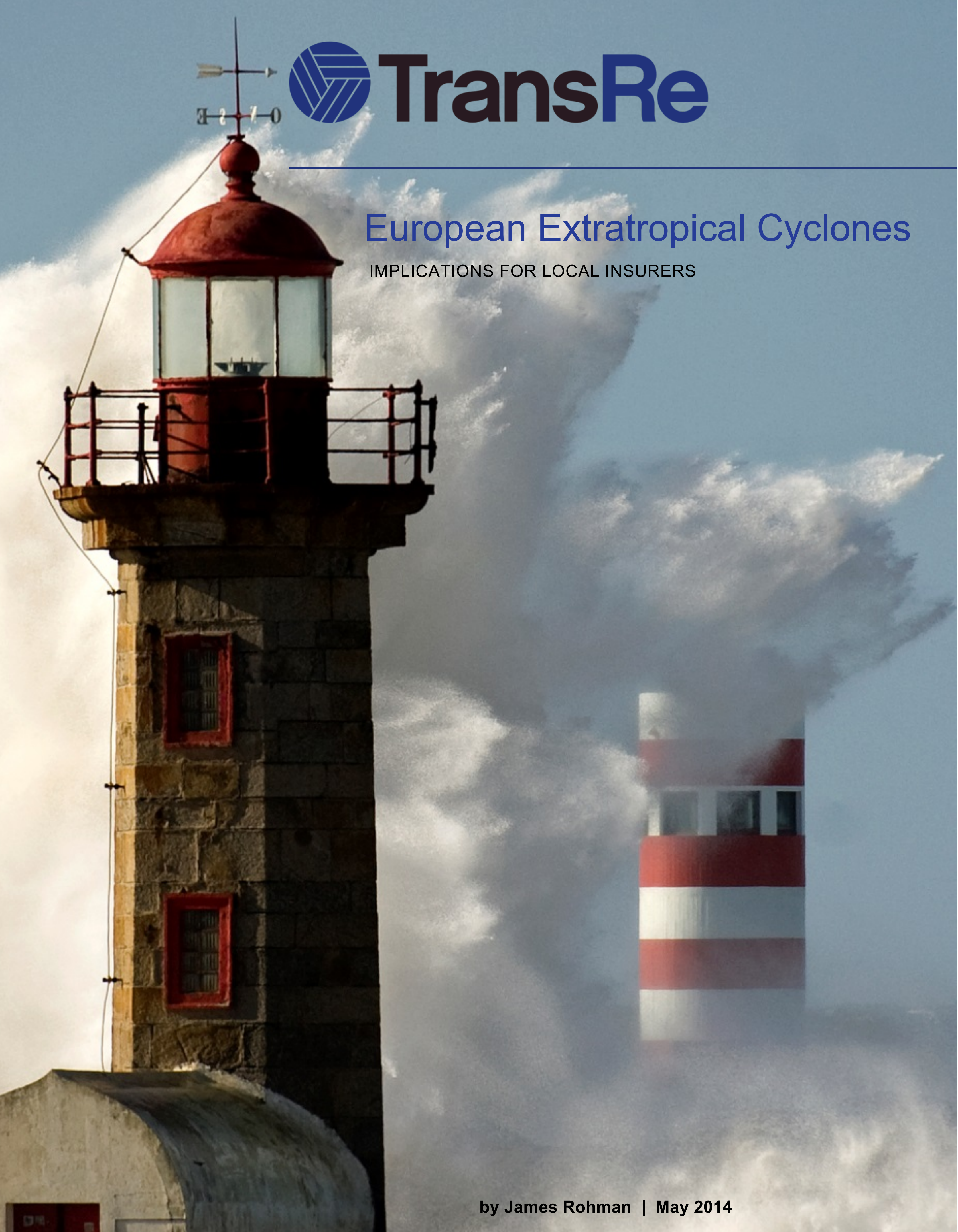


TransRe

European Extratropical Cyclones

IMPLICATIONS FOR LOCAL INSURERS

by James Rohman | May 2014

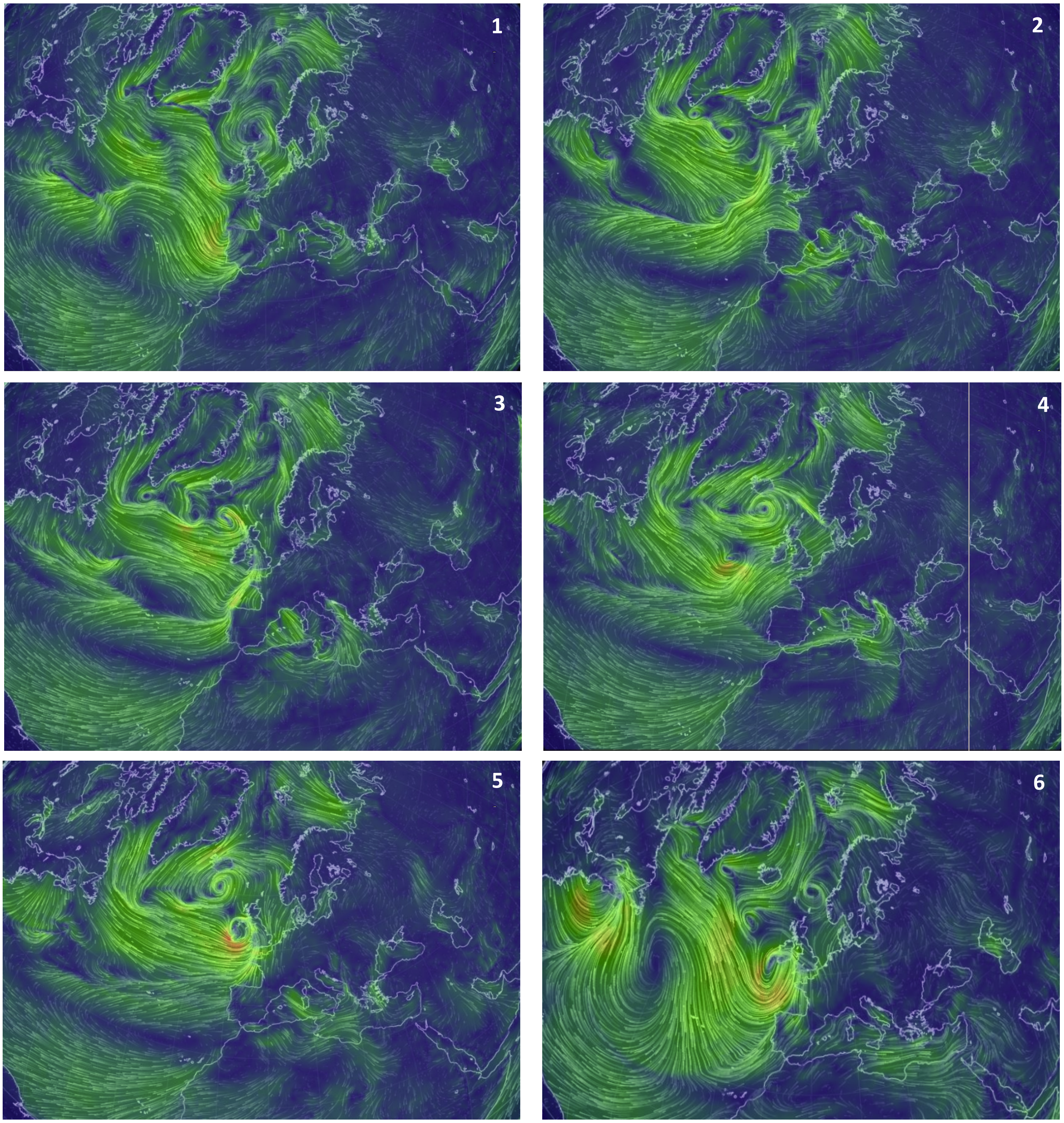


Figure 1. An extratropical disturbance turns into an organized storm in the eastern North Atlantic. Over February 12-14, 2014, a series of storms struck the coastline of northern Europe, causing widespread flood and damage, resulting in approximate insured losses of $1.3B to residences, businesses and infrastructure.

