Validation of the CWB AMIP simulation across multiple time scales

Huei-Ping Huang
Arizona State University

Thanks to Danny Paek, Mong-Ming Lu, and CWB AMIP team

Additional thanks to Jurgen Theiss @ Theiss Research

Typical setup of an AMIP simulation:
Global atmosphere, forced by observed SST

CWB AMIP run: T119 (360x180 Gaussian grid)
1955-2006

Main dataset used for validation:

NCEP Reanalysis-II (R-2), 1979-present
-- Use the 2.5°x2.5° archive (original model is T62, 192x96)

Focus on the overlapping period: **1979-2006**

While needed, daily data from both datasets will be used

Notable features of CWB AMIP dataset:

- Higher resolution than many classical AMIP simulations in AMIP1/2 and CMIP archive.

- Availability of daily (or 4-times daily) output

Previous AMIP runs mostly saved only monthly data

Since the observed SST (used to force the AMIP runs) has at best *monthly resolution*, can anything realistic be produced by an AMIP run at *submonthly* time scale?
→ First analysis using CWB AMIP run

Remarks on "validation":

Reanalysis ≠ absolute truth

Depending on the quantity of interest, different reanalysis datasets can disagree with each other. For example, notable differences were found in the interdecadal trend of global zonal wind among eight reanalysis datasets (Paek and Huang 2012).

Example: Global relative angular momentum

(A useful index of the strength/latitudinal location of tropospheric zonal jets)

$$M_R \equiv \frac{R^3}{g} \int_0^{p_s} \int_{-\pi/2}^{\pi/2} \int_0^{2\pi} u(\lambda, \phi, p) \cos^2\phi \, d\lambda \, d\phi \, dp$$

1. Daily time series (raw, unfiltered)
   - CWB AMIP run
   - Four reanalyses

     NCEP Reanalysis II (R-2)

     20th Century Reanalysis (20CR)

     CFSR Reanalysis

     ERA-Interim

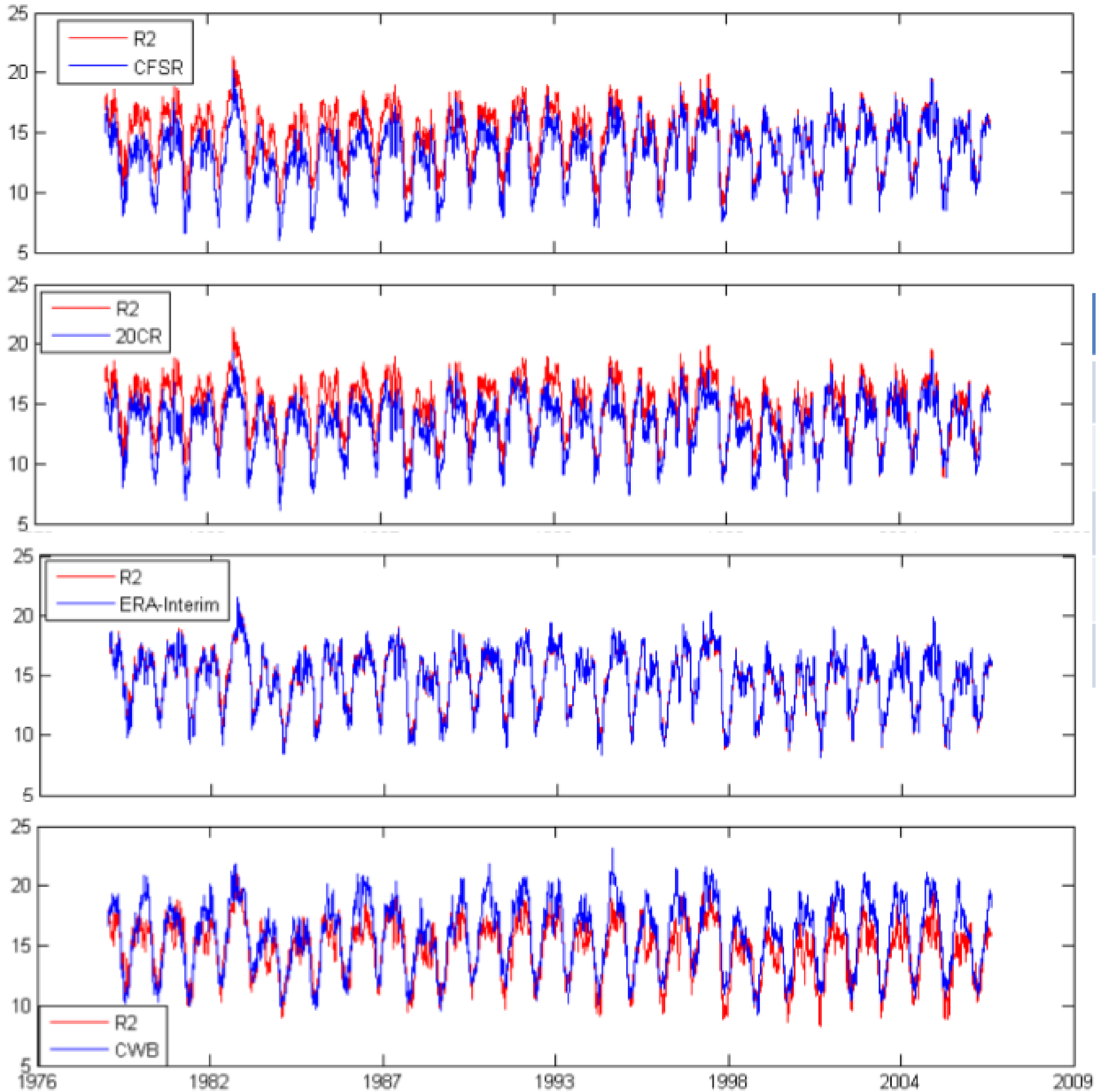
Daily M_R, 1979-2006 (Thanks to Danny Paek)

R2 vs. CFSR

R2 vs. 20CR

R2 vs. ERA-I

R2 vs. CWB



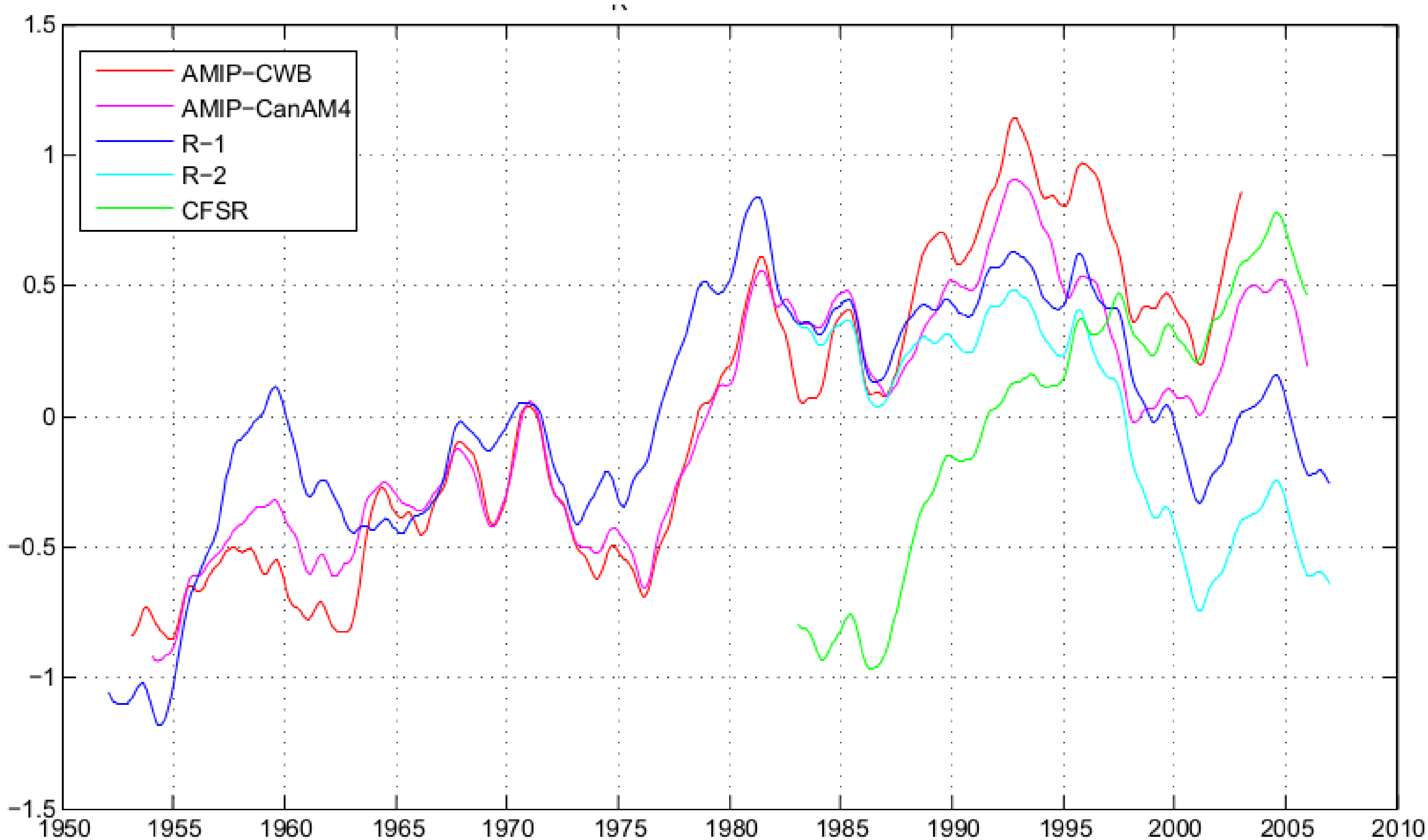
While (as expected) the AMIP run does not reproduce the daily detail, the seasonal cycle and low-frequency variability in the CWB-AMIP simulation fall within the pack of the ensemble of multiple reanalyses.

