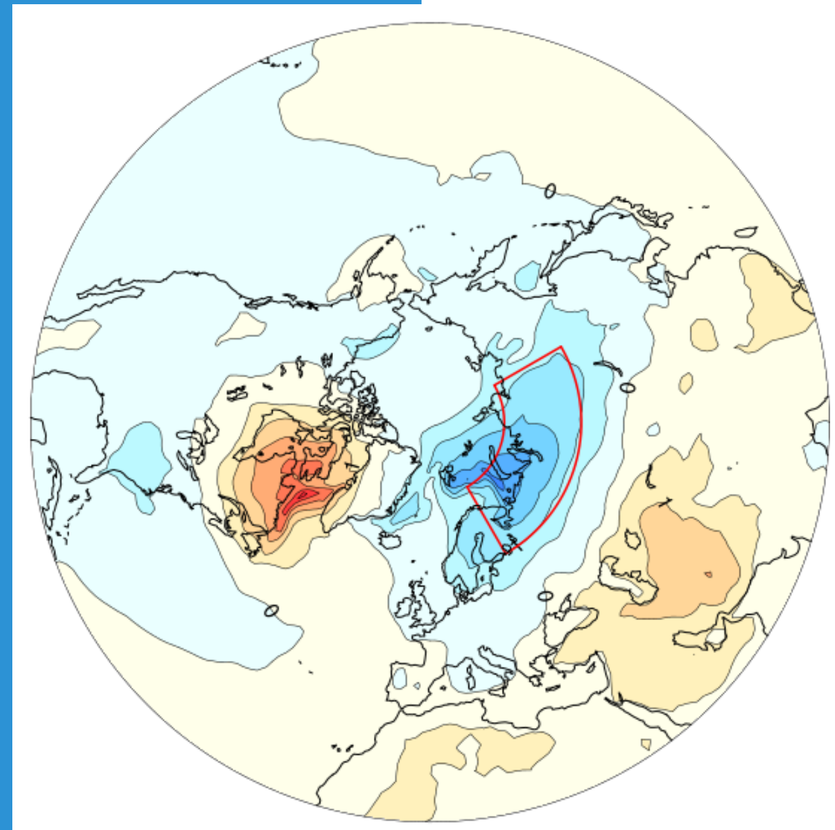


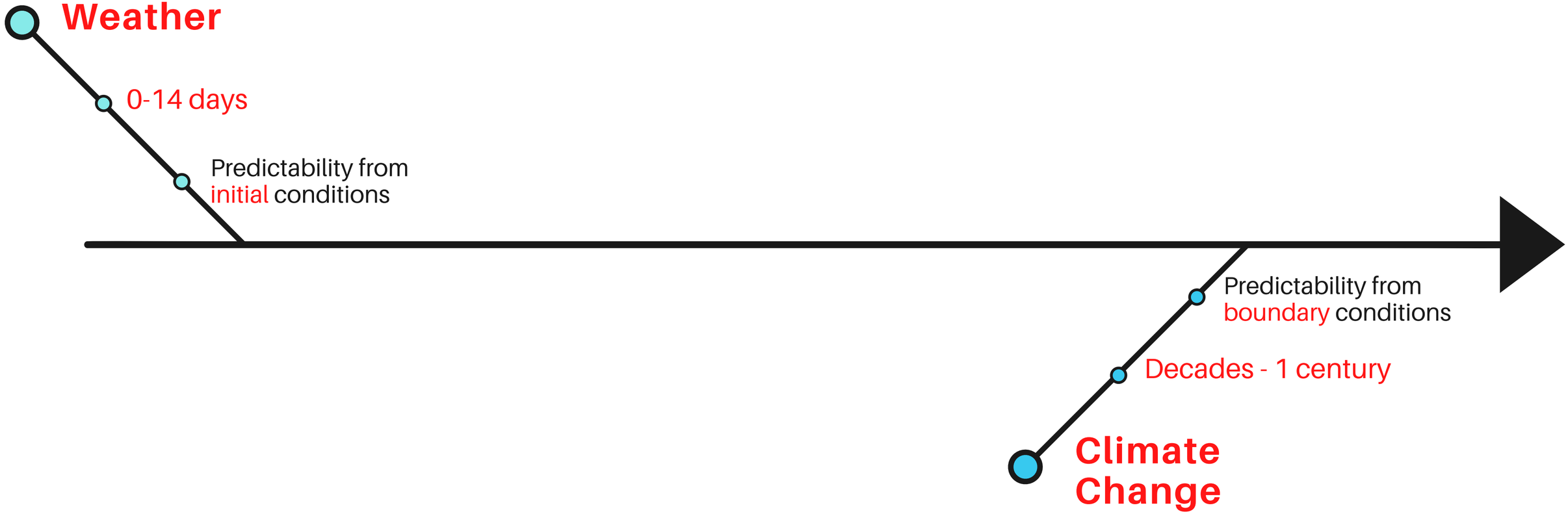
Using Climate Models to Understand Stratosphere-Troposphere Interaction

JESSICA OEHRLEIN

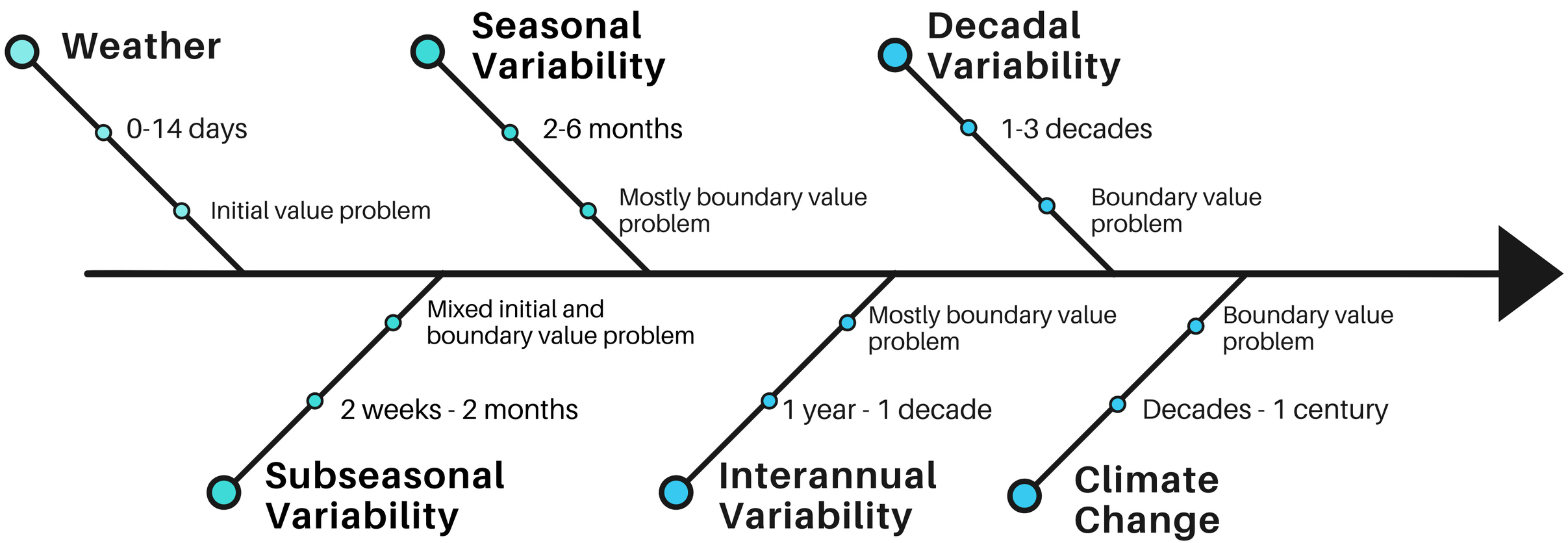
Joint work with Gabriel Chiodo and Lorenzo Polvani

What do you think of when I say atmospheric science?