Executive Summary

- Extratropical Cyclones (ETC) that form in the North Atlantic are, on average, the second most destructive insured natural catastrophe worldwide (after Atlantic hurricanes).
- They can generate winds up to 140mph and waves over 100ft.
- The wind-fields range from 120-1200 miles, with the spread of most damaging winds 50-150 miles from the storm center.
- On average, 200 ETCs form each year.
- They derive their energy from the horizontal temperature difference between warm, subtropical air masses and cold, polar air masses.
- The two most consistent factors driving European ETCs are the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO).
- AO and NAO shape the jet stream, funnel ETCs into various parts of Europe.
    - Positive AO/NAO is associated with storms that have a west-southwest to east-northeast track across Europe.
    - Negative AO/NAO is linked to a more south-to-north track.
    - NAO positive (negative) years are associated with a 10-15% increase (decrease) in losses during winter storm seasons.
- AO/NAO variation is linked to the dynamics of the Madden-Julian Oscillation (MJO), a global tropical weather anomaly.
- Climate projections indicate an increase in ETC wind gusts from the eastern North Atlantic Ocean into Northern and Central Europe.
- Three futuristic climate simulations show ETC frequency is expected to increase over many parts of Europe, from Scandinavia to the Adriatic, due to climate change.
- In addition to land based losses, ETCs will impact marine exposures. Post-Panamax containerships are more prone to a phenomenon known as ‘parametric rolling’ than smaller vessels due to hull shape.
- TransRe is working to support insurers to better understand the causes and implications of European Extratropical Cyclones.

Introduction

This paper highlights the climatology, characteristics, history and climate change projections of European Extratropical Cyclones.

January 2014 was the fourth warmest since record keeping began in 1880, yet it fell in the middle of the most extreme winter Europe (and the Northeast US) has experienced in 15 years. A nexus of storms brought high winds, heavy rainfall and severe snowstorms for almost five months, causing flooding and damage to life onshore and at sea.

Such prodigious weather patterns indicate equally prodigious climate disturbances. **Many of those storms formed as Extratropical Cyclones (ETC)**. The first section of this paper discusses the large-scale climate variations and indices that encourage and energize ETC development.

Every year, roughly 200 atmospheric disturbances form in the North Atlantic. A handful of the disturbances, which develop as cold-core and asymmetric cyclones, morph into organized storms and track east towards Europe. The second section summarizes the characteristics and dynamics of these pandemonium-inducing windstorms.

On average, European ETCs create $1.2 billion of insured loss per year. In extreme years with multiple tail events, they can be the leading cause of global storm losses; in 1990 and 1999, they caused $18 billion and $14 billion of insured losses, respectively. **The 2014 season is expected to exceed $5.5 billion in insured loss.** Section three covers the finer points of the European ETC archival record.

ETCs that form in the North Atlantic are among nature's most powerful cyclones on earth, deriving their energy from the interaction and difference between cold Arctic air masses and warm subtropical air masses. **ETCs can produce storms with central low pressure as low as 916 mb, winds up to 140 mph and wave heights over 100 feet.** Given the recent record of IPCC reports and extreme weather, the final section offers predictions for ETC development and tracking.

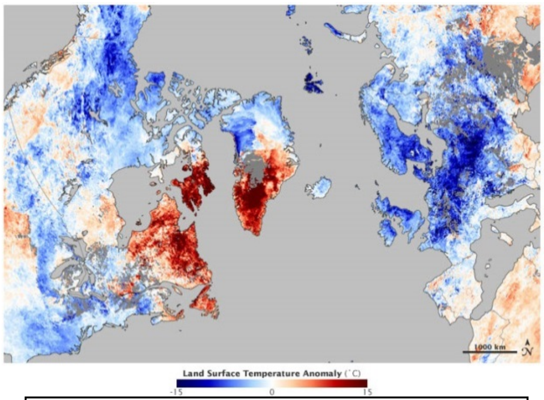
The disruption and loss to everyday life from extreme weather is calamitous. As the science of climatology continues to evolve, TransRe strives to inform the insurance industry of advancements in the field. Our efforts come with the hope that property damage, loss of life and societal interferences will diminish with greater knowledge of extreme natural catastrophes.

The Science of European Extratropical Cyclones

Climatology

The major factors driving European ETCs are the Arctic Oscillation and North Atlantic Oscillation, two climate indices for the Northern Hemisphere.

Arctic Oscillation (AO)



The Arctic Oscillation helps define the jet stream, which can send cold, polar air far south with its large oscillations. This image compares December 2010 to the previous 10-year average, showing that AO and the shape of the jet stream altered the temperature gradient in the Northern Hemisphere. Arctic air was sent as far south as the Carolinas and Portugal. Red (blue) indicates areas that are warmer (colder) than average. Note how the jet stream's strange shape can juxtapose warm and cold weather anomalies, with less than 50 miles between extended warm and cold fronts.

