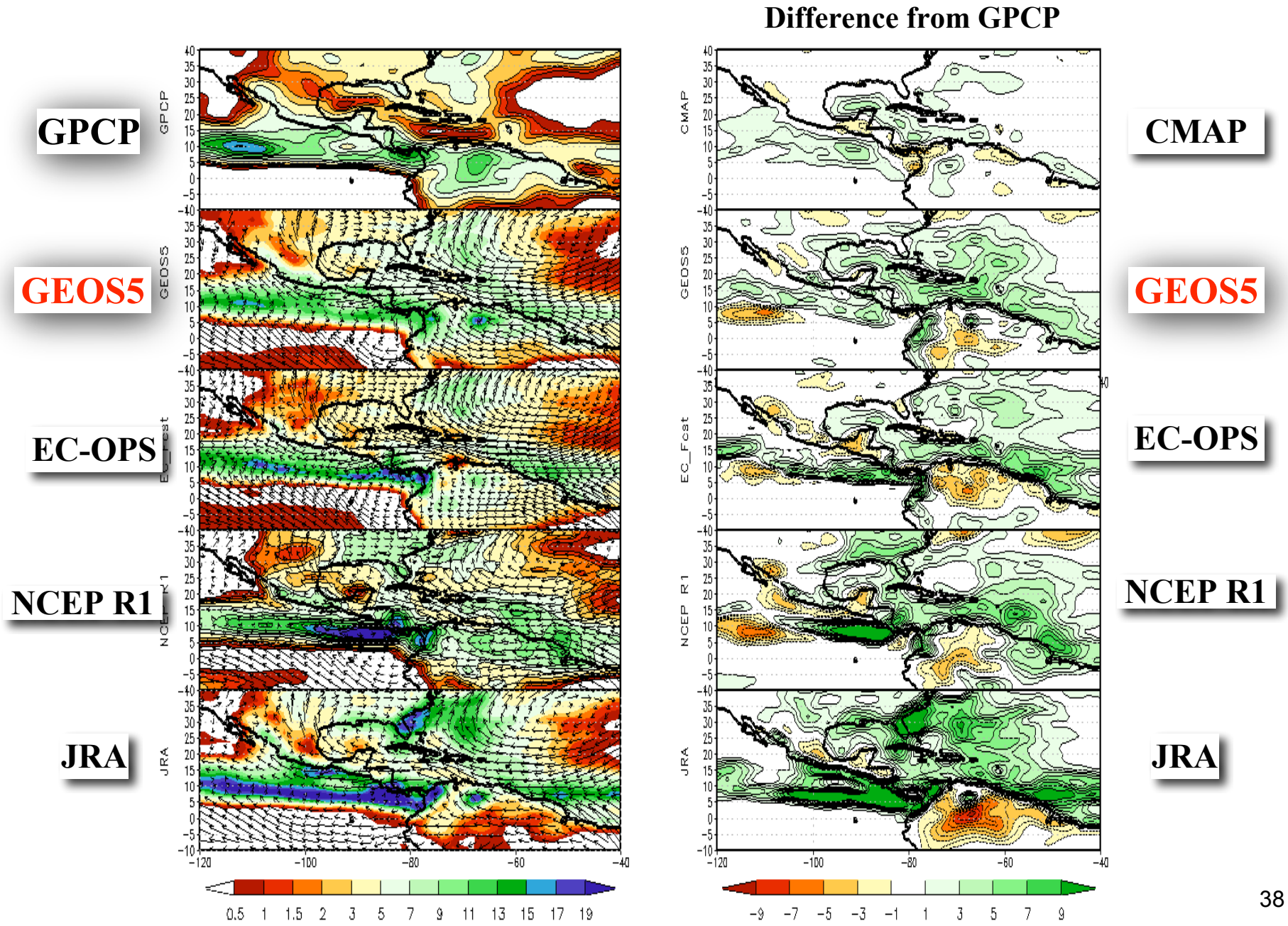
TRMM (daily mean)

GEOS5 (daily mean)

JRA (daily mean)



Monthly Mean Precipitation over Americas July 2004 (mm/day)