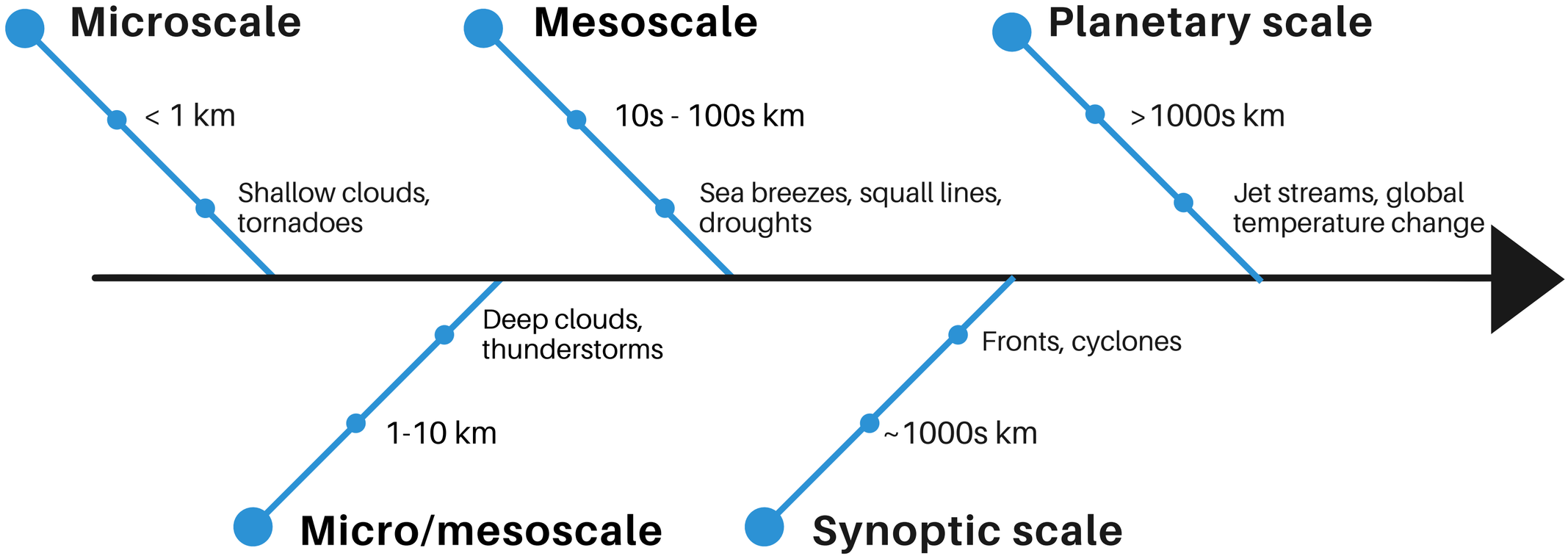
TIMESCALES IN ATMOSPHERIC SCIENCE



TIMESCALES IN ATMOSPHERIC SCIENCE



SPATIAL SCALES IN ATMOSPHERIC SCIENCE



INTERACTIONS

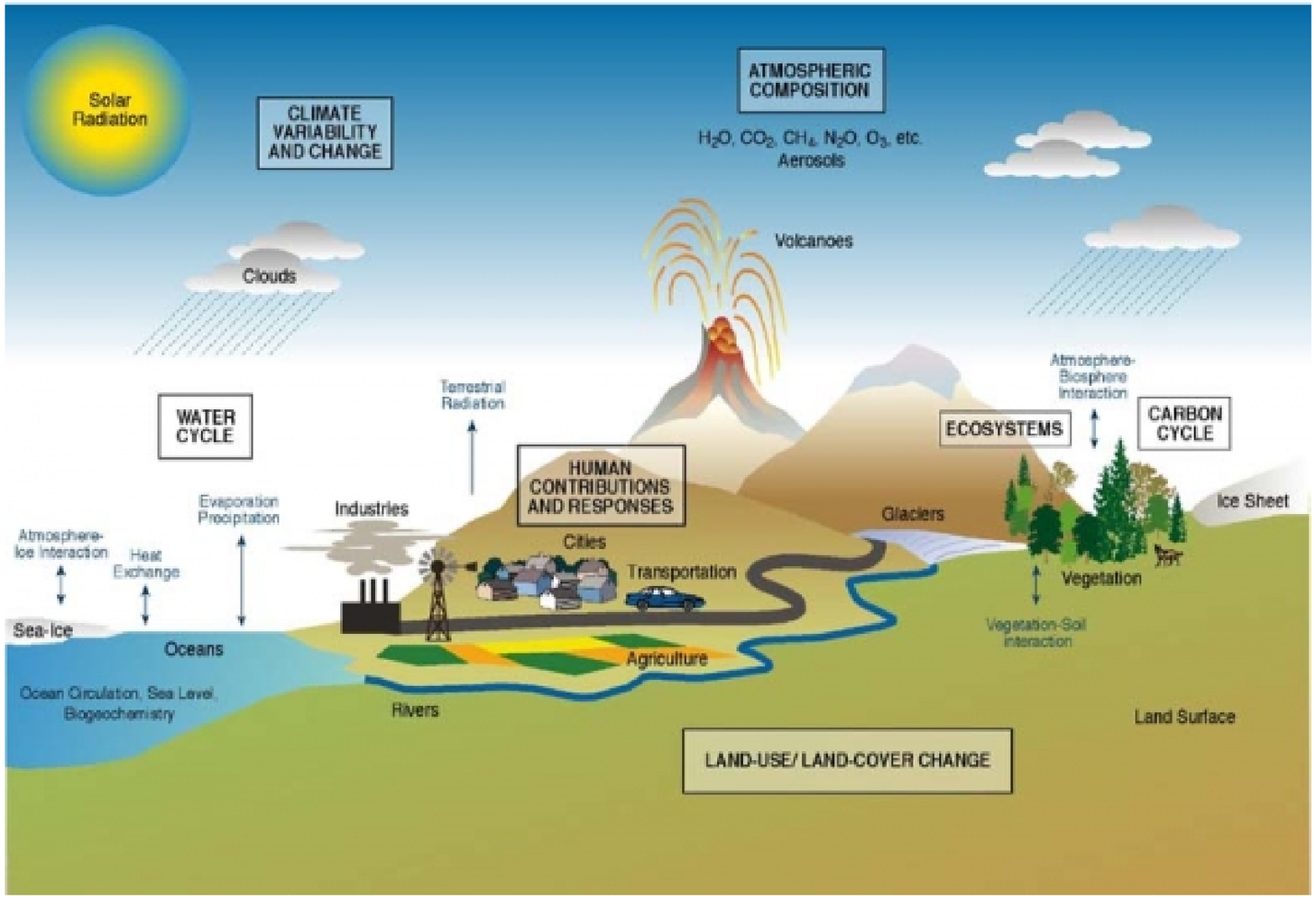


Image from Our Changing Planet 2004

WHAT TOOLS DO WE HAVE?

- Observations
  - Communities' longterm knowledge of their environment
  - Weather stations, weather balloons
  - Ships, planes, dropsondes
  - Satellites

- Reanalysis: observations assimilated into models

- Weather and climate models

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- Reanalysis: observations assimilated into models

- Weather and climate models
  - Prediction
  - Understanding mechanisms
  - Disentangling related processes

A FEW TYPES OF MODELS

CONCEPTUAL MODEL

A minimal model to understand a single phenomenon

LARGE EDDY/ CLOUD-RESOLVING

High spatial and time resolution model for clouds, convection, etc.

GENERAL CIRCULATION MODEL

Large-scale model of the fluid dynamics and thermodynamics of the atmosphere

EARTH SYSTEM MODEL

Connects models of atmosphere, ocean, land, and ice systems

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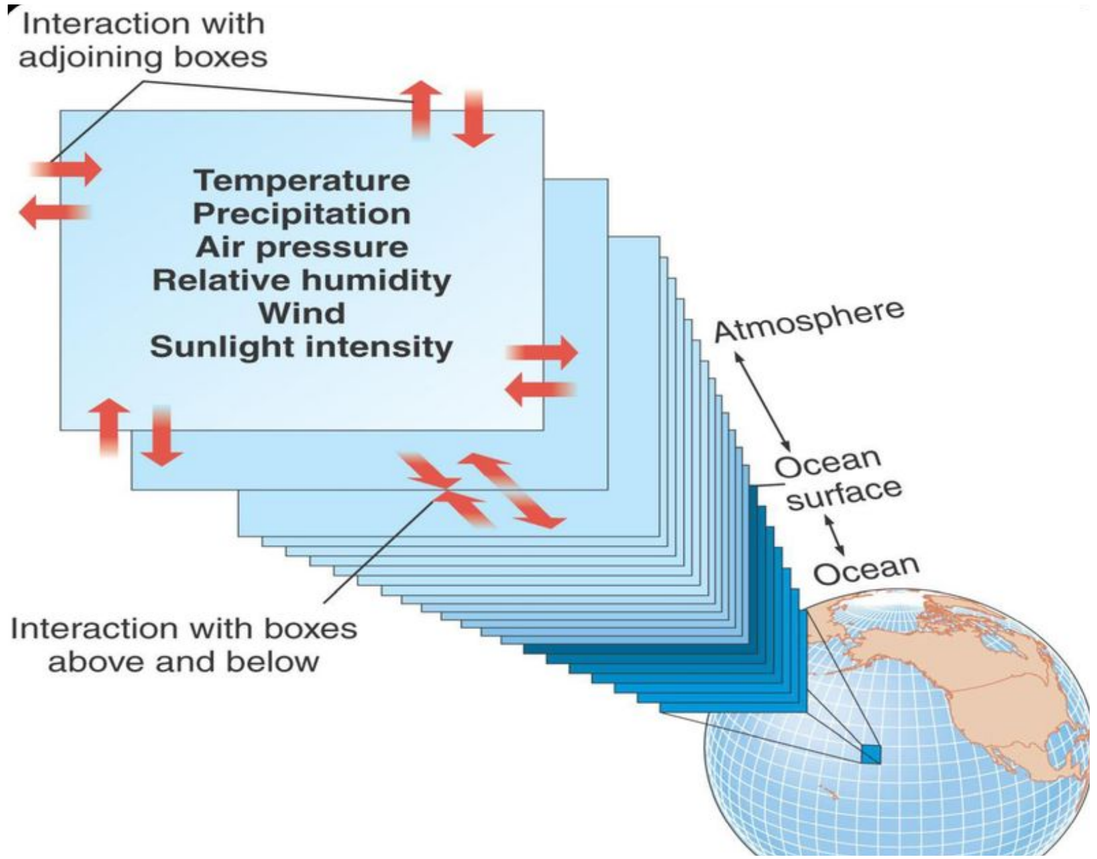
GENERAL CIRCULATION MODEL

What's in a General Circulation Model:

- Ideal gas law (diagnostic equation relating thermodynamic fields)
- Temperature tendency (energy conservation)
- Wind tendencies (momentum conservation)
- Continuity equations (local mass conservation)
- Parametrized physics for other processes
- A *lot* of numerics



GENERAL CIRCULATION MODEL

Horizontal momentum equation:

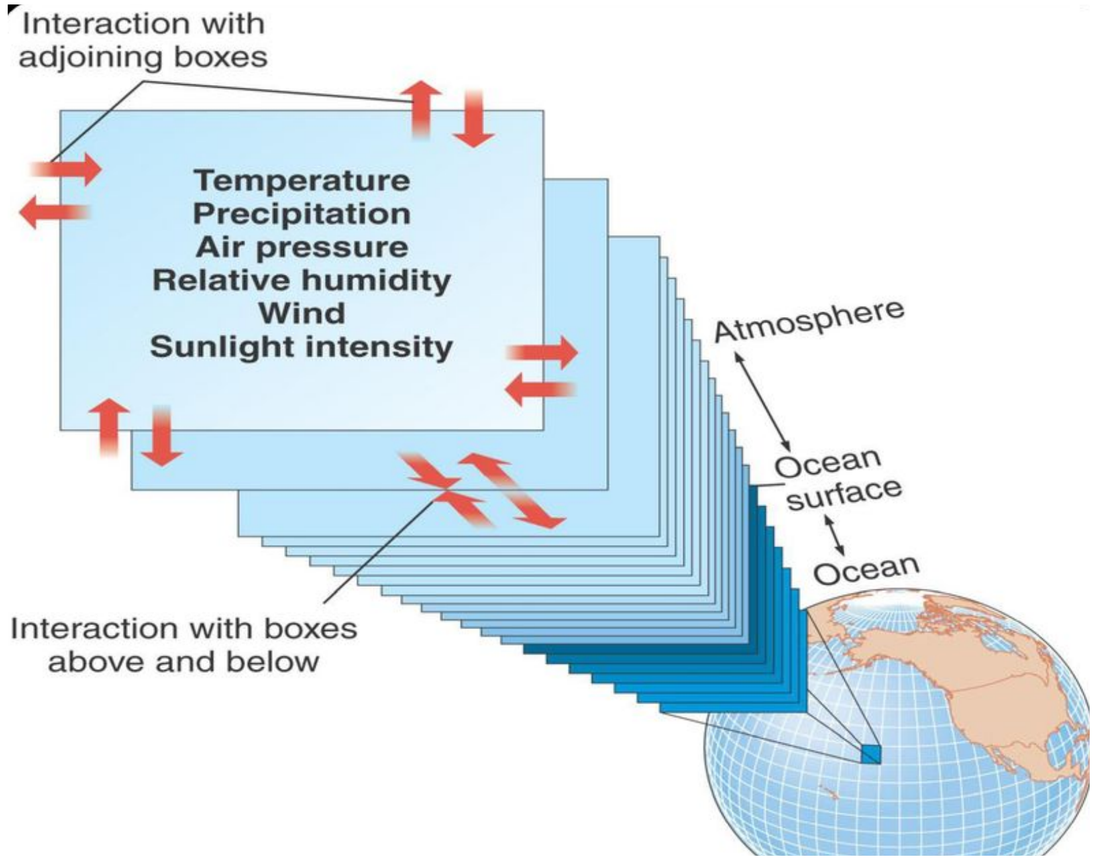
$$\frac{D\vec{u}}{Dt} = \vec{g} + \vec{f} - \frac{1}{\rho}\vec{\nabla}p - 2\vec{\Omega} \times \vec{u} - \vec{\Omega} \times (\vec{\Omega} \times \vec{r})$$