The Arctic is home to a semi-permanent low pressure circulation known as the 'Polar Vortex', which rose to prominence in the first quarter of 2014. The Vortex is in constant opposition to (and therefore represents opposing pressure to) the weather patterns of the northern middle latitudes (i.e. Northern Europe, Northern Asia and northern North America).

AO measures the variation in the strength, intensity and size of the jet stream as it expands and contracts to alter the shape of the fast-flowing air current. AO is measured by opposing sea-pressure anomalies, ranging from the Arctic Circle approximately to the 38th parallel.

During the 'negative phase' of AO, sea-level pressure is high in the Arctic and low in the northern middle latitudes. The 'positive phase' of AO has the exact opposite pattern.

Dr. James E. Hansen of NASA describes AO thus:

"The degree to which Arctic air penetrates into middle latitudes is related to the AO index, which is defined by surface atmospheric pressure patterns. When the AO index is positive, surface pressure is low in the polar region. This helps the middle latitude jet stream to blow strongly and consistently from west to east, thus keeping cold Arctic air locked in the polar region. When the AO index is negative, there tends to be high pressure in the polar region, weaker zonal winds, and greater movement of frigid polar air into middle latitudes."

AO has a dominant role in determining the shape of the jet stream, which in turn plays a crucial role in steering European ETCs. **During active ETC phases, the jet stream tends to be reinforced and prevented from shifting. This is an effect called eddy feedback.**

By maintaining the shape and consistency of the jet stream, **eddy feedback increases the propensity for clustering of ETCs. Such clustering patterns were seen during the destructive 1987, 1990, 2000 and 2014 European ETC seasons**. This is a month-to-month phenomenon. It does not persist on a yearly basis.

AO's Effects on Northern Latitudes

During the **positive phase**, a strong Polar Vortex confines cold Arctic air across Polar Regions. Arctic air is kept in the north, resulting in **brisk winters for Greenland, northern Scandinavia and Russia**, but keeping most of Europe and the mainland US relatively warm.

Extratropical storms are flung further north. **AO positive creates stormy weather in the UK and Scandinavia,** while **Southwest Europe and Mediterranean countries remain dry**.

Storms are pushed further north and affect the UK and Scandinavia.

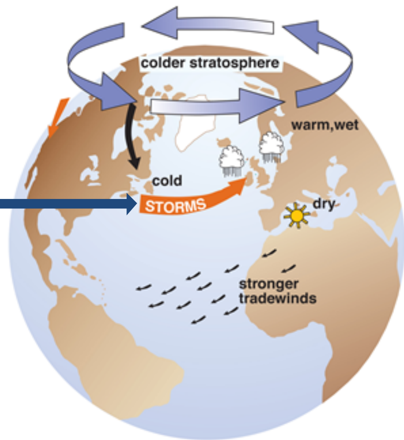


Figure 2. Positive phase of Arctic Oscillation.

During the **negative phase**, the Polar Vortex is weakened by influxes of warm air from Siberia. **Cold air migrates south with the meandering jet stream**. **Arctic air masses freeze over Northern Europe and North America, while the Mediterranean and Southwest US experience stormier winters.**

Storms migrate further south and affect southern Europe and the Mediterranean.

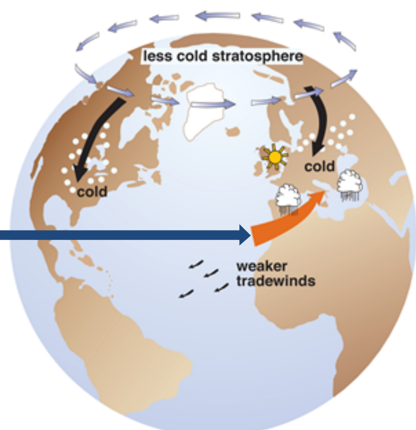
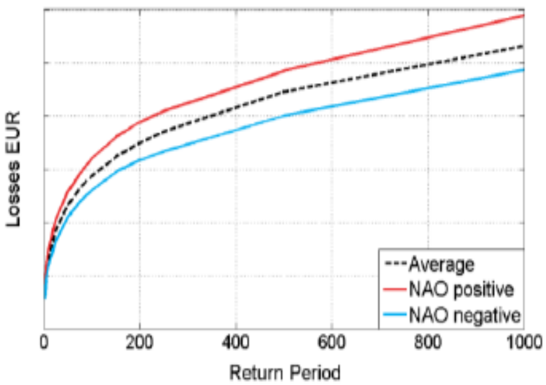


Figure 3. Negative phase of Arctic Oscillation.