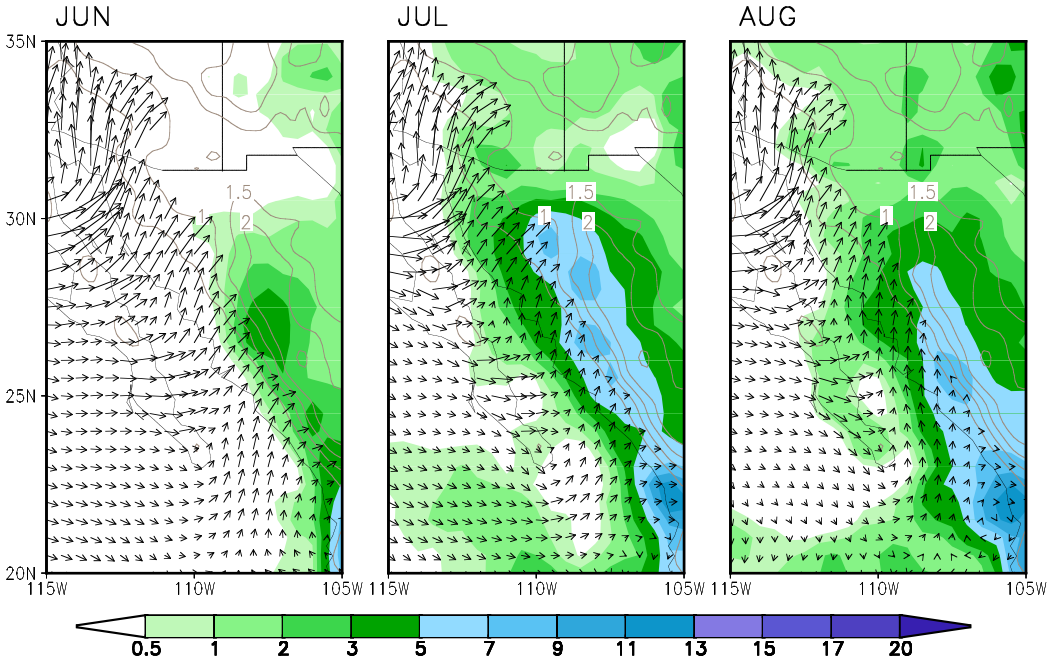
Seasonal evolution of North American monsoon (2004)

Shading: precipitation rate (mm/d),
Arrows: 925 mb winds
Contours: surface elevation

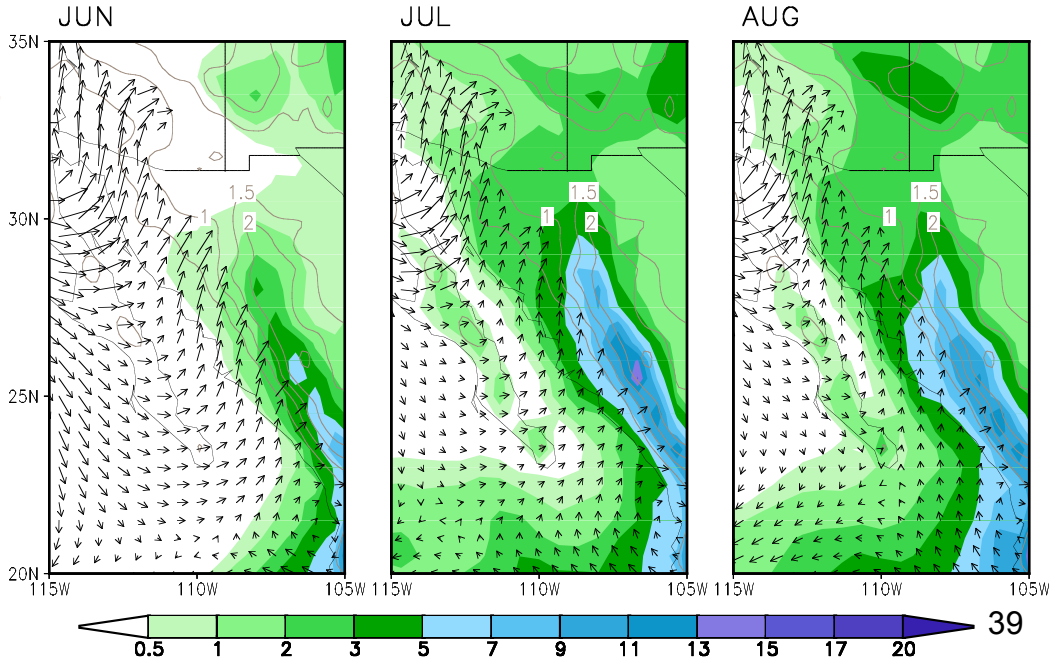
- GEOS-5 reproduces the typical structure of the monsoon rainband. Seasonal march of the rainband is reasonable, with a peak in July.
- Maximum rainfall region is located reasonably well in the windward slope of the mountains (the Sierra Madre Occidental).
- Southwesterly flows in the Gulf of California and in the upslope of the mountains seem to be benefit from the high-resolution (1/2-degree) data assimilation.