Total derivative of wind

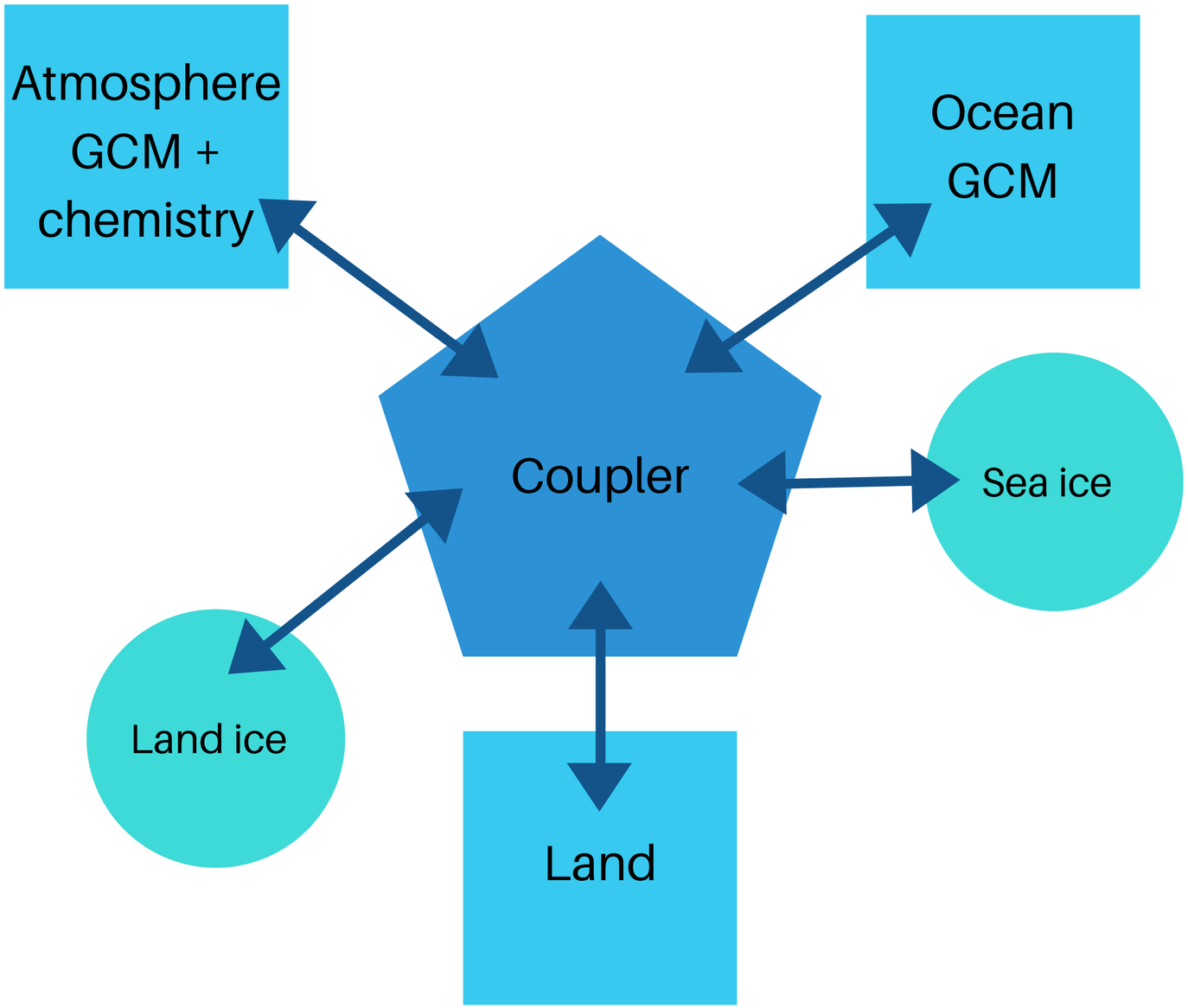
friction and pressure changes

Coriolis

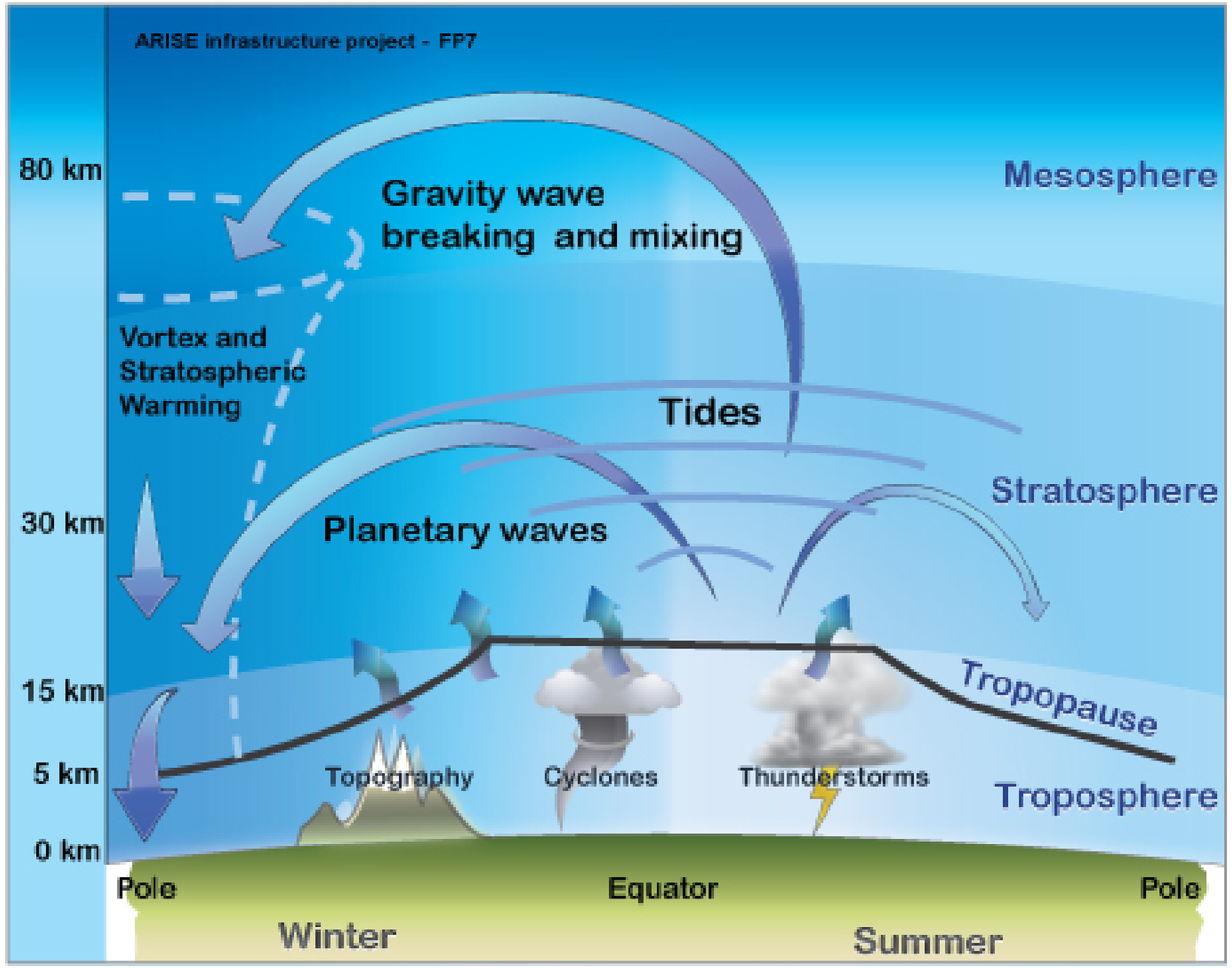
Gravity and centrifugal force (adjusted gravity)



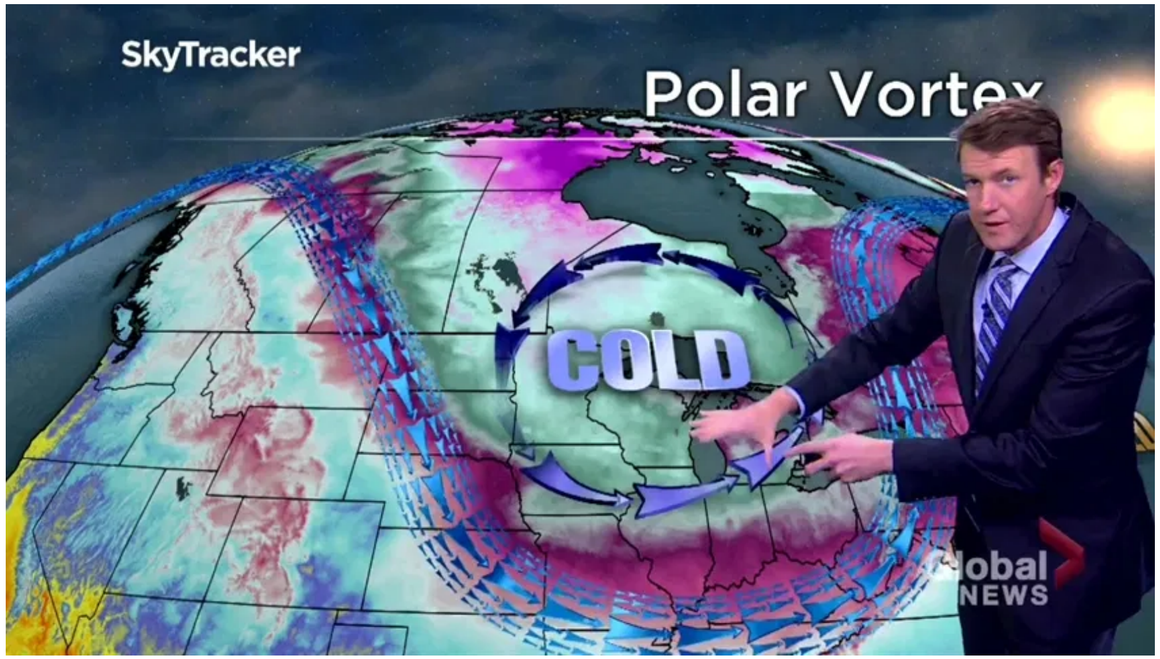
EARTH SYSTEM MODELS



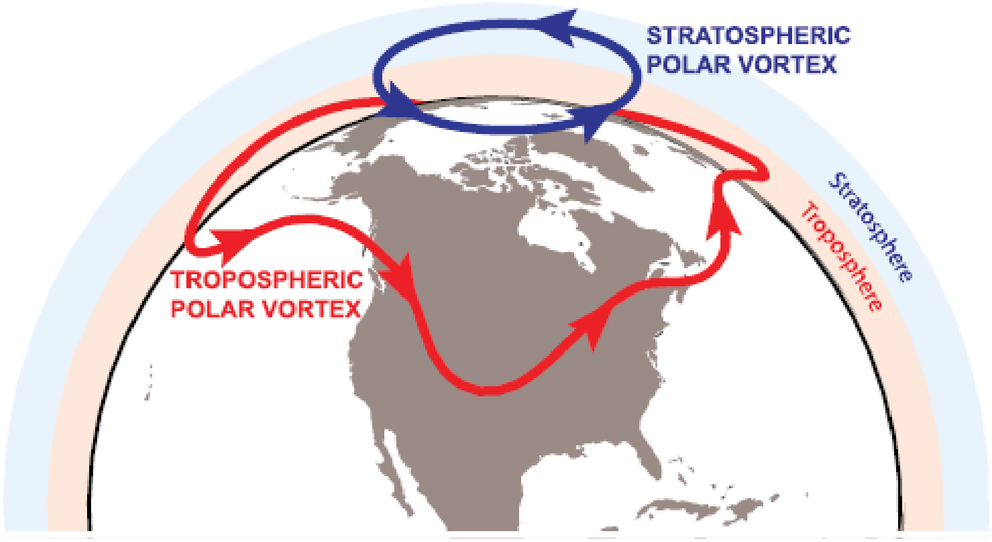
TROPOSPHERE AND STRATOSPHERE



POLAR VORTEX?



THE OTHER POLAR VORTEX



STRATOSPHERIC POLAR VORTEX

East/west wind averaged around latitude circles in December-February

Stratosphere:
~ 10-50 km

Troposphere:
~ 0-10 km

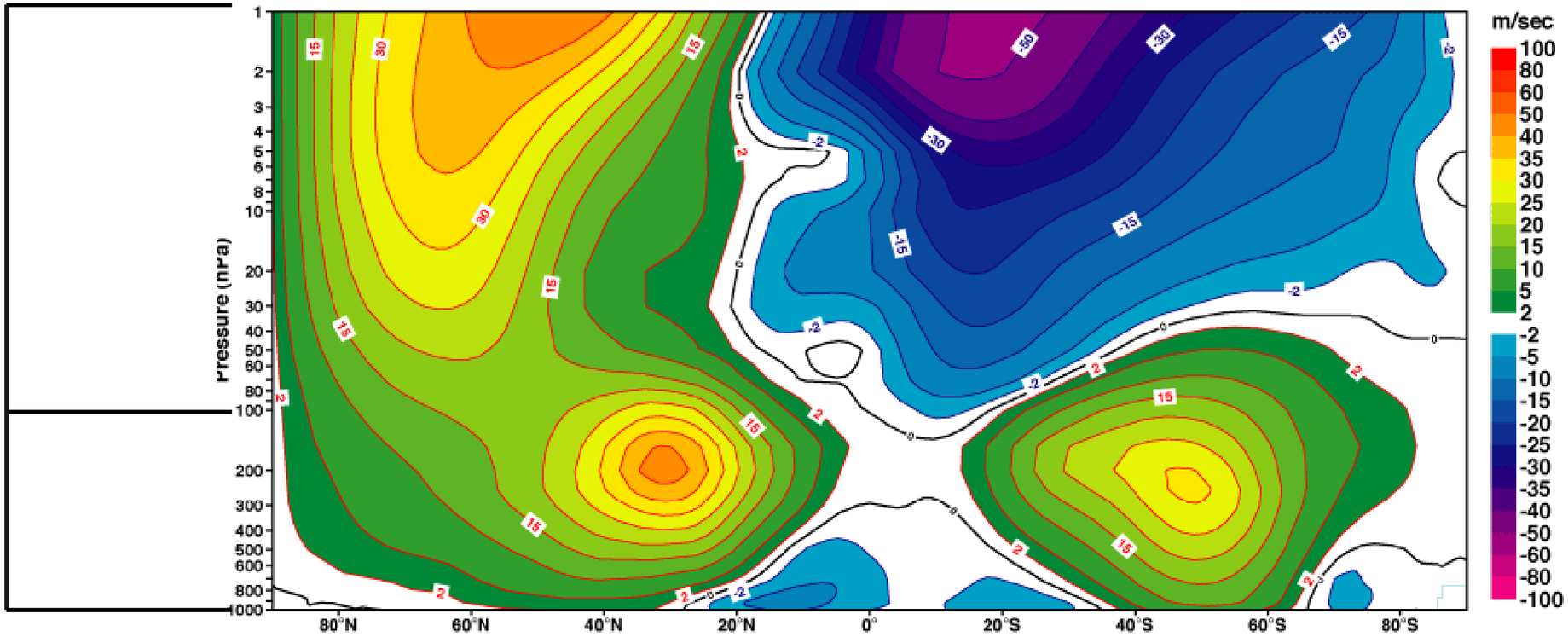


Image from ECMWF

Positive: west-to-east (westerly)
Negative: east-to-west (easterly)