North Atlantic Oscillation (NAO)

Similar to AO, NAO is comprised of north-south dipole anomalies, but is centered over the North Atlantic Gyre. The low pressure center is located over Stykkisholmur/Reykjavík Iceland, while the high pressure anomaly is centered over the Ponta Delgada, Azores.

It is important to note that the centers of the low and high pressure systems migrate on a seasonal and yearly basis; other locations can also be used to measure the NAO index.



The figure from Willis Re shows the effect of positive and negative NAO phases on European windstorm losses. NAO's strong influence on the path of ETCs has a significant effect on loss structure and distribution in Europe, with a 10-15% increase (decrease) in aggregate losses during NAO positive (negative) seasons.

Both phases of NAO are associated with large-scale alterations in strength and location of the North Atlantic jet stream and subsequent storm tracks. They also both modulate patterns of heat and moisture transportation, which affect spatial temperature and precipitation patterns from the Eastern Europe to the coast of North America.

Typically, NAO affects weather patterns across Northern Europe, Greenland, Iceland and Eastern US/Canada. It also has the capability to extend into Scandinavia in winter and Southern Europe over the summer months.

During prolonged periods of either positive or negative NAO, anomalous weather bands can be seen as far east as central Russia and north Siberia.

NAO exhibits variability on a seasonal and yearly basis, with prolonged periods of either phase dominating Atlantic weather patterns. **From 1954-1978, a negative NAO dominated Atlantic circulation patterns for over 75% of the time**.

During the 24-year period, the negative NAO dominated for at least three years straight, with little to no presence of a positive phase. NAO positive did not appear as a seasonal mean in consecutive years.

The winter of 2013-14 has had an overwhelmingly positive NAO index. **This provided more energy in the North Atlantic for intense and clustered storms**, which helps explain the Nordic Storm Series (November 13th to December 19th, 2013) and the almost continuous series of storms from December 17th, 2013 through February 20th, 2014 across Europe.

Though they are two different climate indices, NAO and AO ultimately measure the same phenomenon. They both calculate large-scale differences in sea-level pressure in the Northern Hemisphere, and the ramifications for temperature gradients and storm tracks between Europe and North America.

Positive NAO

When NAO is in its **positive phase**, the Icelandic low and Azores high are strengthened. Heightened pressure systems lead to **an increased pressure gradient across the North Atlantic Gyre**. Because large barometric differentials increase wind speeds between areas of high and low pressure, **Westerly winds intensify across the North Atlantic**. This has the **overall effect of heavy winds flowing into Europe**.

Just like a positive AO, positive NAO sends intense storms in to North Europe and UK.

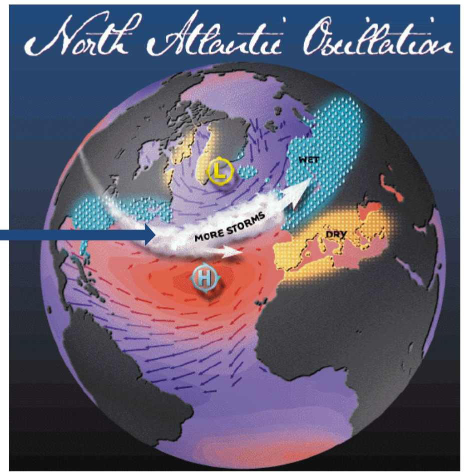


Figure 4. Positive phase of North Atlantic Oscillation.

Negative NAO

Negative NAO is the exact opposite of positive NAO. In the **negative phase**, the difference between the Azores high and Icelandic low lessens, **decreasing the sea pressure gradient**. The slackened gradient results in **weaker Westerlies and less wind in Europe**.

The negative NAO keeps the UK and North Europe dry and sends storms in to the Mediterranean region.