Precipitation (mm/d) and 925mb wind

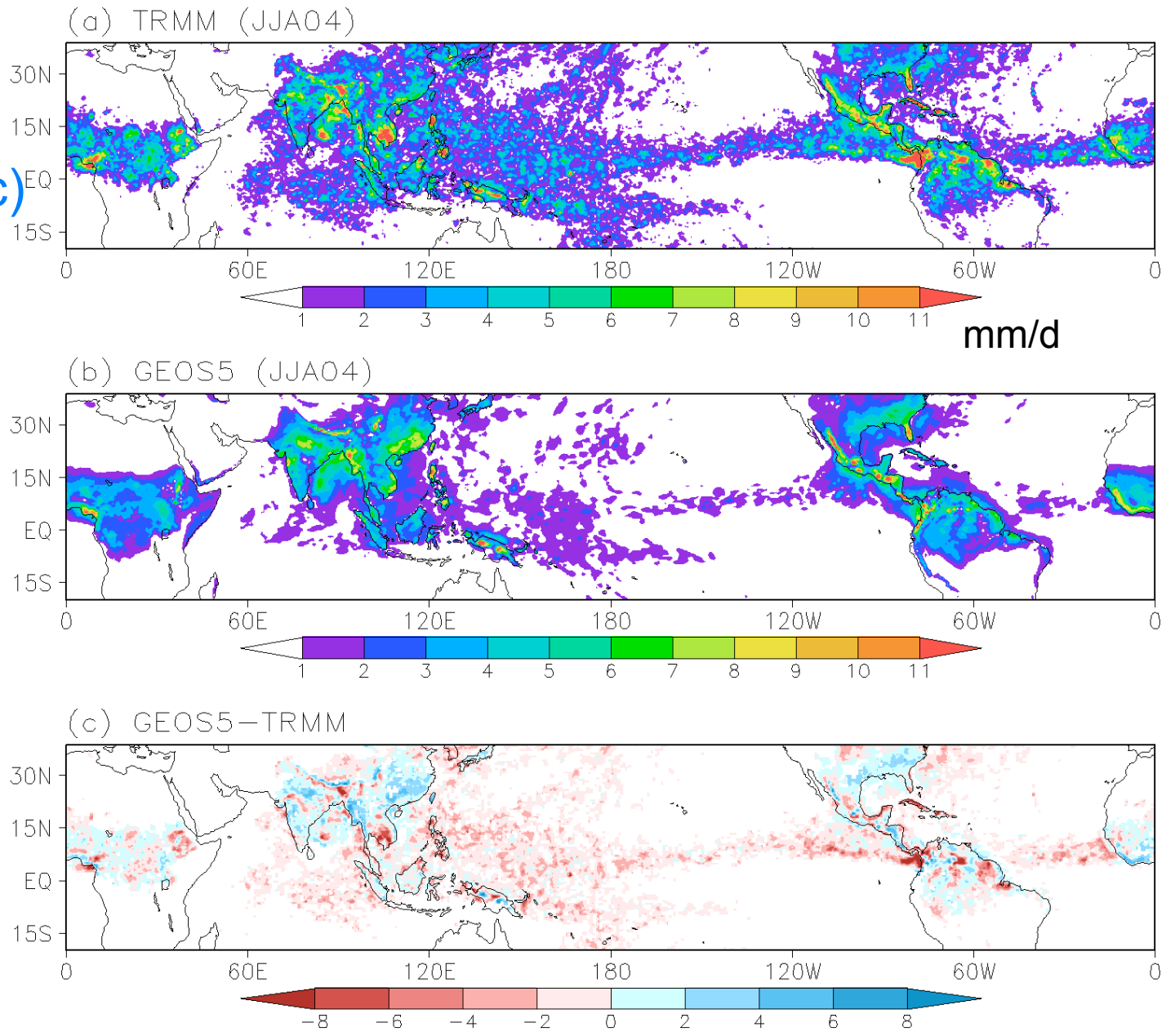
NARR