STRATOSPHERIC POLAR VORTEX

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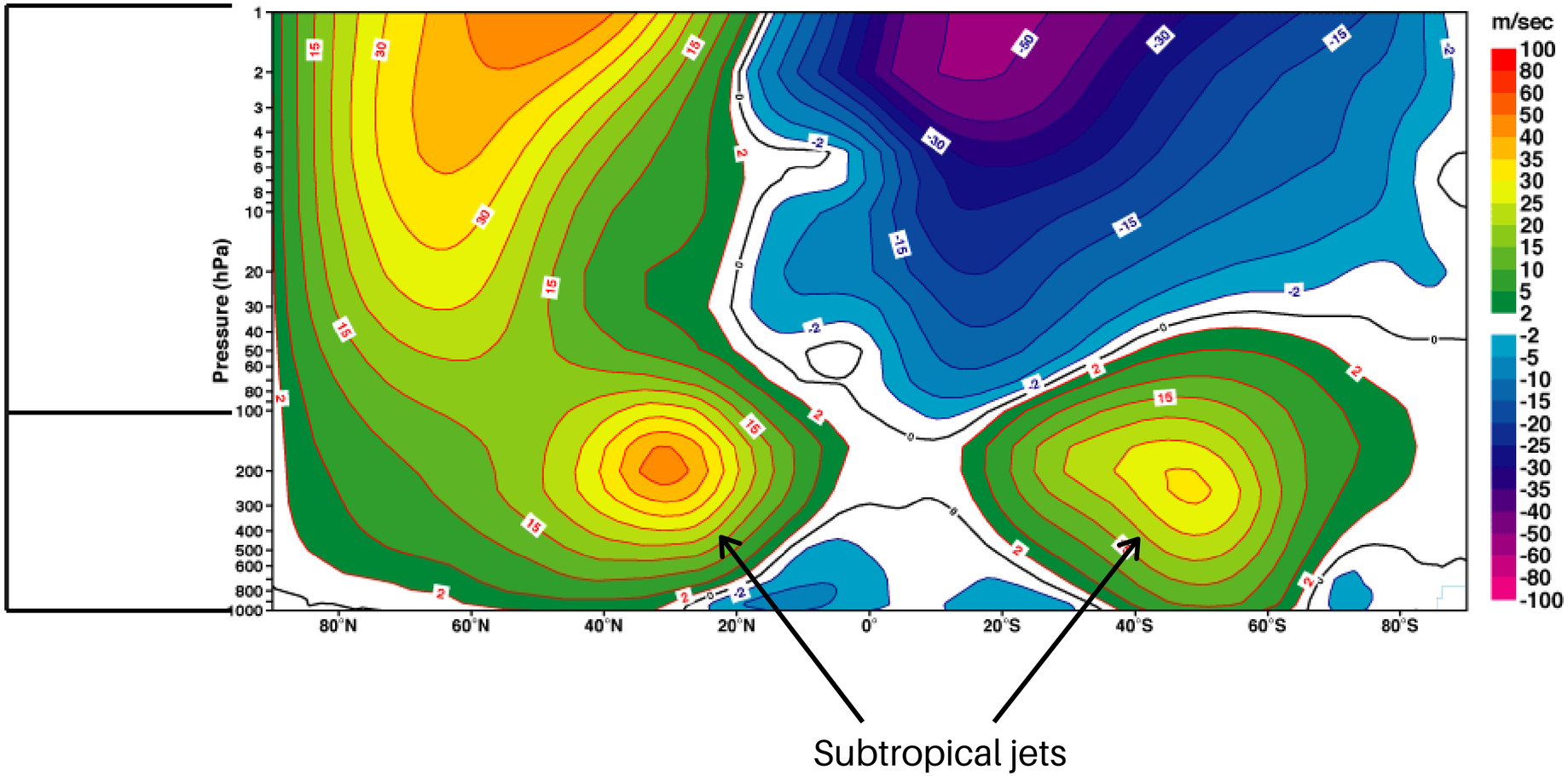
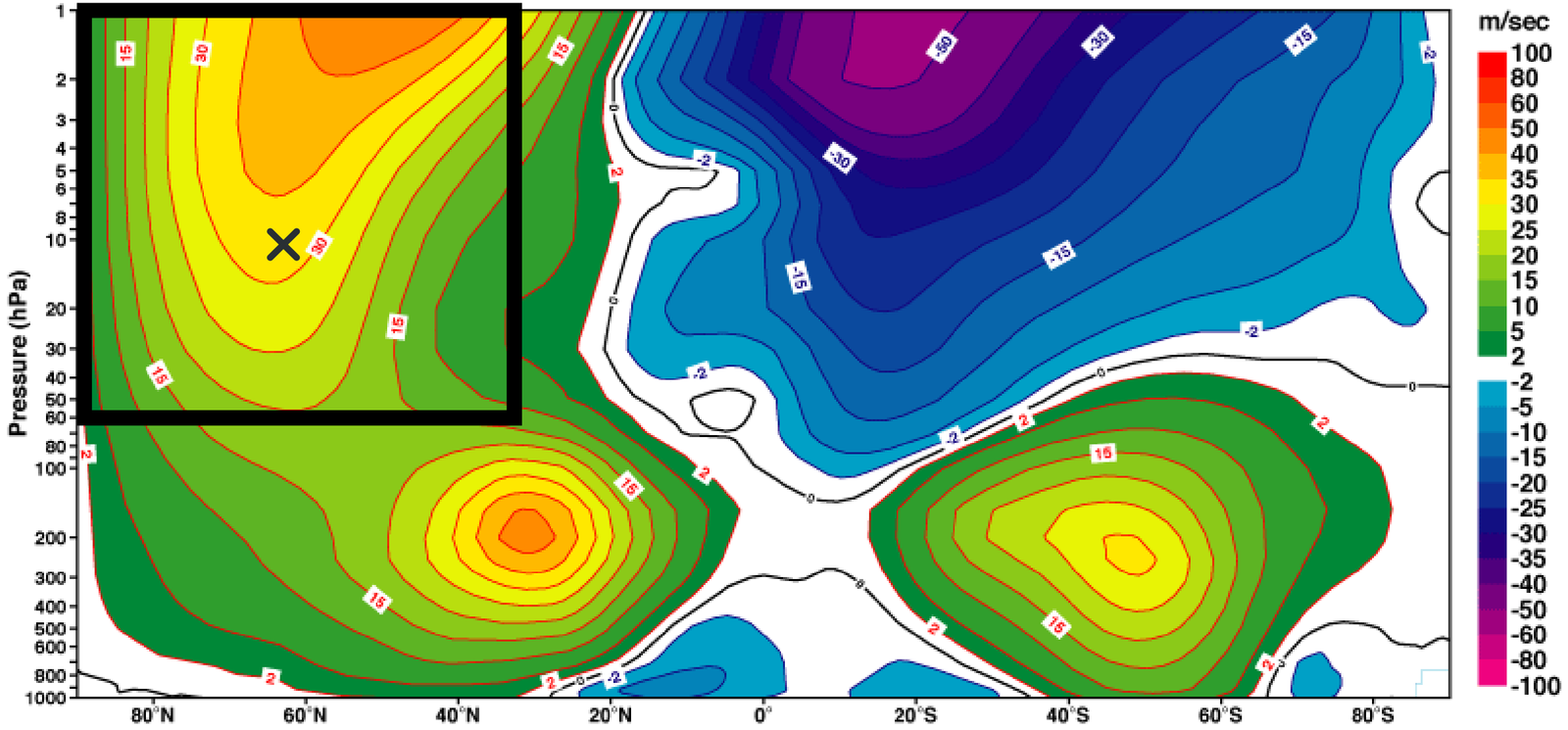