(The difference between CWB-AMIP and R2 is comparable to the difference between CFSR and R2, and so on.)

As an illustration, consider the decadal-to-interdecadal variability and trend of M_R:

- Use monthly mean data
- Remove long-term mean
- Further, perform 60-month running mean (to extract decadal-to-interdecadal variability/trend)
- Add an independent AMIP run (CanAM4) for comparison

60-month running mean of ΔM_R (Thanks to Danny Paek)



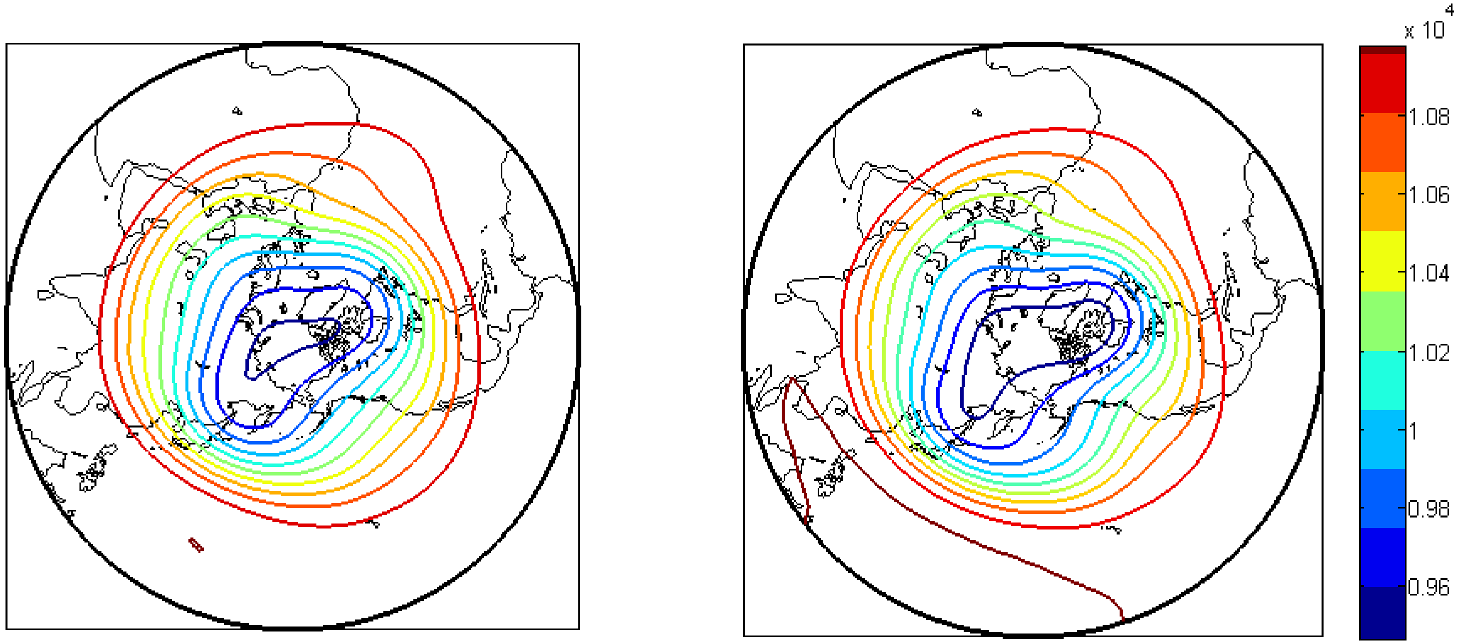
- For the decadal-to-interdecadal variability of M_R, the difference between CWB-AMIP and NCEP R-2 is smaller than the difference between NCEP R-2 and CFSR Reanalysis

- CWB-AMIP also closely agrees with CanAM4-AMIP (Canadian Climate Center AMIP run in CMIP5 archive)

Validation of CWB-AMIP using NCEP R-2

- Climatology of 250 hPa height
- Interannual variability (atm response to ENSO)
- Submonthly variability ($T < 30$ days)

January climatology (1979-2006) 250 hPa height



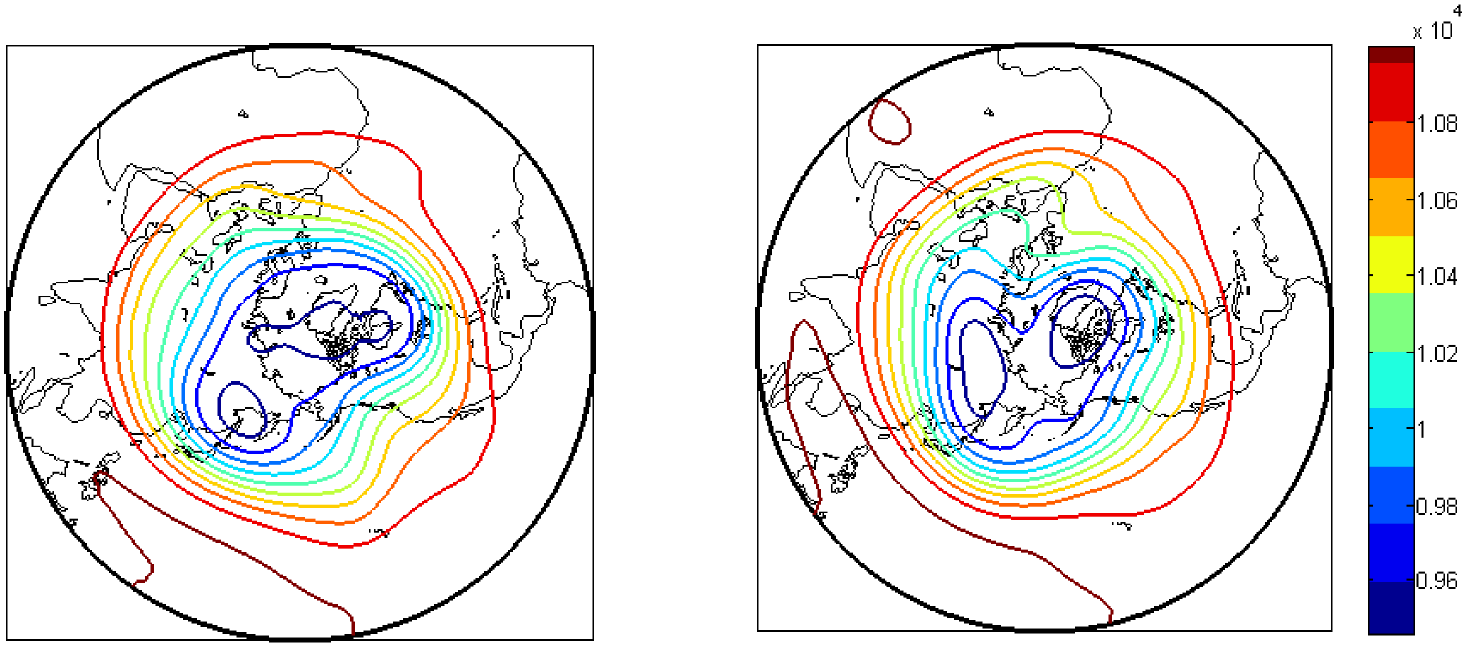
CWB-AMIP

NCEP R-2

Contour interval = 150 m

Reasonable agreement in climatology
(Also, similar behavior at other vertical levels)