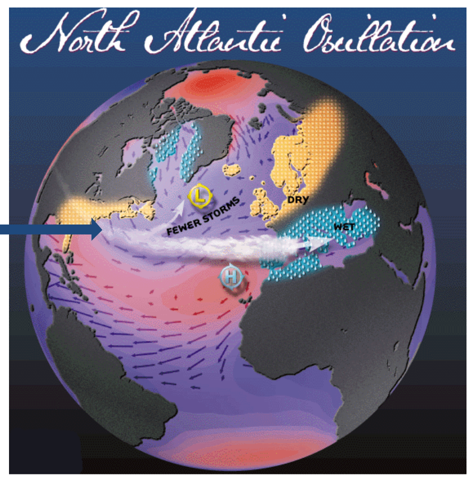
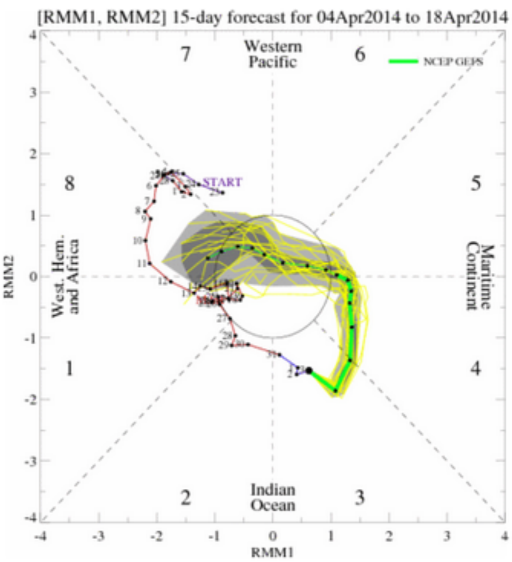


Figure 5. Negative phase of North Atlantic Oscillation.

Relationship between Madden-Julian Oscillation (MJO) and NAO/AO



MJO is a slow-moving atmospheric pattern that impacts global tropical and sub-tropical weather. It can be tracked through NOAA's dynamic MJO forecast.

Above, the forecast index is divided into octants, with each eighth of the index corresponding to a different global tropical basin.

When the index is within the center circle, MJO is considered weak and difficult to read. MJO becomes stronger as the index moves further from the center.

A 2008 study by Hai Lin, Gilbert Brunet and Jacques Derome of Environment Canada and McGill University **found an observed connection between the NAO and Madden-Julian Oscillation (MJO)**.

MJO is a band of low-pressure that develops in the Indian Ocean before propagating east as an anomalous and convective weather band. It dumps rain on Southeast Asia and Australia, continues east towards the Pacific, and ultimately impacts the Atlantic Ocean before dissipating near Africa.

MJO is associated with large-scale variations in atmospheric/oceanic indices, affecting drought, monsoon and tropical cyclone patterns in every ocean basin. **MJO can also affect ETCs through a complex interaction with NAO and AO**.

The authors of the 2008 study found a long-distance connection between tropical convection of MJO and the Northern Hemisphere's NAO. **When MJO is in Phases 2-4, NAO has a significant positive amplification about 5-15 days after depressed convection of MJO reaches the tropical central Pacific**.

Conversely, when **MJO is in Phases 6-8, there is a significant negative amplification roughly 5-15 days after enhanced convection of MJO reaches the tropical central Pacific**.

MJO also has a strong relationship with AO. **When MJO related convection is enhanced (depressed) over the Indian Ocean, AO tends to favor its positive (negative) phase.**

As NAO and AO are intrinsically related, we see how the tropical MJO influences North Atlantic winter weather. The results indicate **that MJO forces have a direct influence on the Atlantic sector's NAO and AO**.

An additional **strong connection** has been observed **between MJO and the Northern Hemisphere's winter stratospheric Polar Vortex**. **Large variations in the jet stream and sudden warming events tend to follow certain MJO phases**. This provides further for support for the complex and important link between global tropical weather and North Atlantic winter storms.

Due to the observed relationships between MJO convection and NAO/AO behavior, **there exists the potential to create medium to long range forecasts for NAO and AO**, **given accurate predictions of MJO phase and future movements.**

A predictive method of this sort would allow for more detailed and far-sighted forecasts for ETCs.

Characteristics of Extratropical Cyclones

Dynamics

Every year, approximately 200 extratropical disturbances form in the North Atlantic. They **derive their energy from the horizontal temperature differential between warm, subtropical air masses and cold, Arctic air masses**. Most storms develop during the winter months, when the temperature differential between the tropics and poles are the greatest.

We can see the importance of an in-depth knowledge of the science and workings of the NAO and AO indexes, which track that exact temperature and pressure gradient, as well as the shape and location of the North Atlantic jet stream.