Subtropical jets

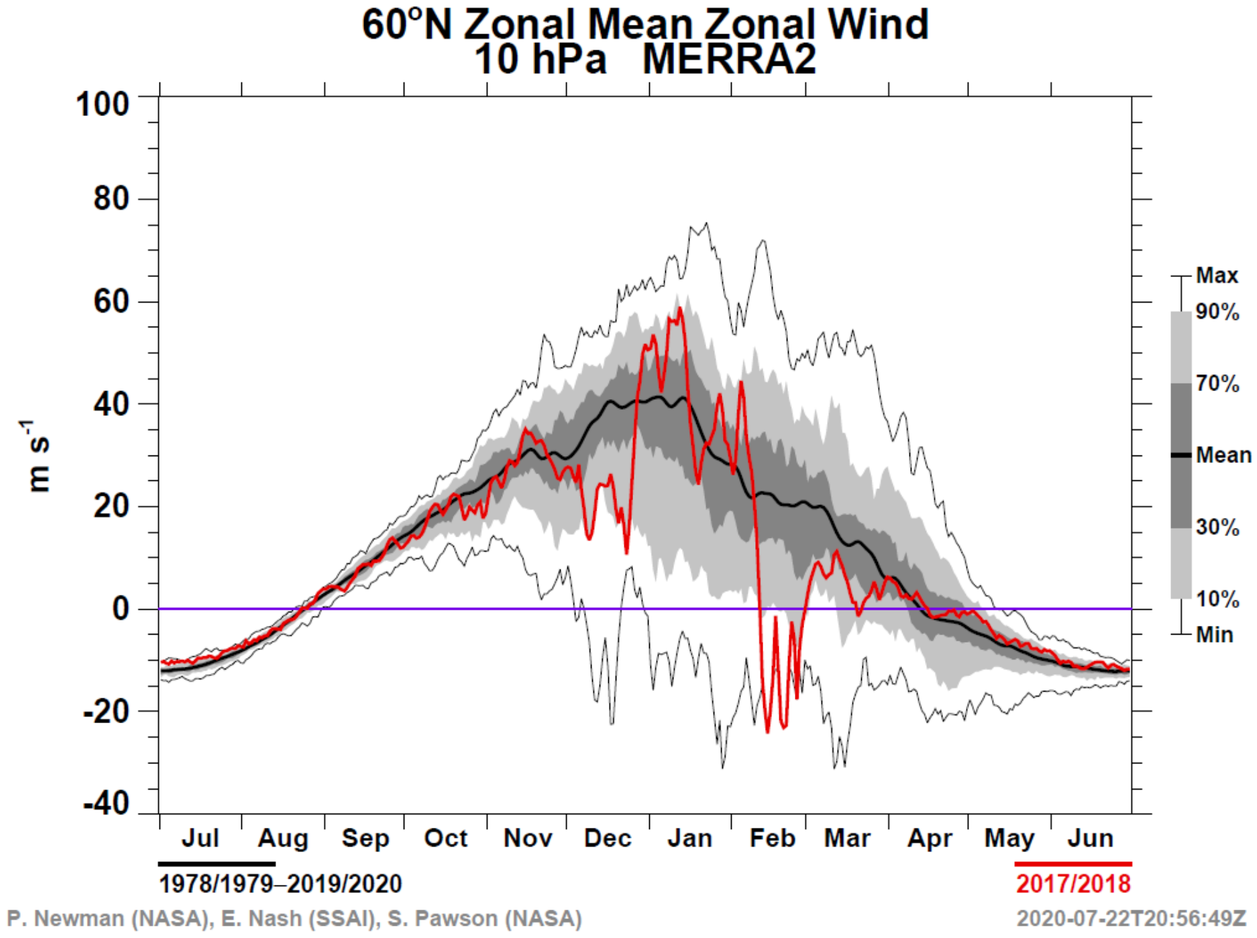
STRATOSPHERIC POLAR VORTEX

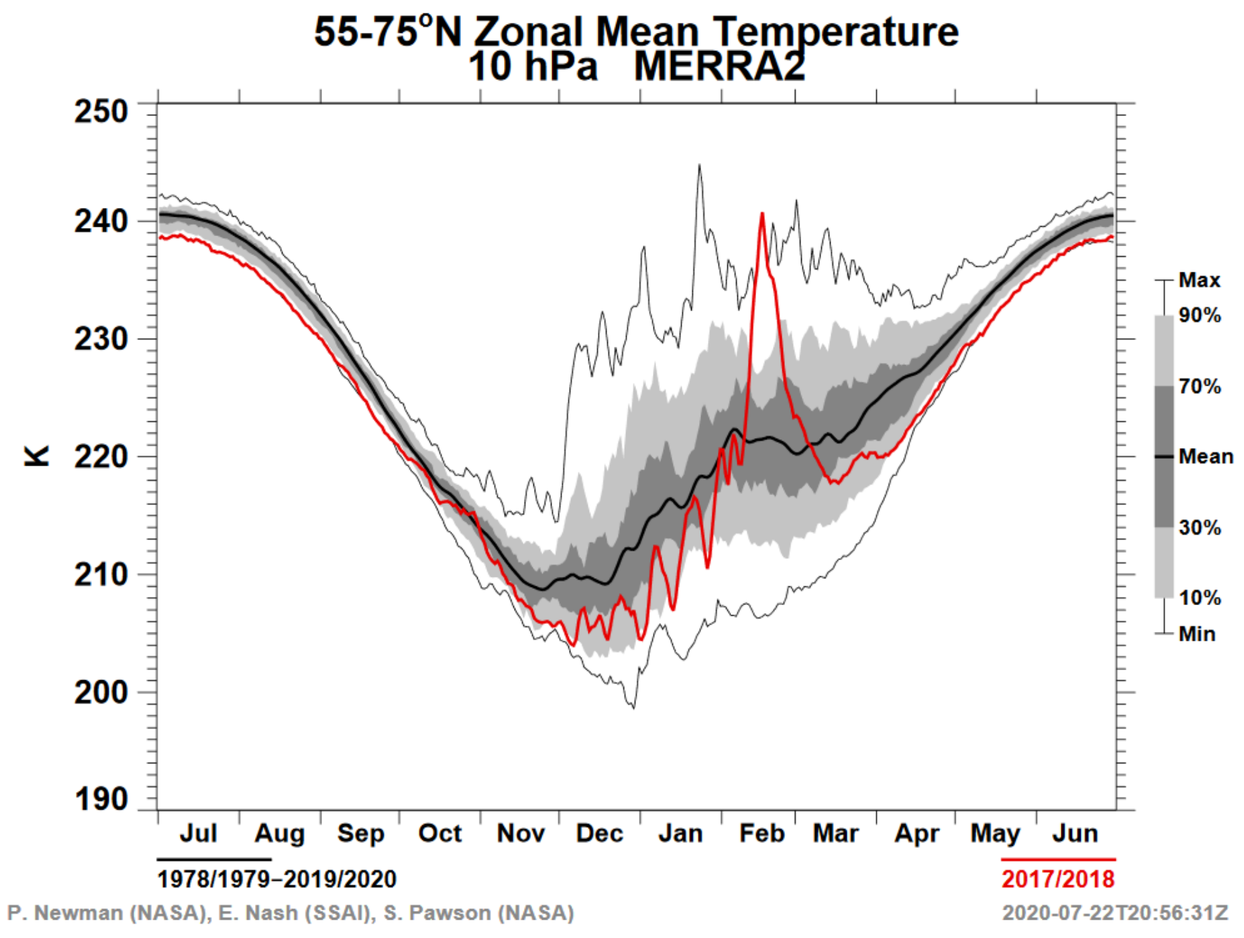
Stratospheric polar vortex: Region of strong westerly winds over the winter pole

East/west wind averaged around latitude circles in December-February



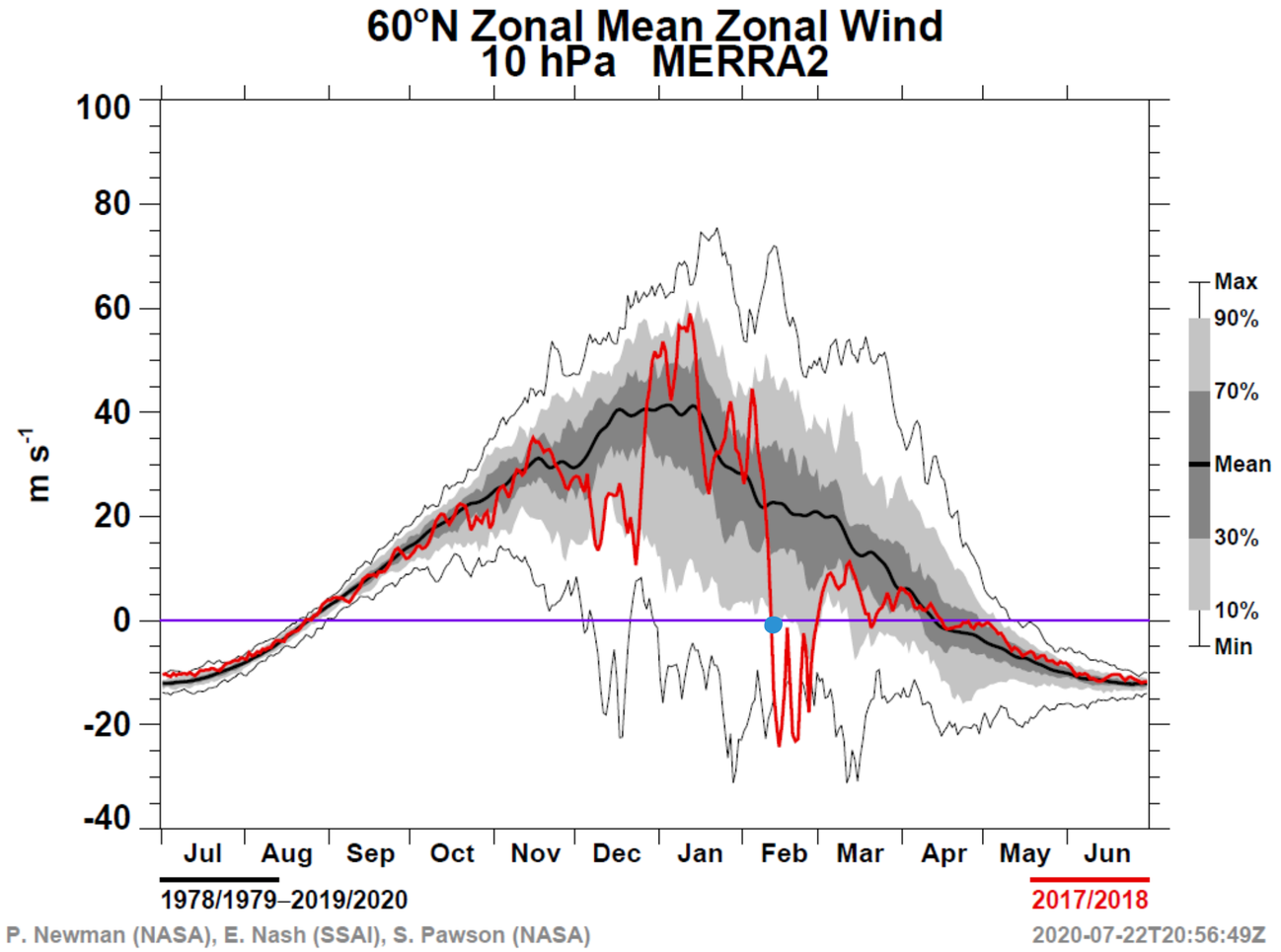
POLAR VORTEX EVOLUTION



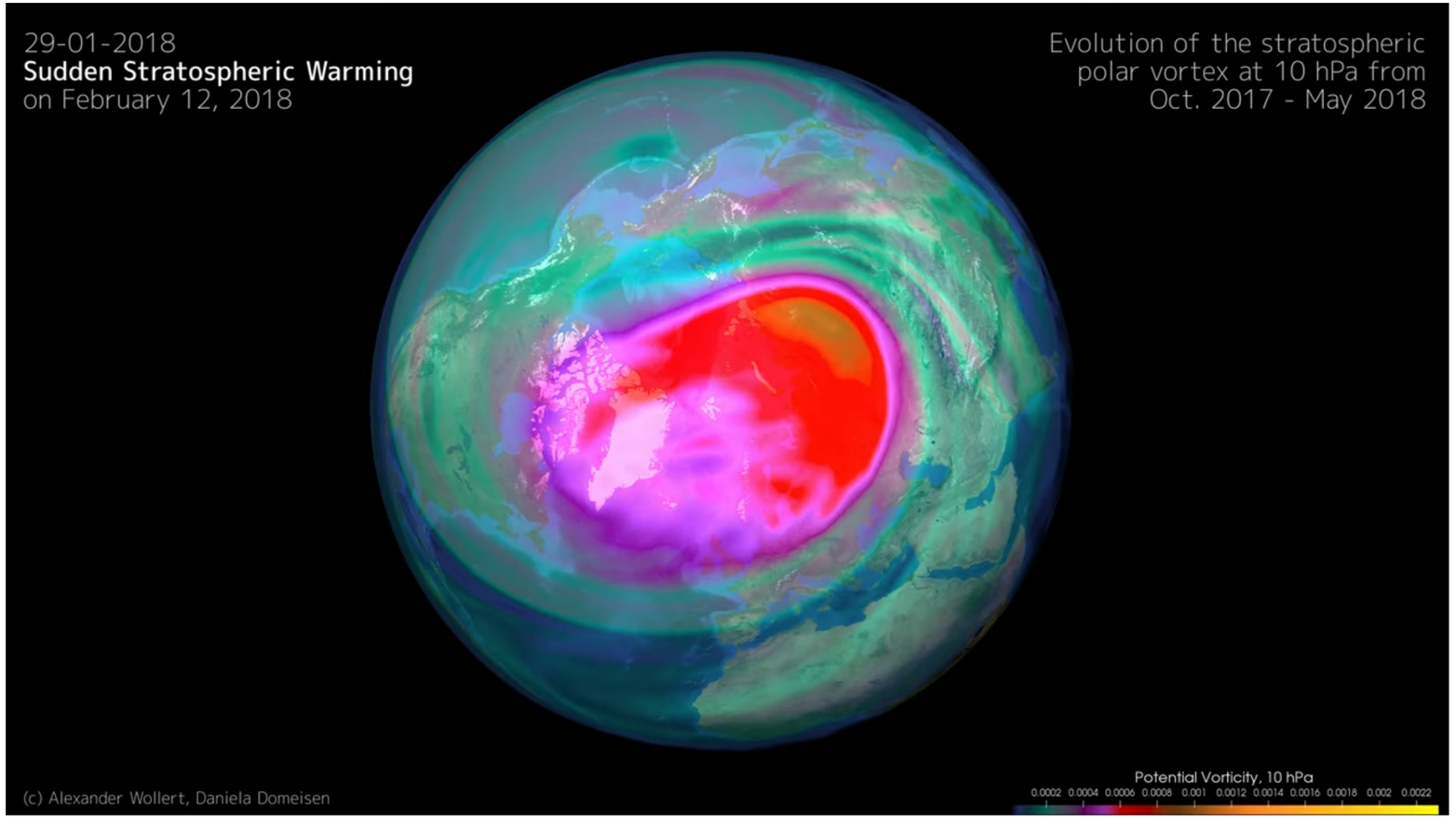


SUDDEN STRATOSPHERIC WARMING (SSW)