Example of a single month: January 2006 250 hPa height



CWB-AMIP

NCEP R-2

Contour interval = 150 m

Notable differences exist for individual months

Interannual variability

Use monthly mean 250 hPa height data, 1979-2006

Construct the monthly anomaly by removing the 28-yr mean seasonal cycle

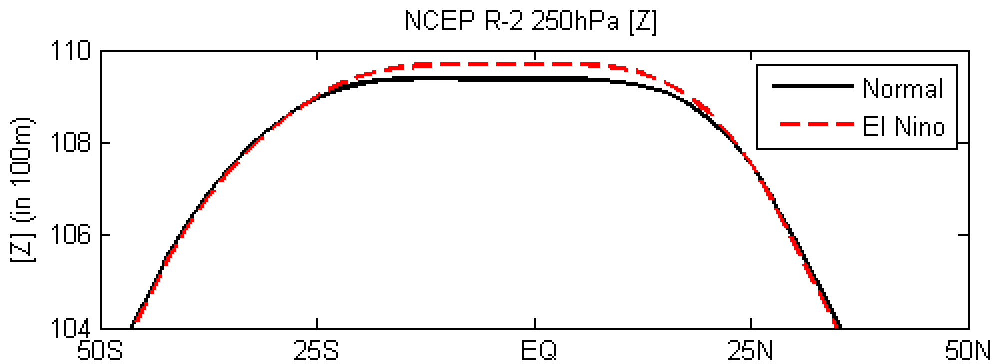
Monthly NINO3.4 SST index used to guide the El Nino composite

Use the average of 250 hPa height over the tropical belt (15S-15N) as an index for tropical tropospheric temperature. In observation, this index closely varies with El Nino SST and with the strength of subtropical jets.

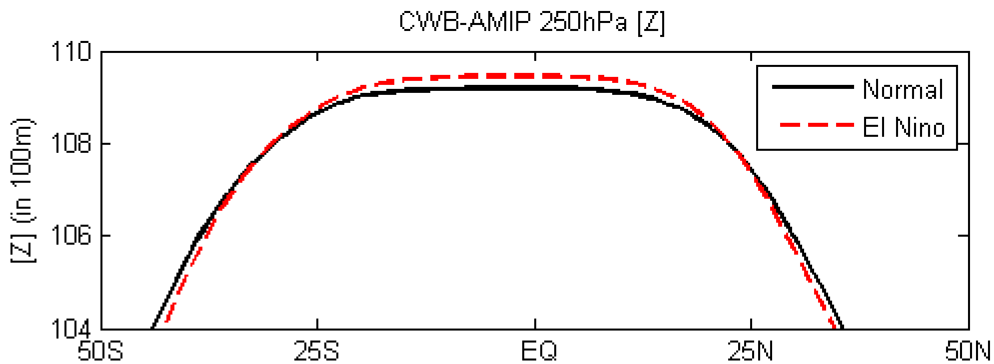
January zonal mean 250 hPa height, El Nino vs Normal conditions

(El Nino composite = 1983, 1992, 1998   Normal = 1980-2005 climatology)

NCEP-R2

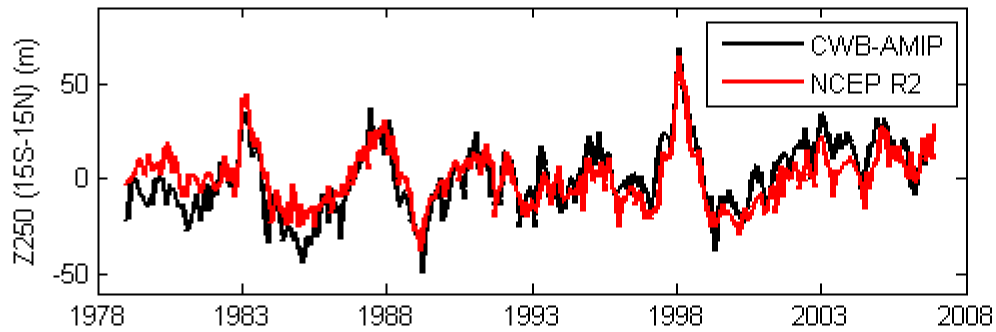


CWB-AMIP

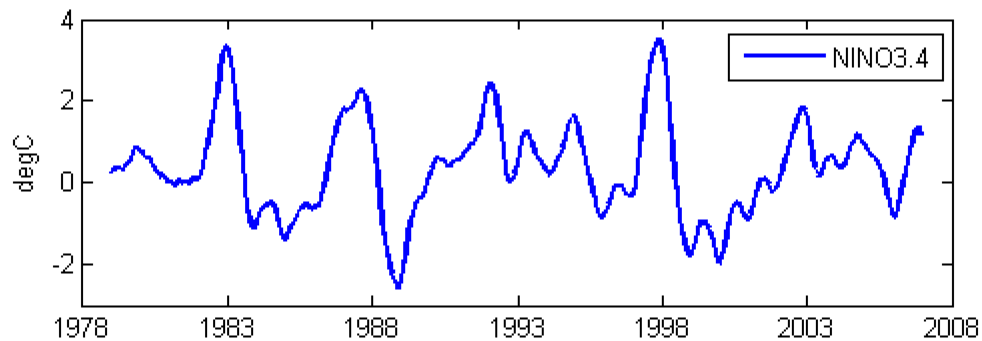


El Nino: higher tropical SST → higher tropical tropospheric temperature
→ vertical expansion of tropical atmosphere
→ positive 250 hPa height anomaly