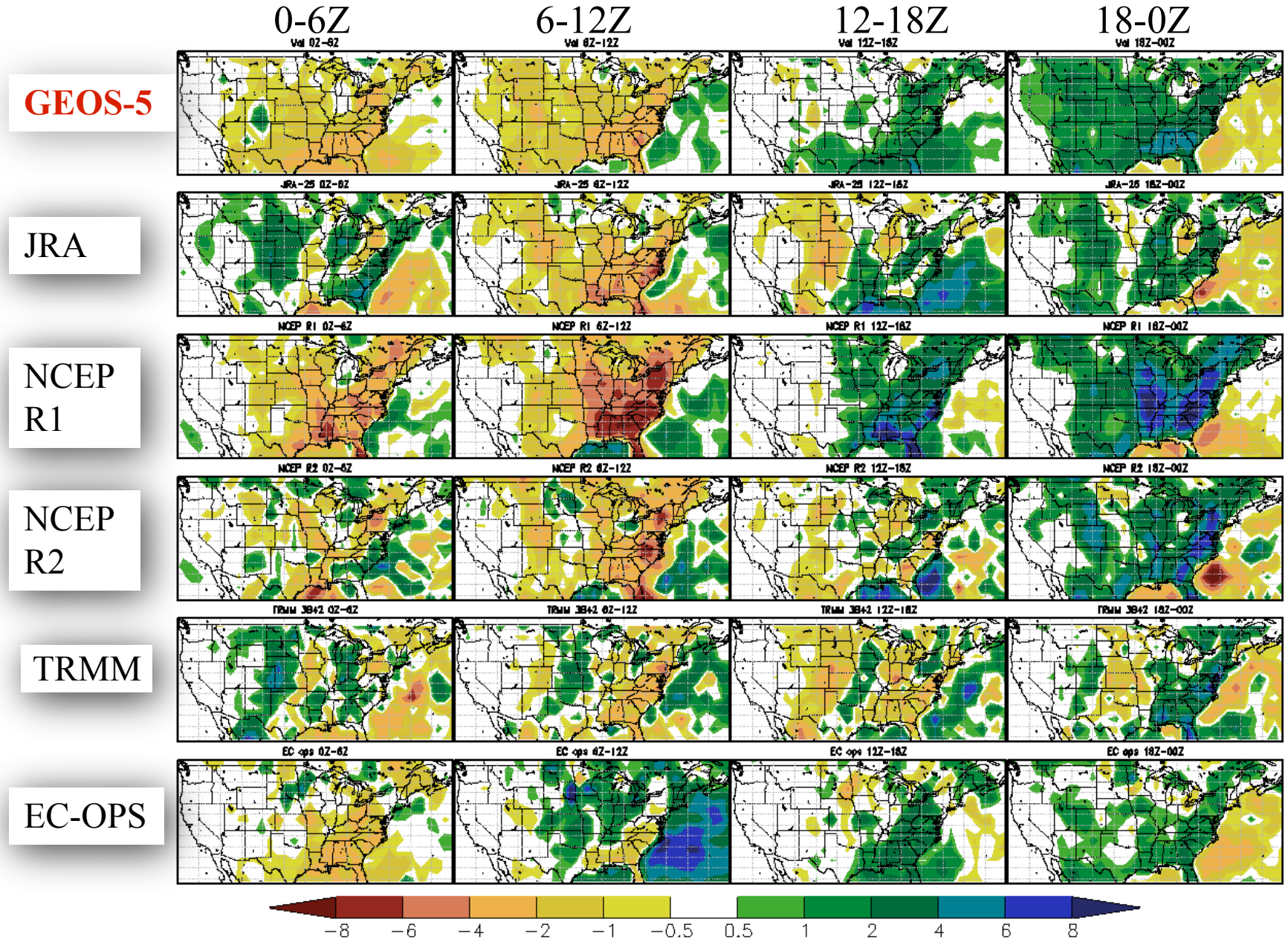
GEOS-5



Amplitude of Precipitation Diurnal Cycle (24-h harmonic)