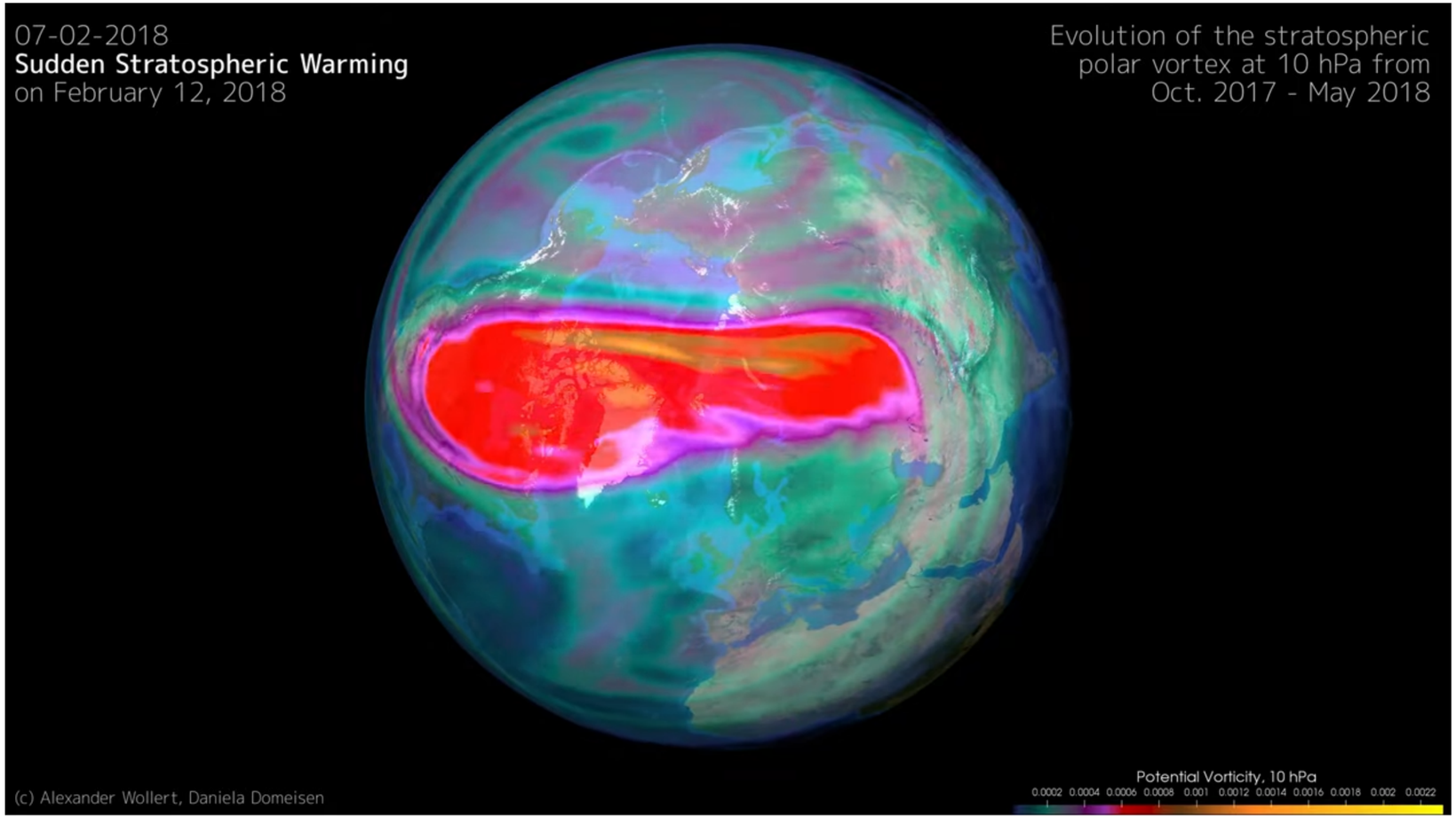
Sudden Stratospheric Warming:
A midwinter reversal in the direction of winds (from westerly to easterly) averaged at 60 N and 10 hPa



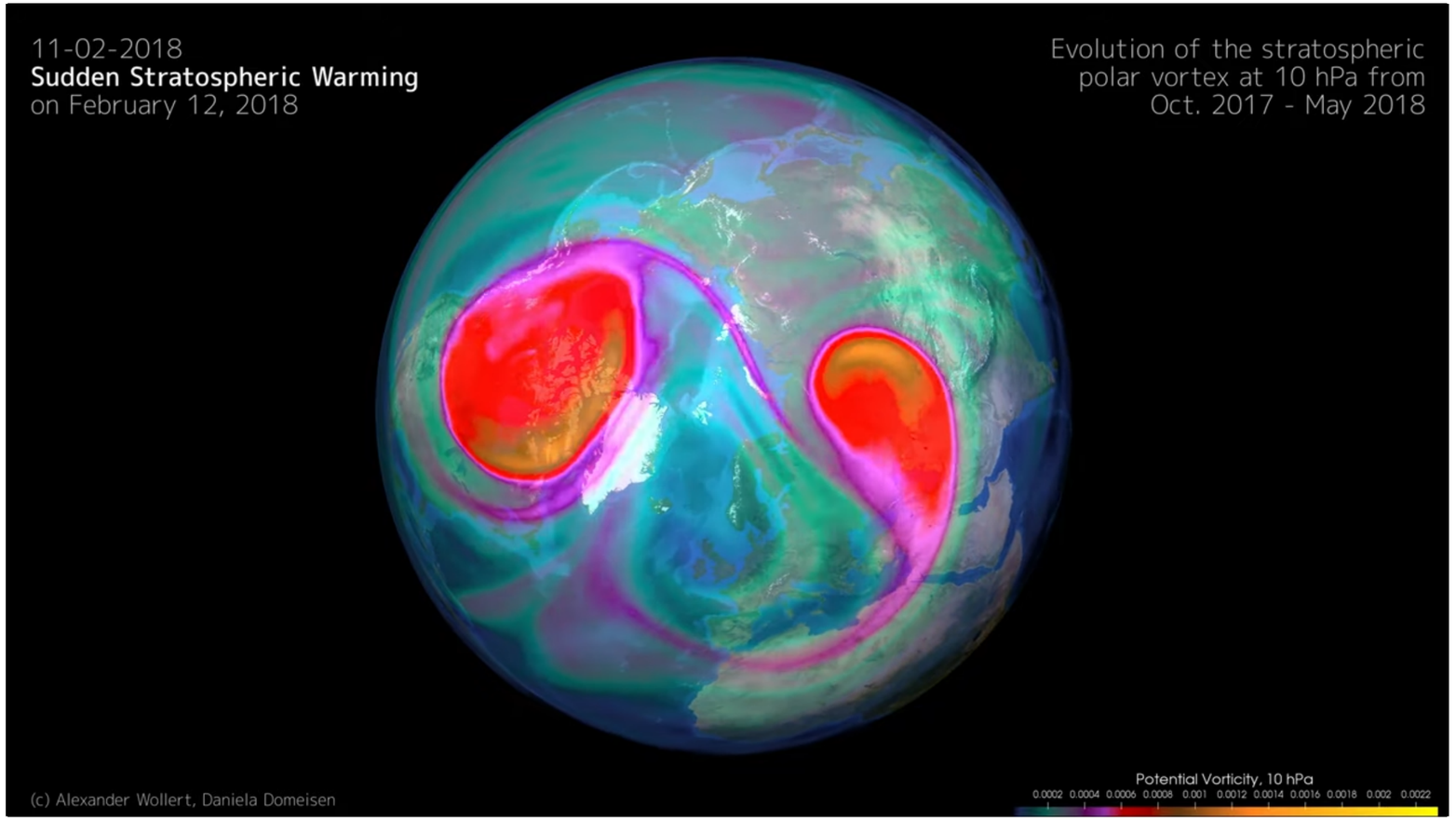
STRONG POLAR VORTEX



A FEW DAYS BEFORE SSW



SUDDEN STRATOSPHERIC WARMING



LOOKING FOR A CONCEPTUAL MODEL OF AN SSW

What we would like the model to capture:

- How and why do the winds reverse direction suddenly from their mean state?
- Why is this accompanied by a temperature increase?

LOOKING FOR A CONCEPTUAL MODEL OF AN SSW

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- Why is this accompanied by a temperature increase?

Waves!

Periodic disturbance to some atmospheric variable

NON-ACCELERATION THEOREM

Waves do not modify the east/west-averaged flow if the waves:

- are steady;
- are non-dissipative (conservative);
- are of small amplitude (linear);
- do not affect boundary conditions (no critical levels).

CONCEPTUAL MODEL OF AN SSW

Matsuno (1971) model components:

- Quasi geostropic equations
  - On a plane tangent to a sphere in the midlatitudes
  - Based on shallow water equations
  - Coriolis most important term
- Sudden, large vertically-propagating wave activity
  - No vertical motion ahead of the wave front
  - Steady behind the wave front

Model story:

1. Anomalously large waves in the troposphere
2. Waves propagate into stratosphere
3. Because waves are non-steady, they affect mean flow, decelerating it

CONCEPTUAL MODEL OF AN SSW

Deceleration by non-steady waves:

1. Upward wave activity => poleward heat flux
2. Quasi geostropic equation for buoyancy gives vertical velocities
3. Continuity means we get a circulation
4. Coriolis force => deceleration of east/west wind

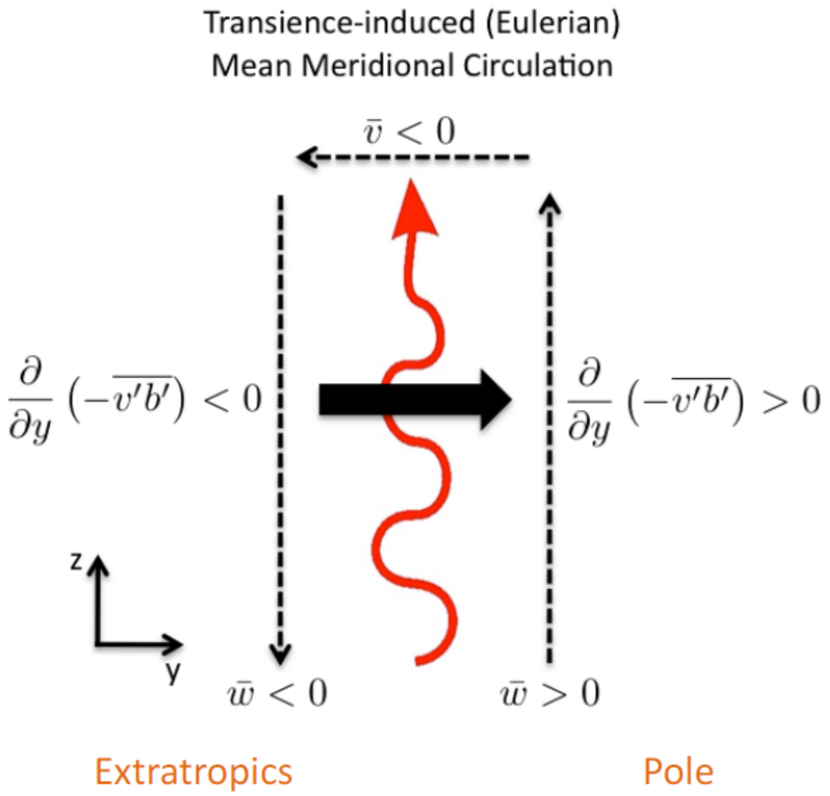

Image from Ron Miller

SURFACE EFFECTS OF AN SSW

In the two months following an SSW:

- Anomalously high pressure (weak low) near Iceland
- Anomalously low pressure (weak high) near the Azores
- Temperature and precipitation dipole in Eurasia
- *Sometimes* a cold and snowy eastern US and warm Labrador/Greenland

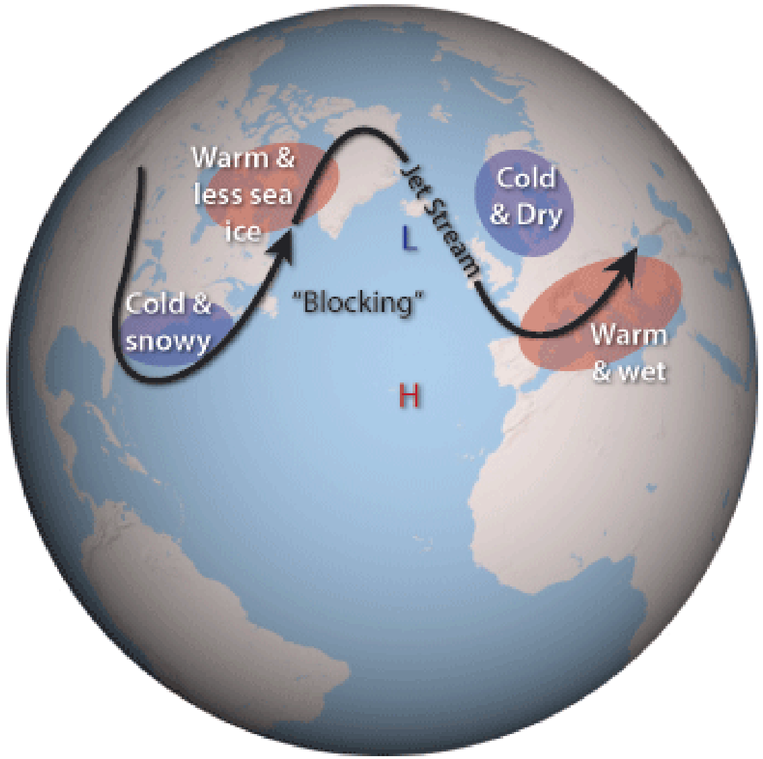

Image from NOAA

Typical pattern following SSWs

SSW AREAS OF STUDY

Prediction	How do we predict SSWs? What features tend to precede them?
Impacts	How do the effects of SSWs descend to the surface, and what affects that descent?
Change	How will SSWs and their effects change in the future?
Interactions	What other atmospheric features or phenomena interact with SSWs or their effects, and how?
Models	How well do different models represent processes related to SSWs and their impacts?