Tropical (15S-15N) 250 hPa height anomaly & NINO3.4 index



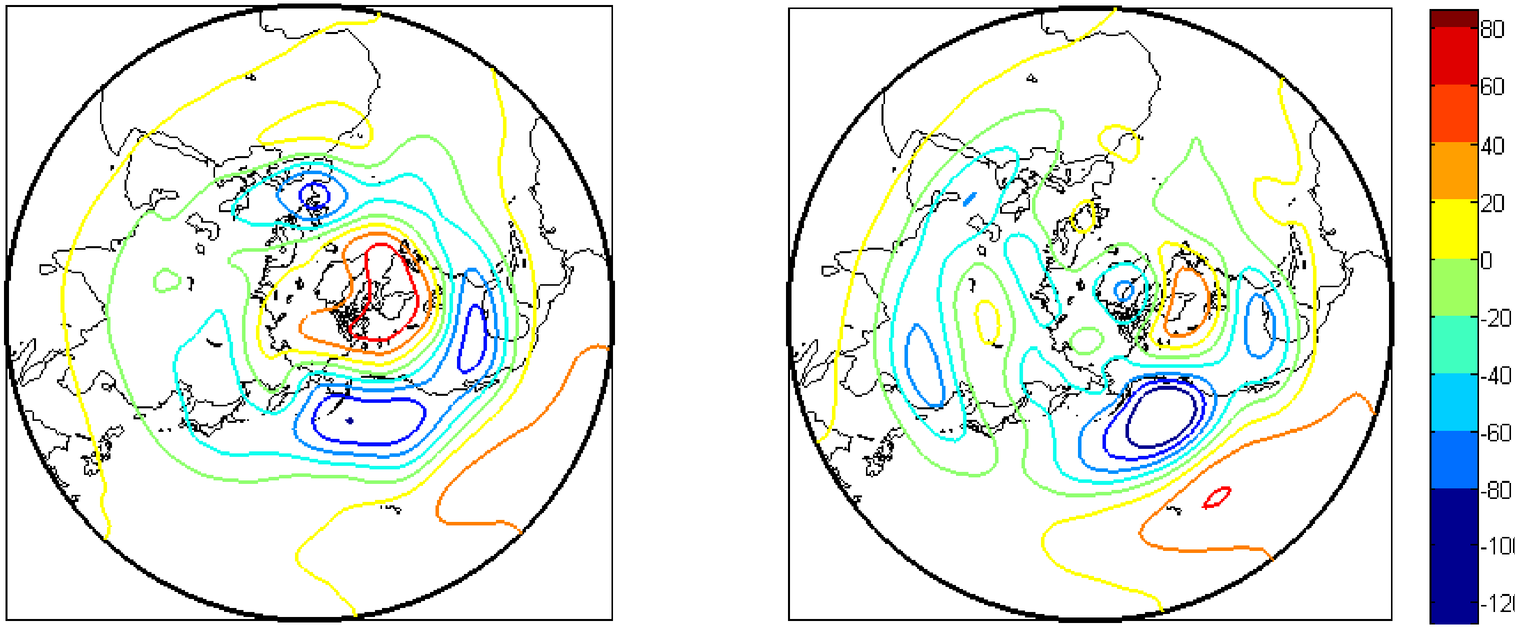
ΔZ250 (15S-15N)
NCEP R-2
vs.
CWB-AMIP



NINO3.4 SST

CWB-AMIP and NCEP R-2 agree quite well

El Nino composite, 250 hPa height anomaly
(all months with NINO3.4 > +2.5C, 1979-2006)

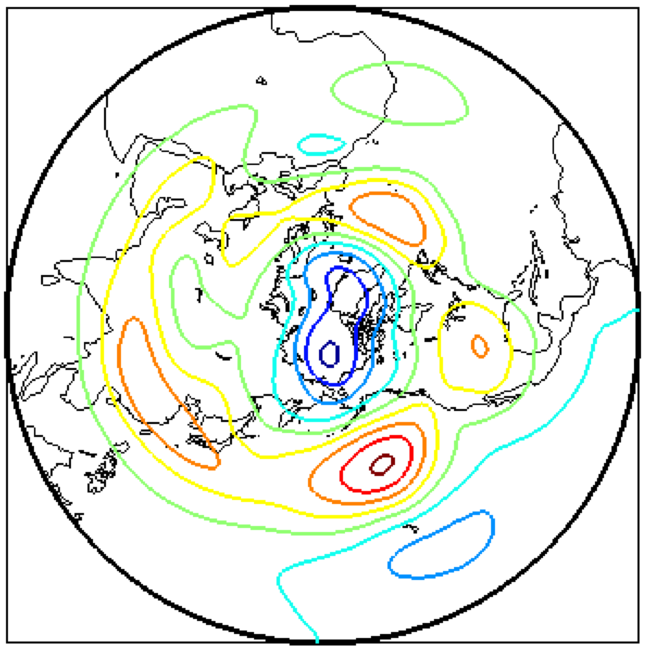


CWB-AMIP NCEP R-2

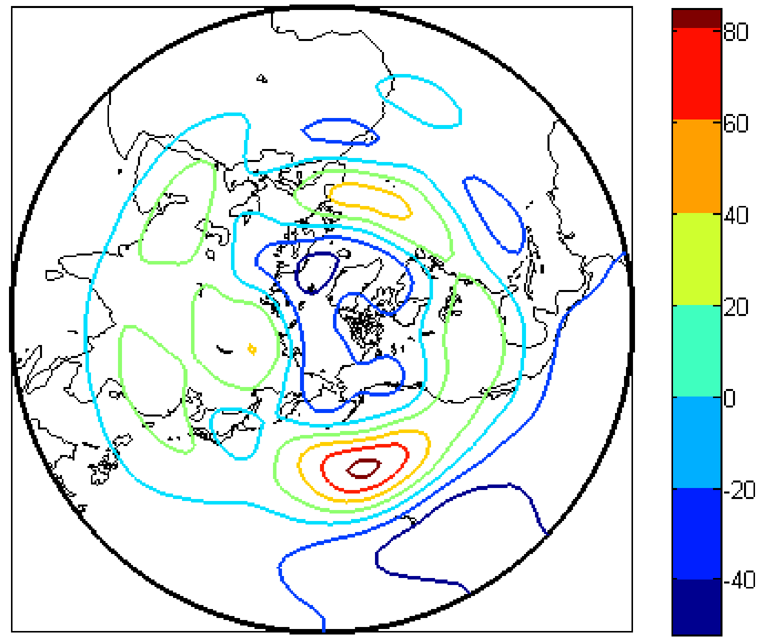
Contour interval = 20 m

- Reasonable agreement over North American sector ("PNA pattern")
- The response in CWB-AMIP is more "zonal"

La Nina composite, 250 hPa height anomaly
(NINO3.4 < –1.5C)



CWB-AMIP



NCEP R-2

Contour interval = 20 m

Reasonable agreement over PNA and North Atlantic sectors

Submonthly variability

1 week $< T <$ 1 month: This is the range where "weather" ends and "climate" doesn't quite begin

AMIP runs are driven by observed SST with monthly resolution: We do not expect the reproduction of detailed day-to-day or week-to-week observed flow pattern by an AMIP run. Nevertheless, can it reproduce some aspects of the statistics of the submonthly variability?

Organized variability for 1 week < T < 1 month

Large-scale, hemispherically confined retrograde waves (zonal wavenumber 1 and 2 in particular)

- Period ~ 10-25 days
- Max amplitude at 60N but has wide latitudinal extent
- Equivalent barotropic structure for wave-1

  (we will consider 250 hPa height)

Observation:

Madden and Speth (1989), Speth and Madden (1992),
also Branstator (1987), Kushnir (1987)

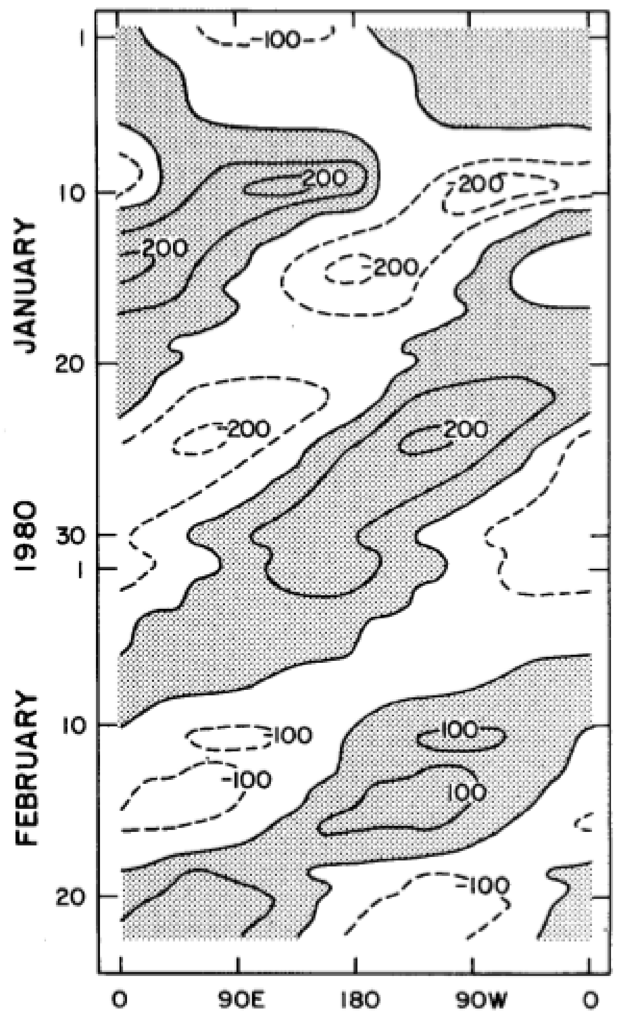
Dynamical connection to seasonal-mean basic state:

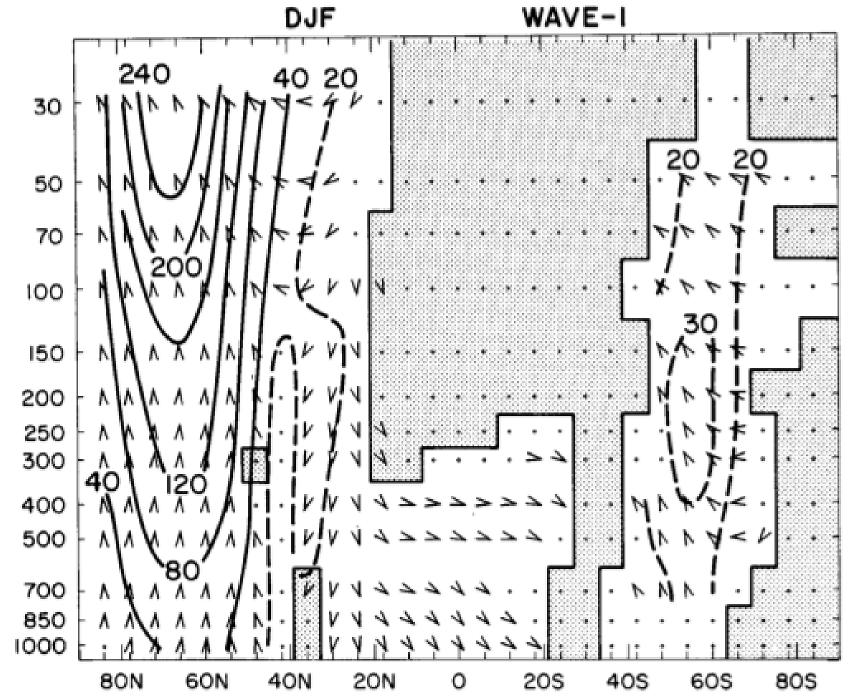
Huang and Robinson (1995), Branstator and Held (1995)

Submonthly traveling long waves might influence:

Rainfall over western U.S. (Mo 1999)
East Asian cold-air outbreak? (e.g., Takaya and Nakamura 2005)

Madden and Speth (1989) Wave-1 (predominantly retrograde)





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Vertical structure

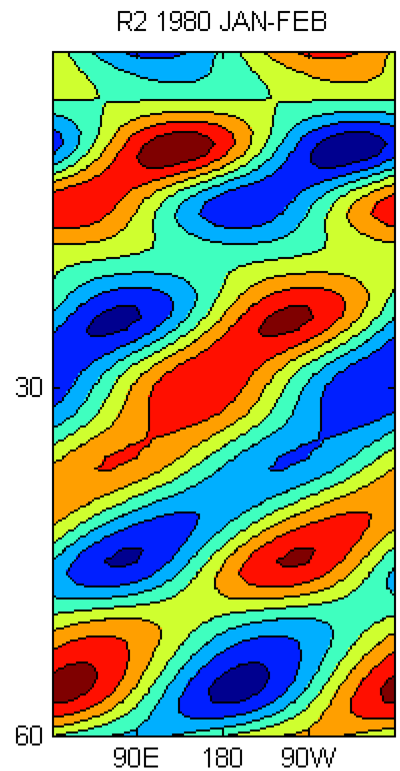
Hovmoller diagram
250 hPa Z'

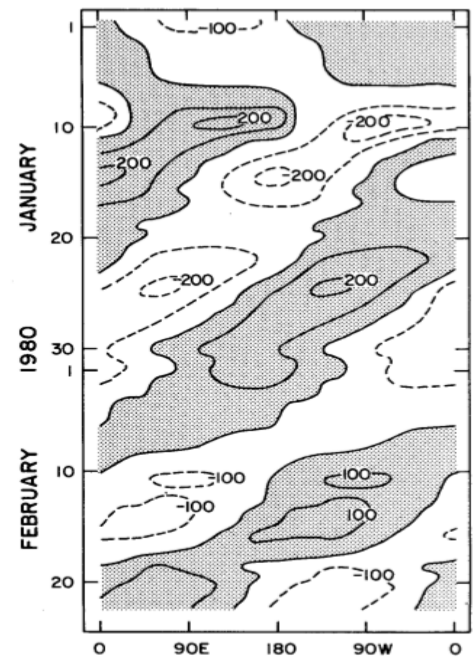
Has a strong seasonal cycle: Larger amplitude in N.H. winter
(Madden and Speth 1989)

Analysis of submonthly waves

- Use daily 250 hPa height data for both CWB-AMIP and NCEP R-2
- Take Z250 along the 60N latitude circle for the analysis
- Construct "daily climatology" from 28 years of daily data, then use the sum of the annual mean + first 3 harmonics in time (annual, semiannual, & triannual modes) as the mean seasonal cycle.
- Define the daily anomaly as the departure from the smoothed mean seasonal cycle
- Run a 8-30 day band pass filter on the daily data through the entire 28-year period. Discard end points. (Keep only 1980-2005 for convenience.)
- Perform Fourier analysis in longitude to extract zonal wave-1, wave-2, etc., components of Z250 at 60N

Example of Hovmoller diagram for Wave-1, January-February 1980 from NCEP R-2; quick check with Madde & Speth (1989)