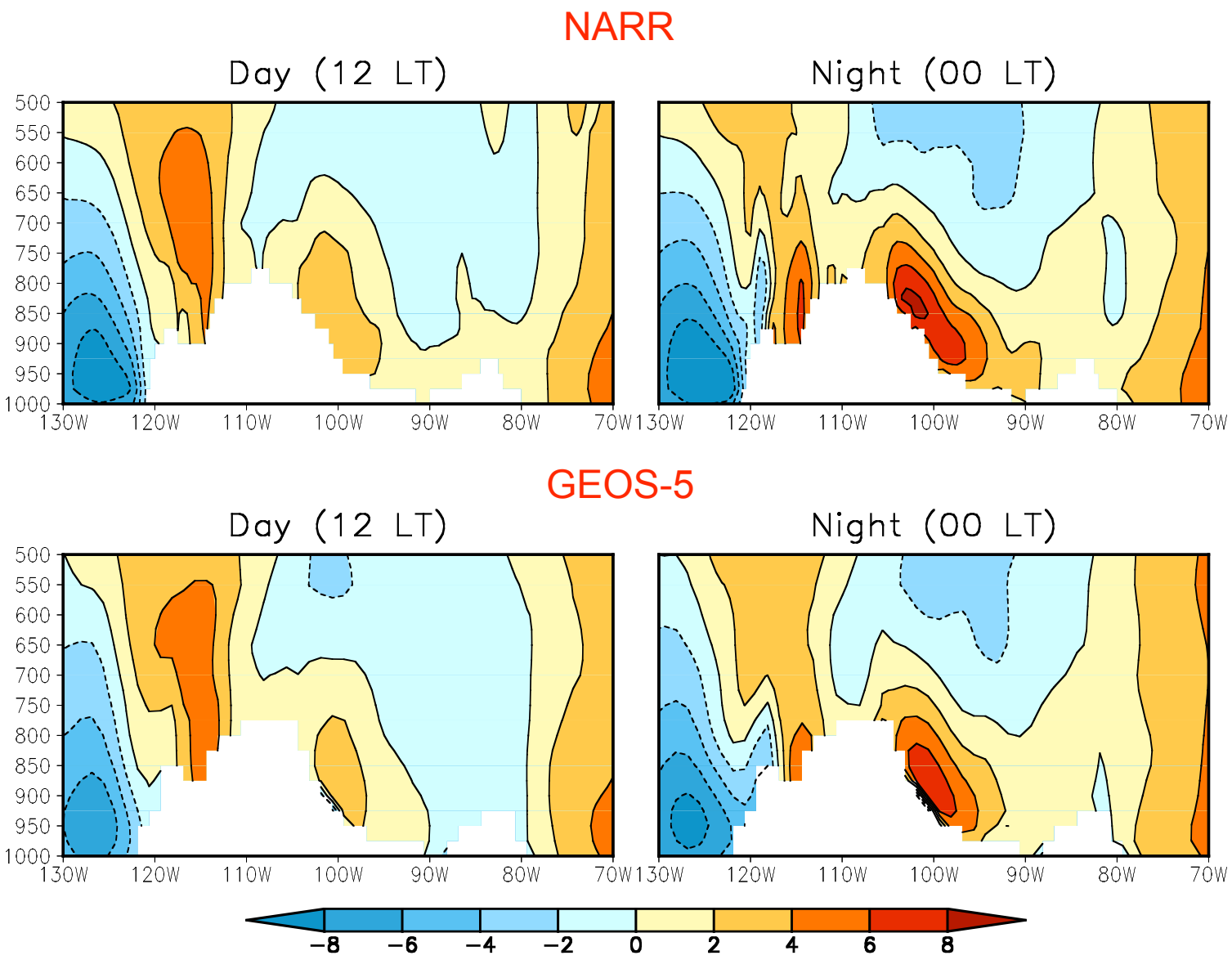


- Larger diurnal variability over continents than oceans
- GEOS-5 tends to overestimate the amplitude over continents and underestimate over oceans