How do ozone chemistry and transport affect SSWs and their surface impacts?

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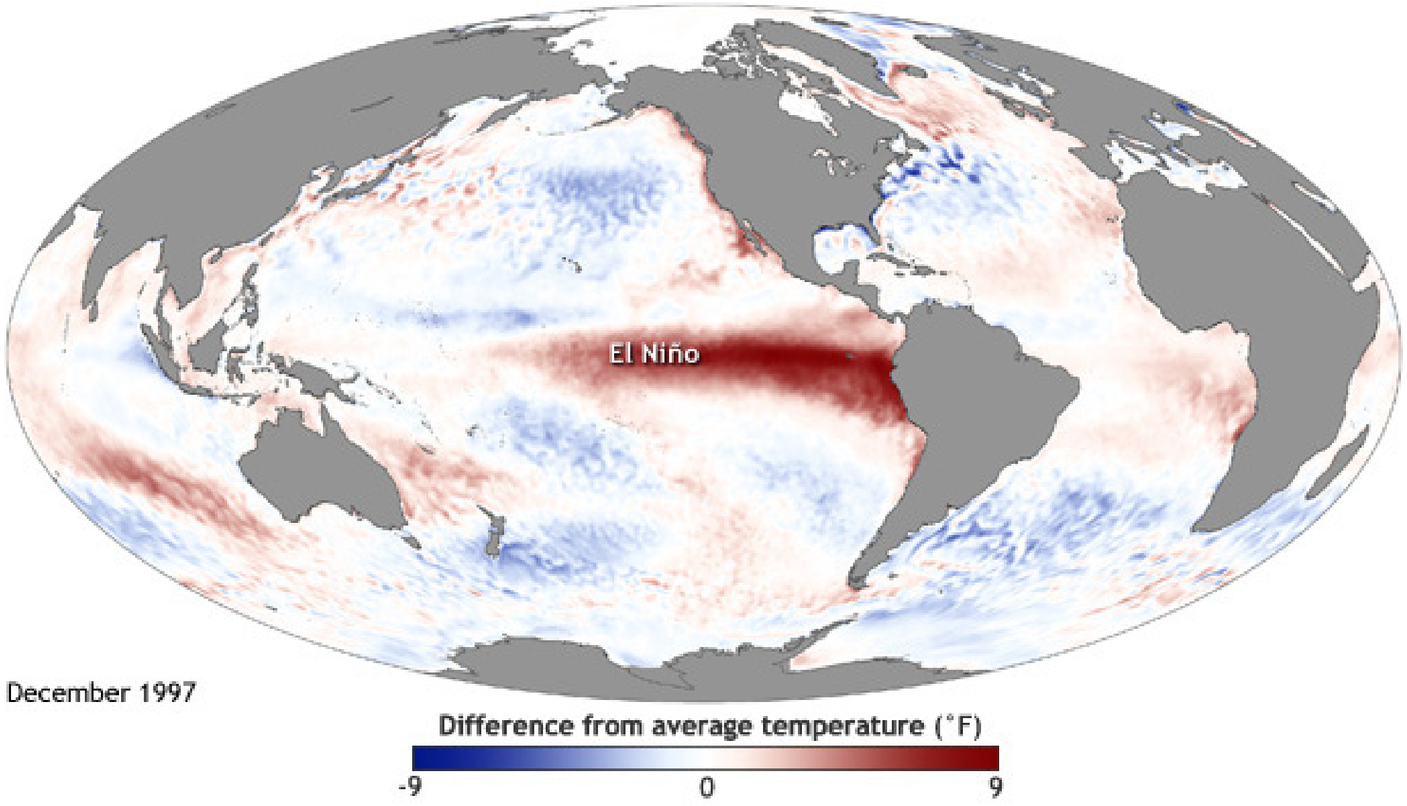
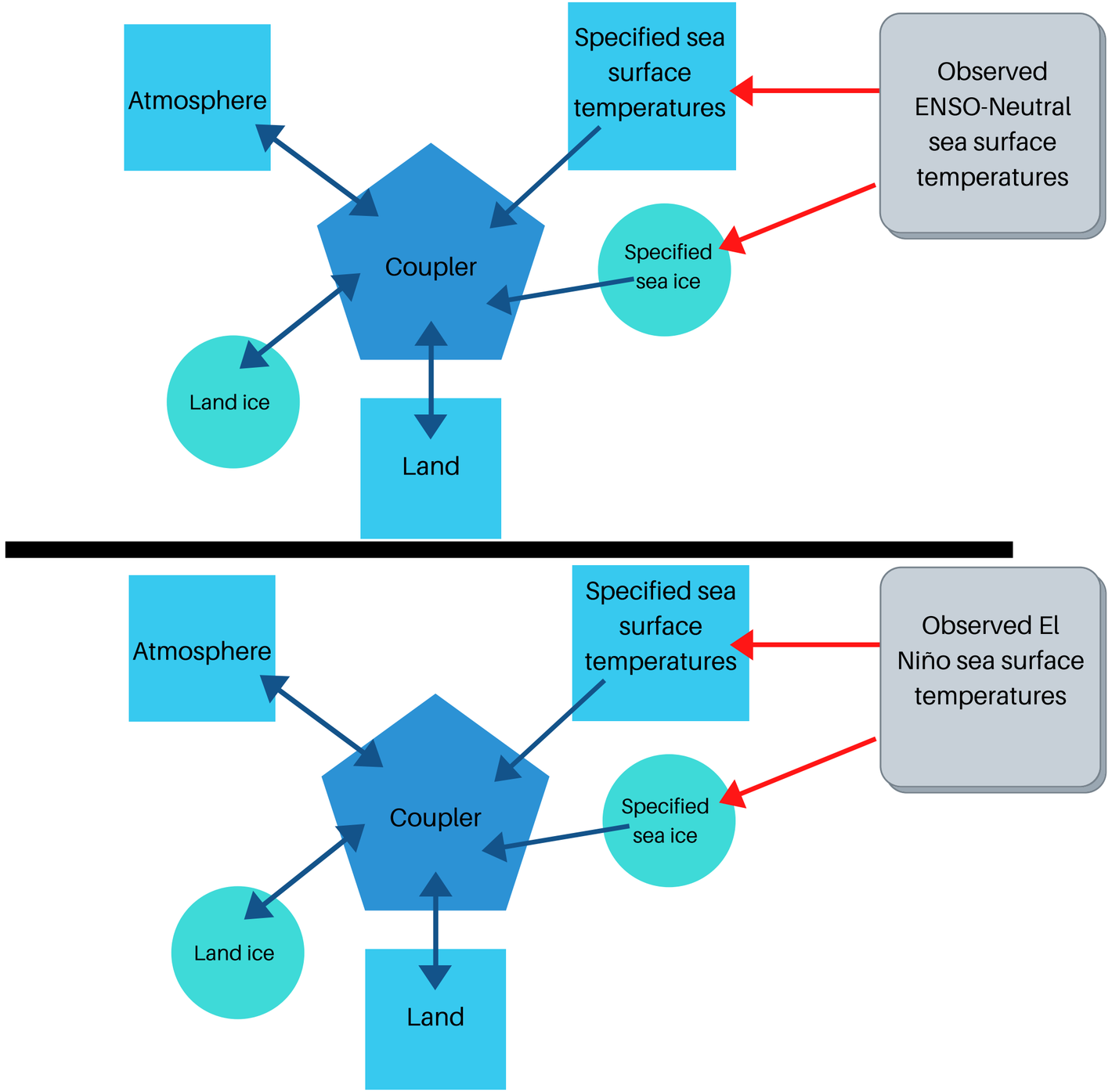
EL NIÑO


El Niño
December 1997
Difference from average temperature (˚F)
-9
0
9

EL NIÑO AND SSWS

How do the surface impacts of SSWs change with El Niño-Southern Oscillation (ENSO) phase?

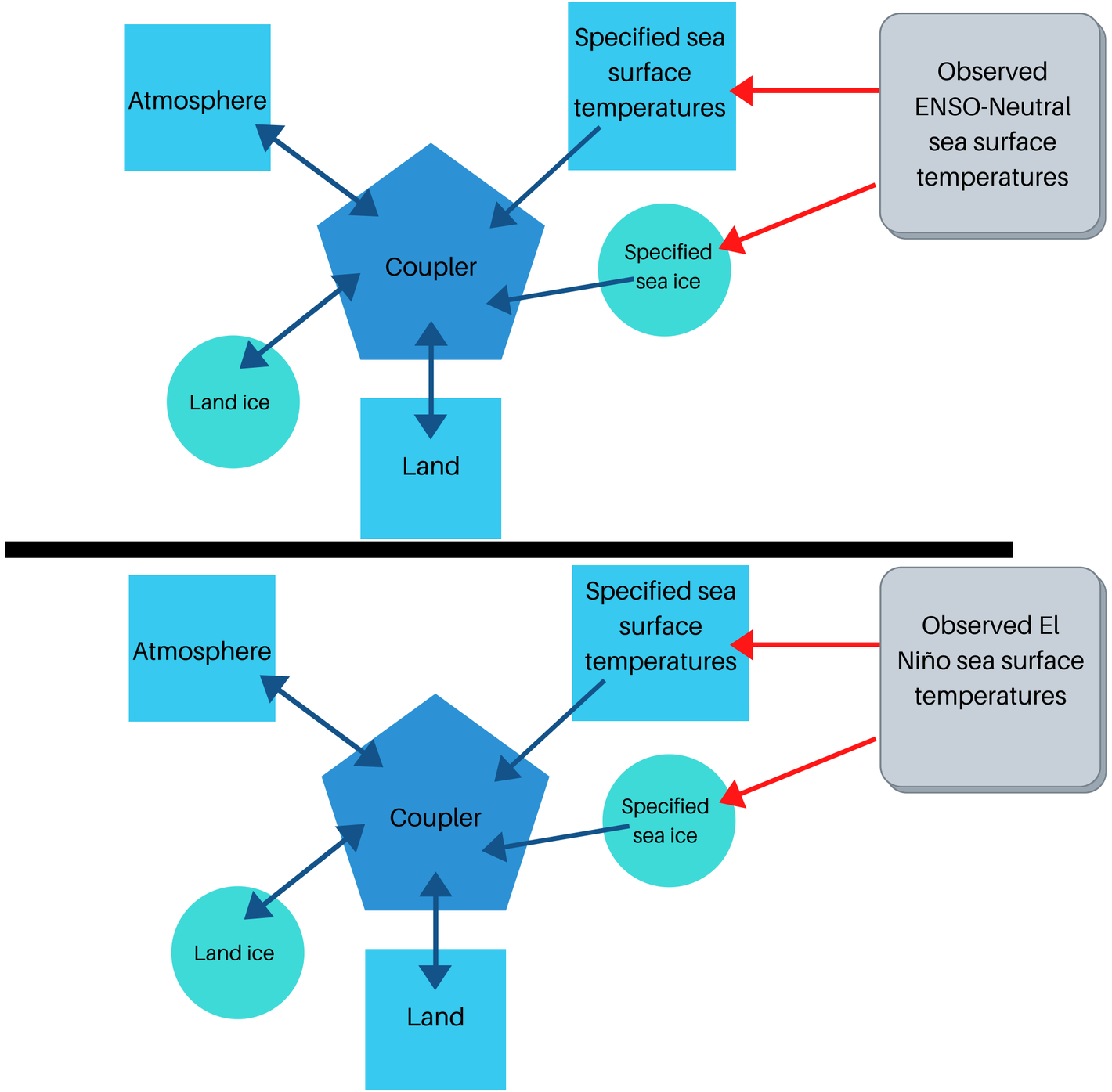
- Two sets of 200 year model runs with different specified sea surface temperatures
- We use simulation because
  - few events in observations;
  - isolates role of ENSO.