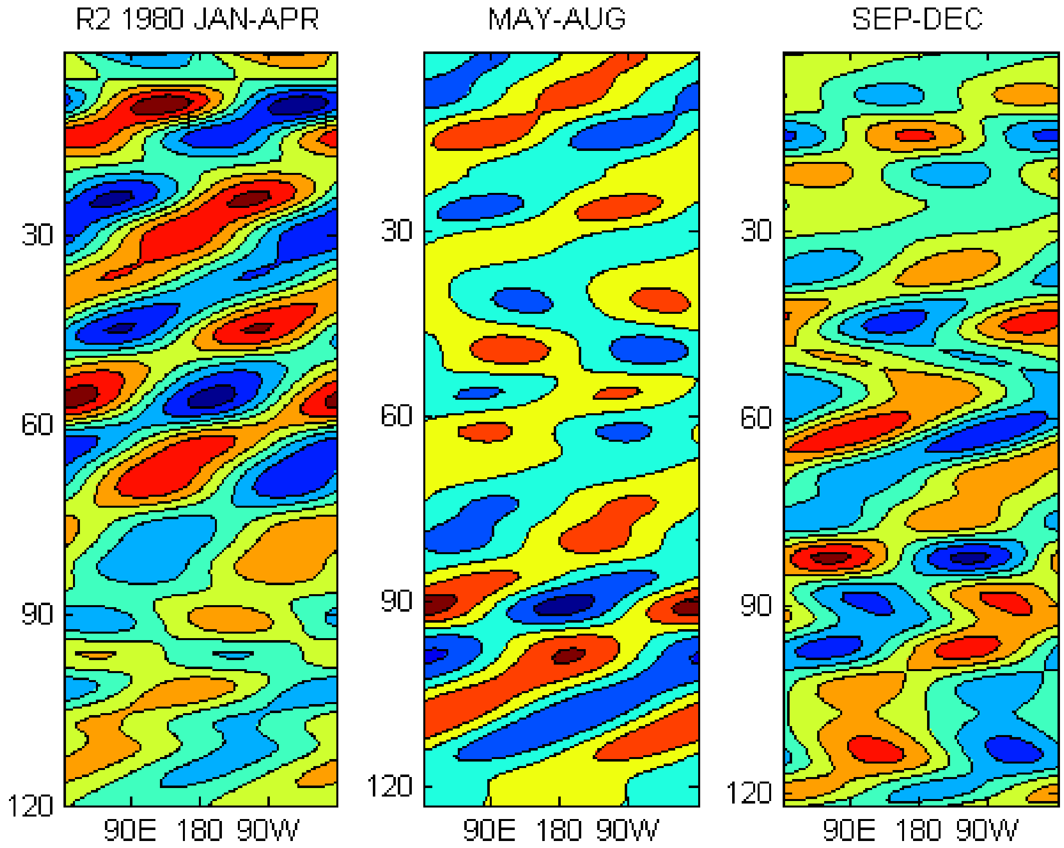


NCEP R-2

contour interval = 50 m
blue is negative

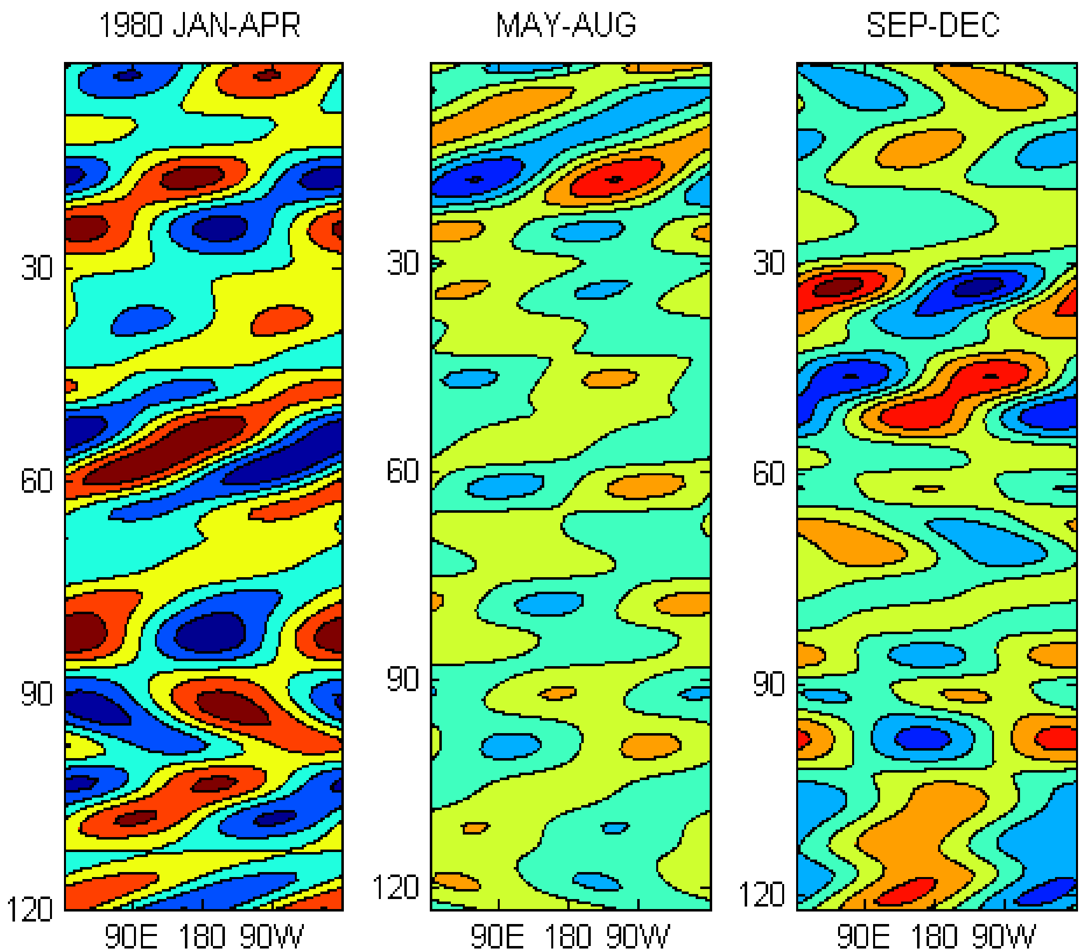
Madden & Speth (1989)

Hovmoller diagram for 1980 (all year), Wave-1, NCEP R-2



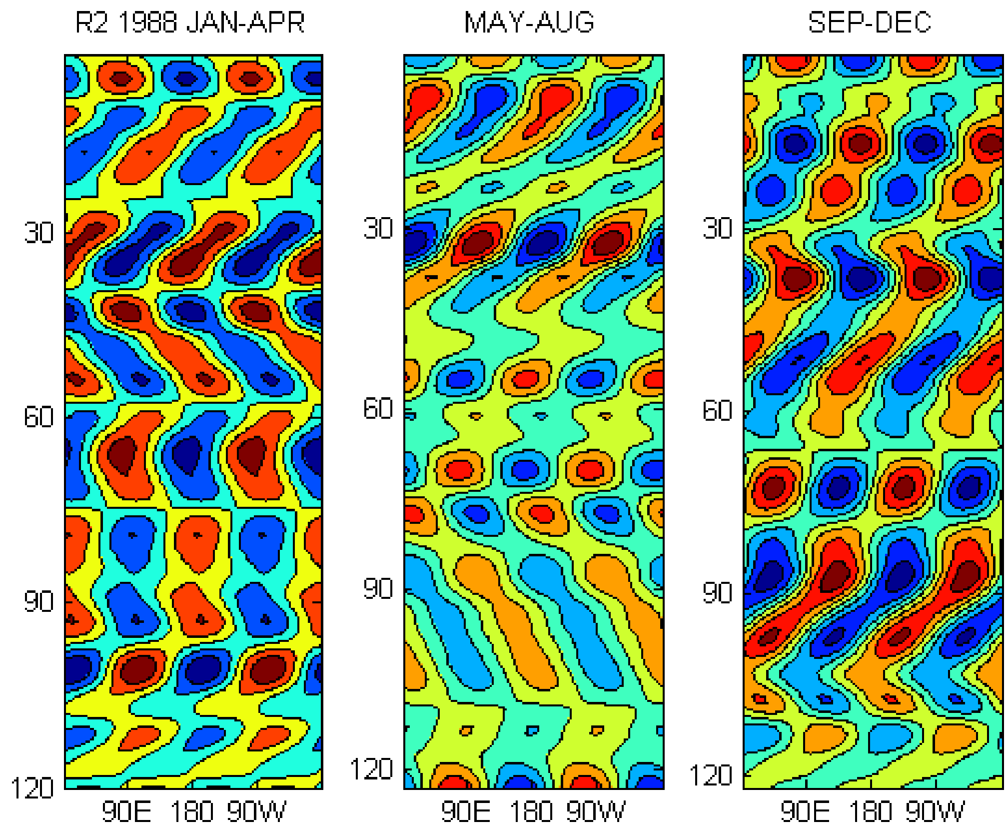
Contour interval = 50 m (blue negative)

Hovmoller diagram for 1980 (all year), Wave-1, CWB AMIP



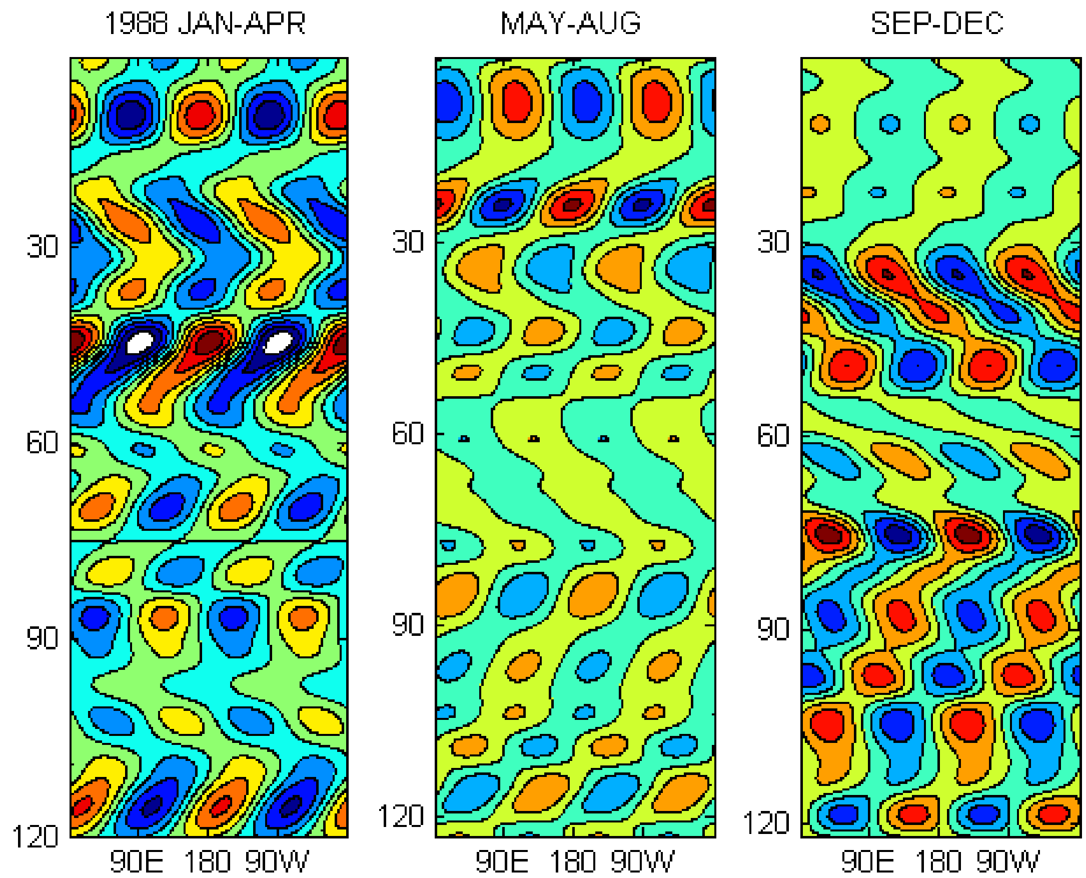
Contour interval = 50 m (blue negative)