Diurnal variation in precipitation over the United States for July 2004 (mm/day). The July mean is removed.

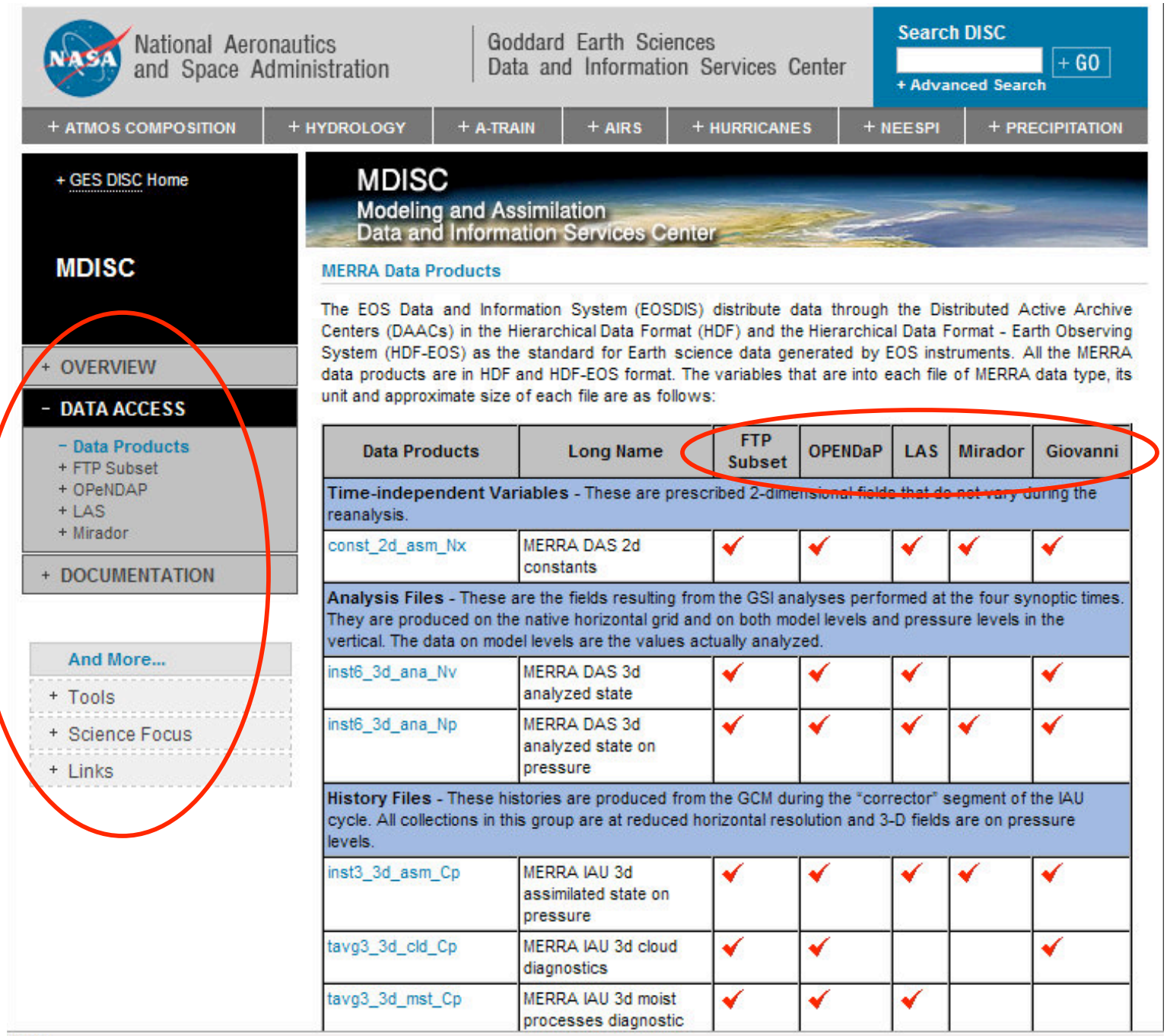
Vertical Structure of LLJ: Jul/Aug 2004 v-wind at 35°N