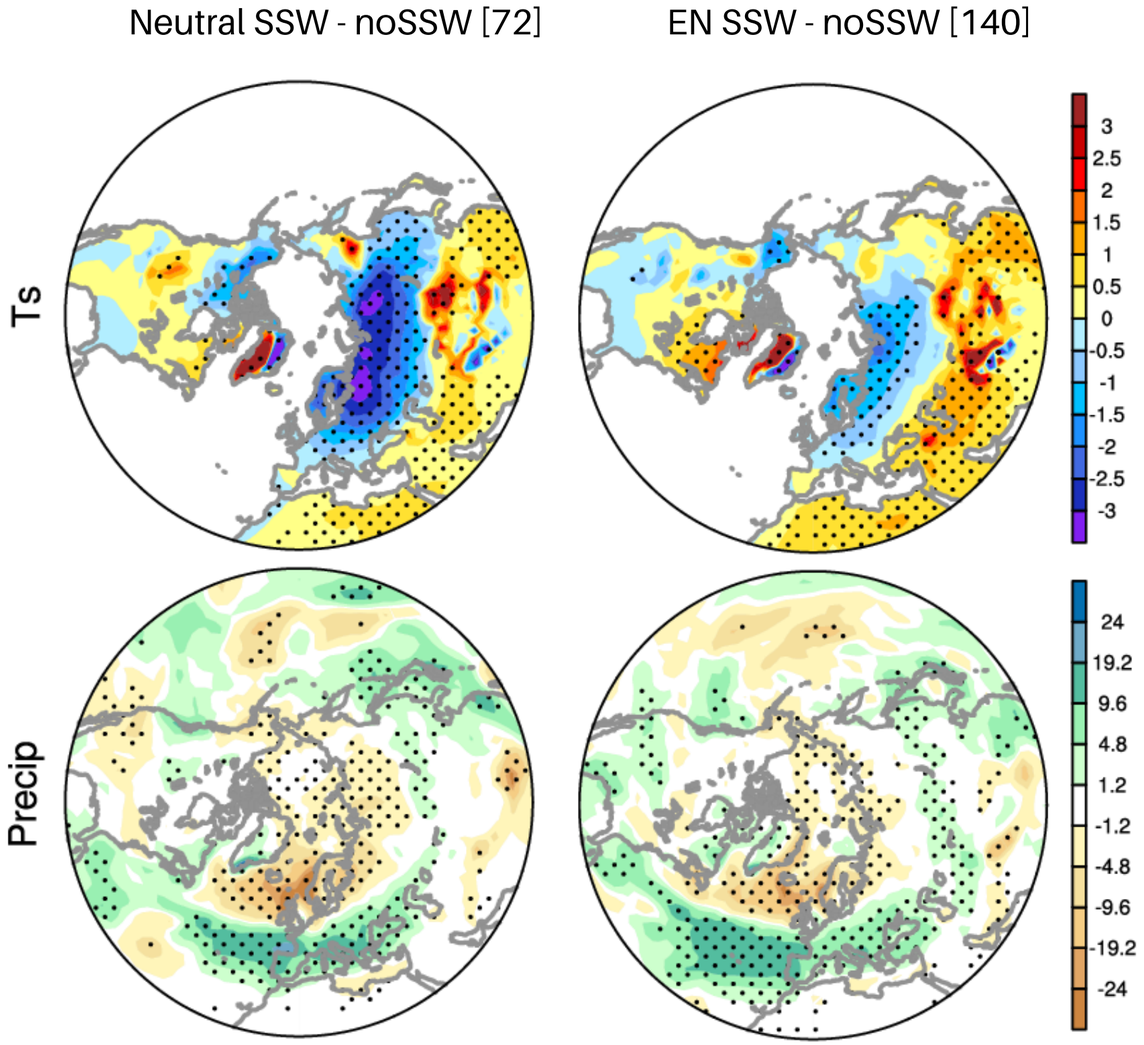
EL NIÑO AND SSWS

How do the surface impacts of SSWs change with El Niño-Southern Oscillation (ENSO) phase?

- Two sets of 200 year model runs with different specified sea surface temperatures
- Find SSWs in each set
- Compare surface climate in the two months following SSWs to non-SSW years under each condition



EL NIÑO AND SSWS



CONCLUSIONS

- Atmospheric variability occurs (and matters) on a wide range of time and spatial scales, with different sources of variability and predictability.

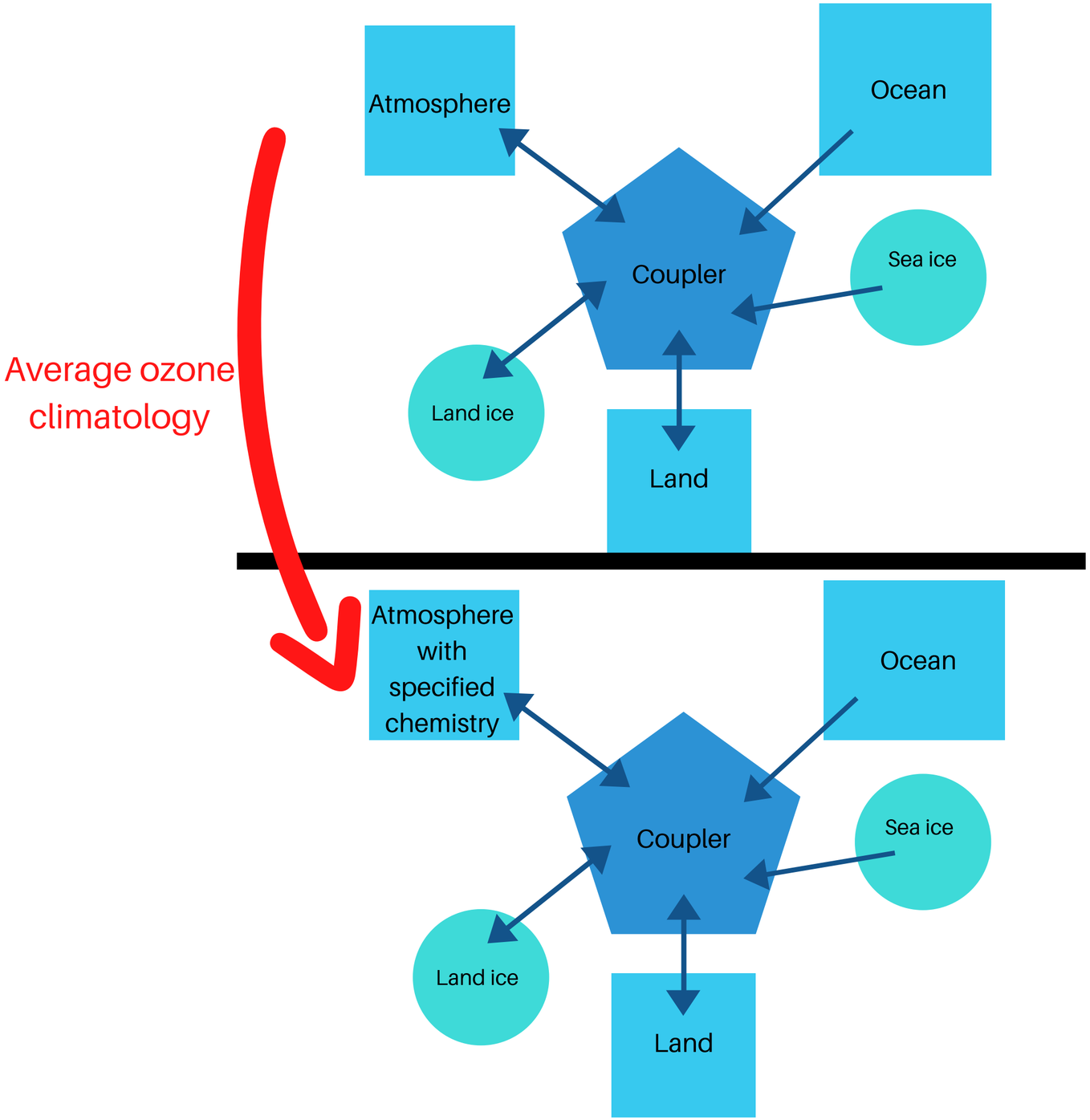
- Comprehensive climate models are helpful not only for prediction but also for understanding physical processes
  - in the absence of observed data;
  - through nonphysical experiments.

- The polar stratosphere is an important factor for subseasonal climate in the North Atlantic region.

OZONE AND SSWS

How do ozone chemistry and transport affect SSWs and their surface impacts?

- Two sets of 200 year model runs, one that includes chemistry
- The second has specified ozone based on the average for each day in first simulation
- Simulation because this question is hard to answer observationally



OZONE AND SSWS

How does the inclusion of interactive ozone chemistry affect modeled surface impacts of SSWs?

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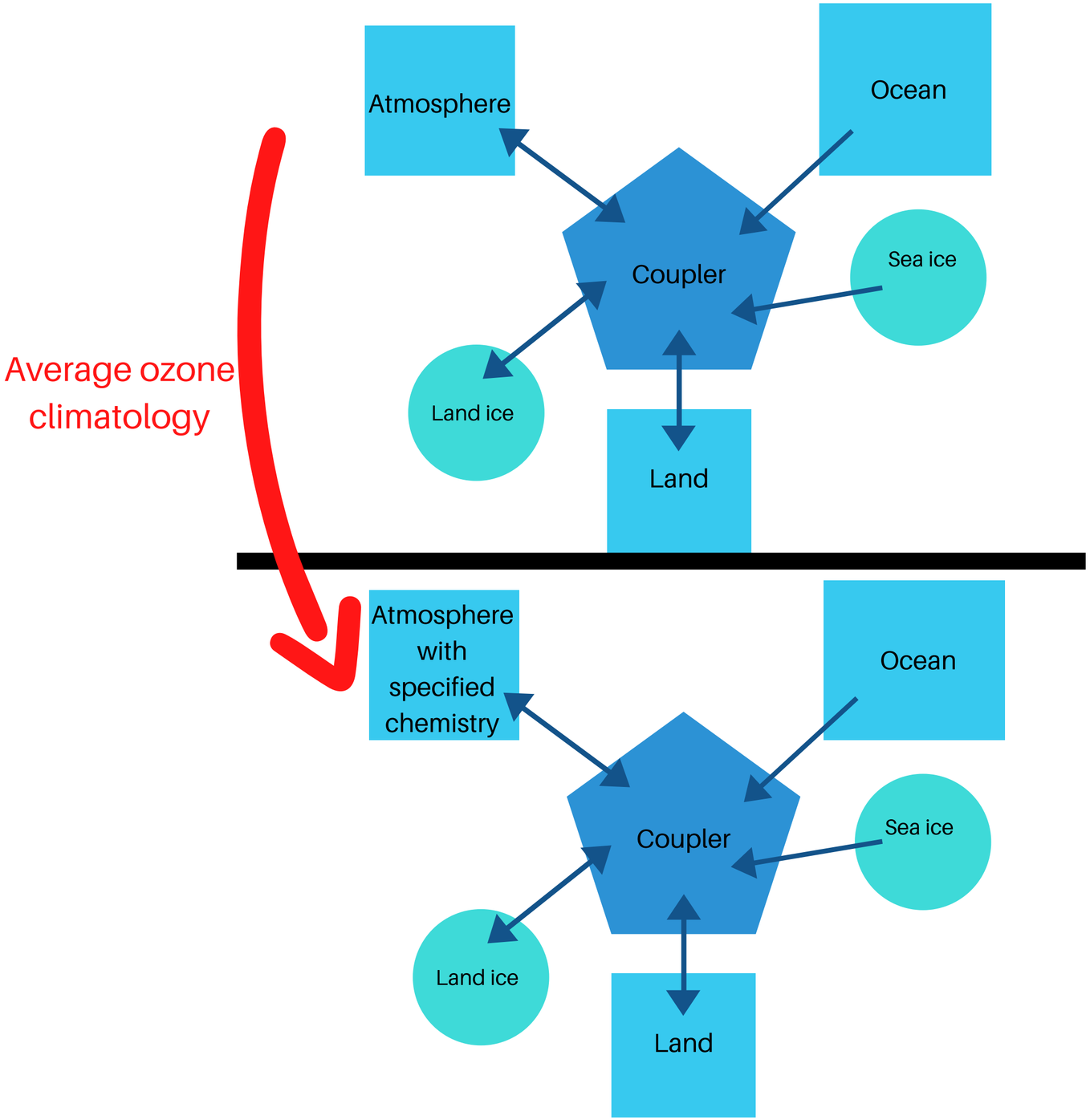
- Find SSWs in each set
- Compare surface climate following SSWs under each condition



OZONE AND SSWS