Hovmoller diagram for 1988 (all year), Wave-2, NCEP R-2



Contour interval = 50 m (blue negative)

Hovmoller diagram for 1988 (all year), Wave-2, CWB-AMIP



We don't expect the AMIP run to reproduce the observed daily/weekly detail of the individual retrograde wave events, but what about the statistics?

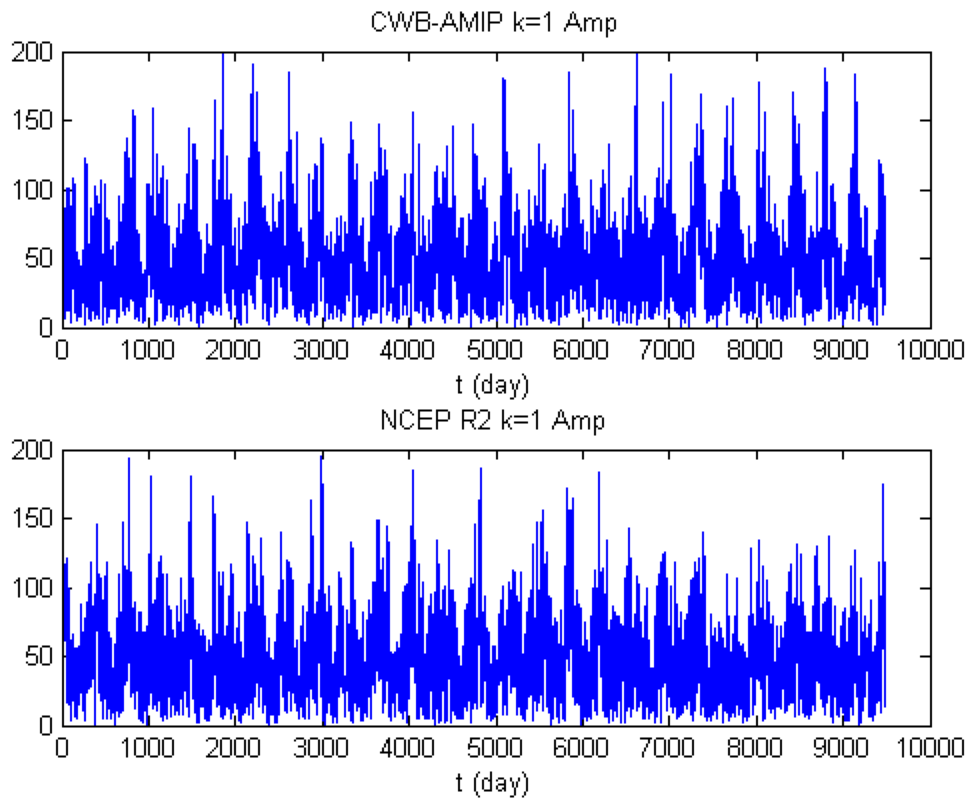
To validate the statistics of submonthly (8-30 day) variability:

1. Calculate the daily amplitude of Wave-1, Wave-2, etc.

2. Calculate the monthly mean of the quantities in (1)

3. Use the monthly mean in (2) as the basis for comparison between CWB-AMIP and NCEP R-2

Daily time series of the amplitude of Wave-1, Z250 at 60N
(8-30 day band pass filtered as before)   1980-2005



CWB-AMIP

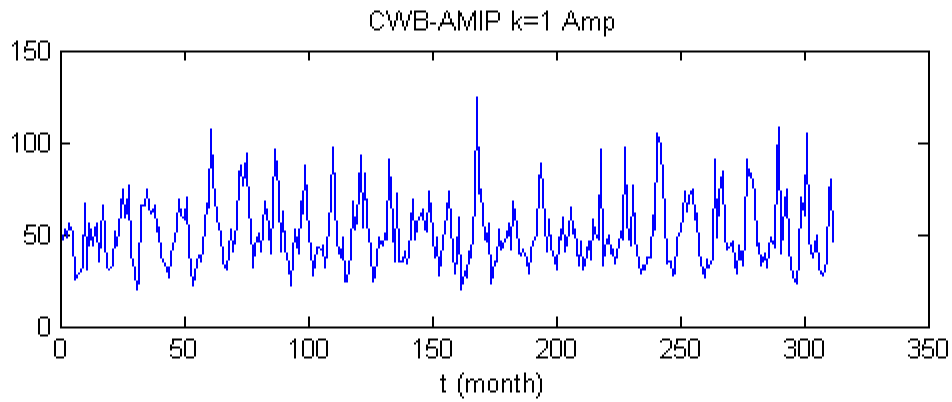
NCEP R-2

(Z' in meters)

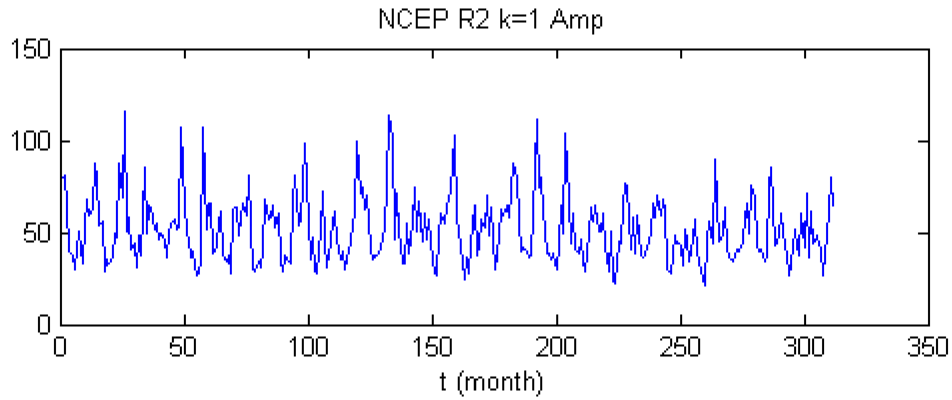
Amplitude of Wave-1 has a clear seasonal cycle in AMIP and in reanalysis

Retrograde long waves are stronger in winter; consistent with Madden and Speth (1989)