Distributing MERRA products

MERRA FILE COLLECTIONS

- MERRA products are organized into 24 collections in HDF
- Data are produced on three horizontal grids:
  - Native ---------- (1/2 by 2/3 w/ FV conventions)
  - Reduced ------- (1⅔ by 1⅔ Dateline-edge, Pole-edge)
  - Reduced FV -- (1 by 1¼ w/ FV conventions)
- In the vertical, 3-D data are at:
  - 72 model layers
  - 42 pressure levels
- Temporal resolution:
  - 3D products are 3-hourly
  - 2D products are hourly
- Total online collections ~150TB
- Distributed through a modeling data portal at the Goddard DAAC


National Aeronautics and Space Administration
Goddard Earth Sciences Data and Information Services Center
Search DISC
+ GO
+ Advanced Search
+ ATMOS COMPOSITION
+ HYDROLOGY
+ A-TRAIN
+ AIRS
+ HURRICANES
+ NEESPI
+ PRECIPITATION
+ GES DISC Home
MDISC
+ OVERVIEW
- DATA ACCESS
- Data Products
+ FTP Subset
+ OPeNDAP
+ LAS
+ Mirador
+ DOCUMENTATION
And More...
+ Tools
+ Science Focus
+ Links
MDISC
Modeling and Assimilation Data and Information Services Center
MERRA Data Products
The EOS Data and Information System (EOSDIS) distribute data through the Distributed Active Archive Centers (DAACs) in the Hierarchical Data Format (HDF) and the Hierarchical Data Format - Earth Observing System (HDF-EOS) as the standard for Earth science data generated by EOS instruments. All the MERRA data products are in HDF and HDF-EOS format. The variables that are into each file of MERRA data type, its unit and approximate size of each file are as follows:
Data Products
Long Name
FTP Subset
OPENDaP
LAS
Mirador
Giovanni
Time-independent Variables - These are prescribed 2-dimensional fields that do not vary during the reanalysis.
const_2d_asm_Nx
MERRA DAS 2d constants
Analysis Files - These are the fields resulting from the GSI analyses performed at the four synoptic times. They are produced on the native horizontal grid and on both model levels and pressure levels in the vertical. The data on model levels are the values actually analyzed.
inst6_3d_ana_Nv
MERRA DAS 3d analyzed state
inst6_3d_ana_Np
MERRA DAS 3d analyzed state on pressure
History Files - These histories are produced from the GCM during the "corrector" segment of the IAU cycle. All collections in this group are at reduced horizontal resolution and 3-D fields are on pressure levels.
inst3_3d_asm_Cp
MERRA IAU 3d assimilated state on pressure
tavg3_3d_cld_Cp
MERRA IAU 3d cloud diagnostics
tavg3_3d_mst_Cp
MERRA IAU 3d moist processes diagnostic

Summary

- GEOS-5 analysis improves upon many features of existing reanalyses
- Biases generally smaller than climate signals
- Precipitation issues remain: trends; diurnal cycle

- 2-degree SCOUT run precedes 1/2-degree production to provide performance preview

- Comprehensive output suite

- Spin-ups and Scout underway
- Expect to complete processing by mid-2009

Potential for collaborations between MERRA & NCEP CFSRR
- Comparisons
- Observing system issues: sensitivity of the systems (different models, same analysis);
  radiosonde corrections; performance of assimilation tools (bias corrections);
  feedback files from scout runs
- etc