Monthly mean of daily amplitude of Wave-1 Z250 at 60N 1980-2005

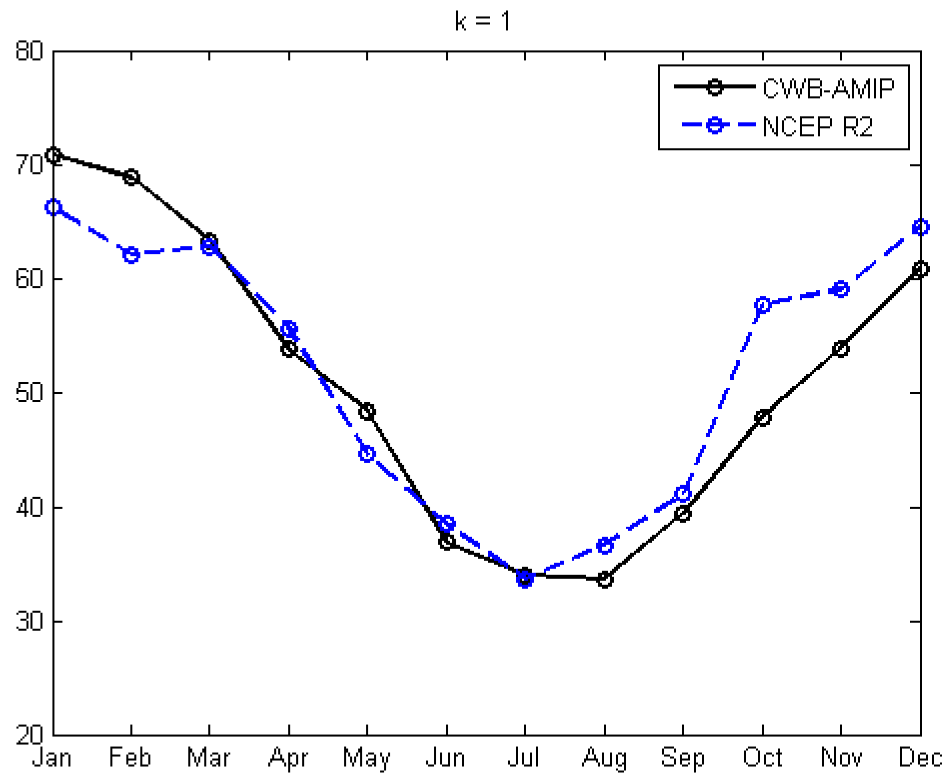


CWB-AMIP



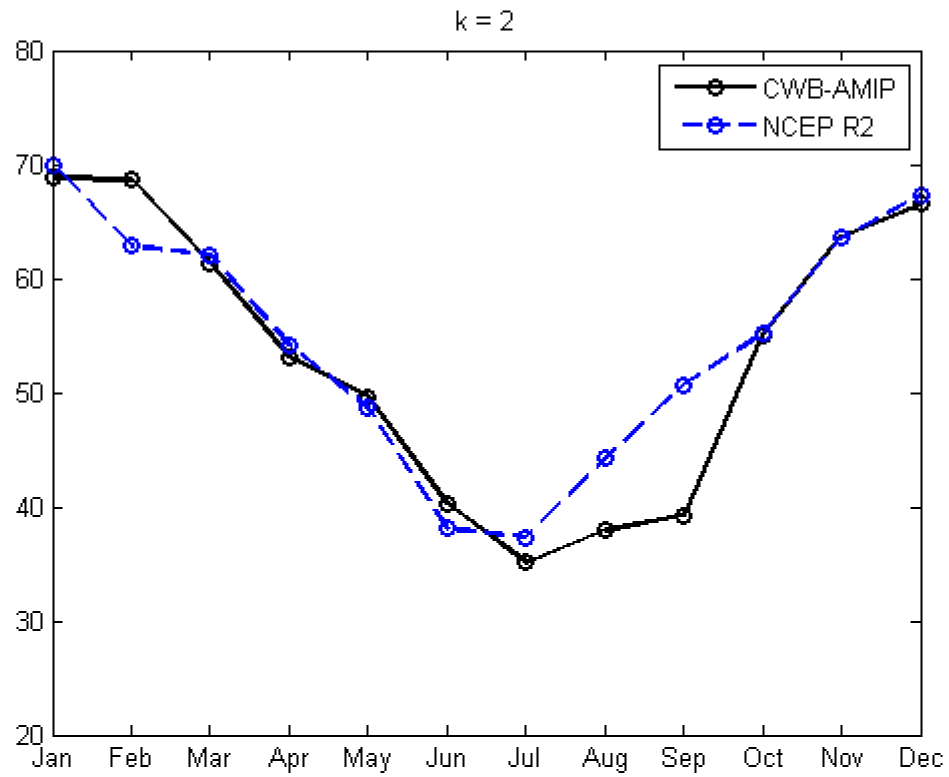
NCEP R-2

Monthly-mean of the amplitude of Wave-1, averaged over 1980-2005



CWB-AMIP reproduced the observed seasonality of the amplitude of submonthly traveling waves quite well.

Monthly-mean of the amplitude of Wave-2, averaged over 1980-2005

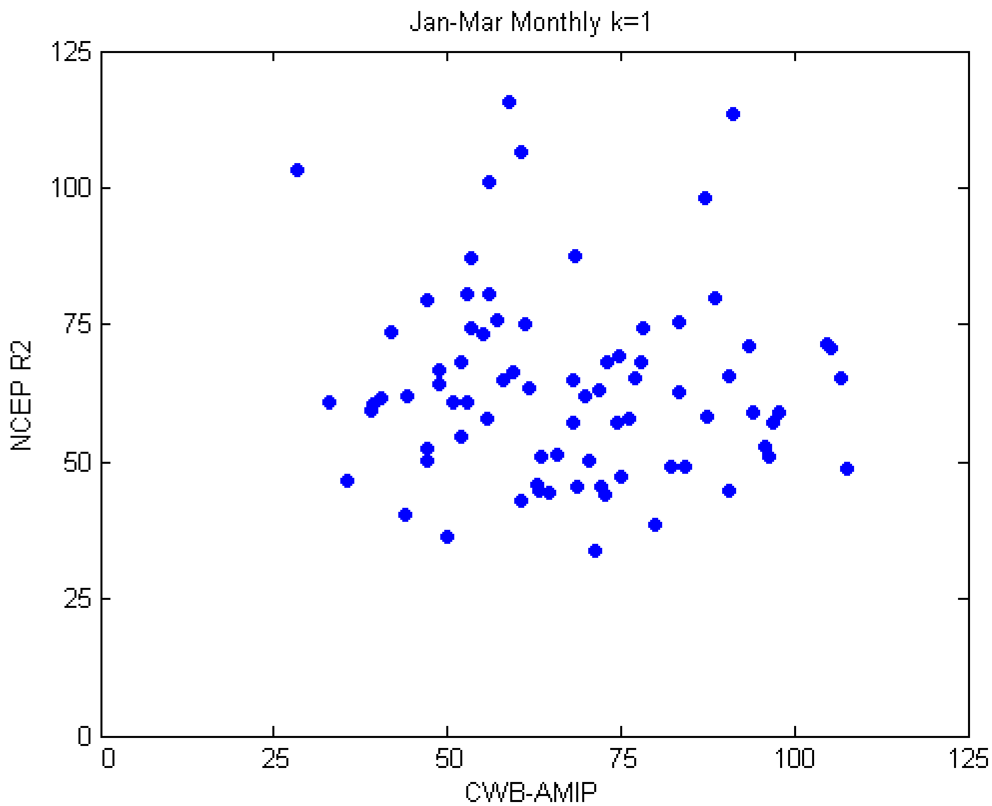


Since the AMIP run was forced by the observed SST with only monthly resolution, it is not trivial that the AMIP run reproduced the seasonal dependence of the submonthly variability.

What about the interannual variability of the submonthly waves?

This would be a more stringent test since the interannual variability of SST is much weaker in amplitude than the seasonal cycle itself.

Monthly mean of the amplitude of Wave-1, January-March only
CWB-AMIP vs. NCEP R-2



The interannual variability of the wintertime amplitudes of Wave-1 for CWB-AMIP and NCEP R-2 are not significantly correlated

Summary of validation, CWB AMIP run vs. Reanalysis

250 hPa height, climatology	Good agreement
250 hPa height, individual months	Notable differences exist for some months
Decadal-to-interdecadal variability & trend of atmospheric angular momentum	Good agreement with the majority of reanalyses; *Notable differences exist among the reanalyses*
Interannual variability of tropical tropospheric temperature	Good agreement
ENSO variability of 250 hPa height	Reasonable agreement with some bias
Seasonal cycle of the amplitude of submonthly variability	Good agreement
Interannual variability of the amplitude of submonthly variability	Not reproduced in AMIP run

Future directions for further validation

1. More in-depth analysis of model bias in interannual variability (atmospheric response to ENSO)

2. Intraseasonal variability

3. Regional monsoonal circulation/precipitation
   -- A stringent test. The majority of CMIP models are known to have substantial biases in monsoon circulation and rainfall (e.g., Lin et al. 2008, Baker and Huang 2012, for N. American monsoon)
   -- Could focus on Asian and East Asian monsoon

4. Statistics for the phase (in addition to amplitude) of submonthly waves

Thank you.