Cold core disturbances that organize into larger storms and track east are steered by the jet stream. With its undulating movements and sometimes erratic oscillations, the jet stream's shape helps define storm track. Because the AO and NAO help define the extremes of the eccentricities in the jet stream, a refined understanding of the development of AO/NAO is imperative to understand both past and future trends.

Storms that affect Europe have tracked across the North Atlantic with the sinusoidal, upper-atmospheric jet stream. With an average forward motion of 35mph, **an ETC's asymmetrical windfield creates the greatest swath of damage along its southeast quadrant near the frontal wave**.

European ETCs can, at times, produce gusts in excess of 150 mph. These storms, (which include) Xynthia or Kyrill, experienced rapid intensification after interacting with a trough of low pressure high in the atmosphere.

Phase I- A perturbation forms along a baroclinic zone between low and high pressure systems.

Phase II- The wave amplifies, scale contracts and the fronts of the storm form.

Phase III-The fronts 'T-bone' and waves amplify. Storm force winds form between the warm and occluded fronts.

Phase IV-Full seclusion of the warm front. Storm and hurricane force winds found on cold side of the occluded front.

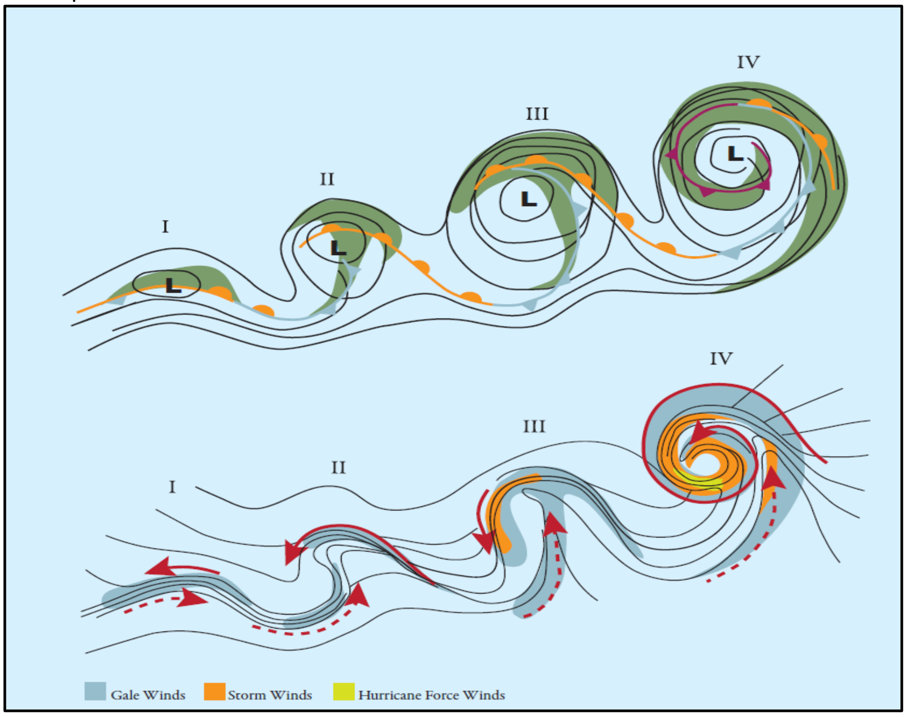


Figure 6. The Shapiro-Keyser Extratropical Cyclone Model, developed in 1990 shows the life-cycle of an ETC.

Structure, Shape and Size

ETCs differ in structure, shape and size from Atlantic, east Pacific, west Pacific and Indian Ocean hurricanes/typhoons. The latter are warm core tropical cyclones, deriving their energy from a vertical temperature differential between the upper and lower atmosphere.

Because ETCs are fueled by a horizontal temperature differential, they **do not lose strength as they track over land, unlike tropical cyclones**. **ETCs keep their energy throughout landfall**, affecting a single location anywhere between 6 and 24 hours.

Another **difference between ETCs and tropical cyclones is the distinct fronts**. The **comma-shaped appearance of ETCs identifies the location of warm and cold air masses that feed the circulation of the storm**. The distinct warm and cold fronts pack the greatest punch, with the highest surface winds and heaviest precipitation along their boundaries.

ETCs become asymmetric when mature because the tropical and polar air masses that provide the energy are not uniform in temperature and pressure. **Full-blown storms vary greatly in size, with diameters ranging from 120-1200 miles. The spread of most damaging winds tends to stay within 50-150 miles of the storm center.**

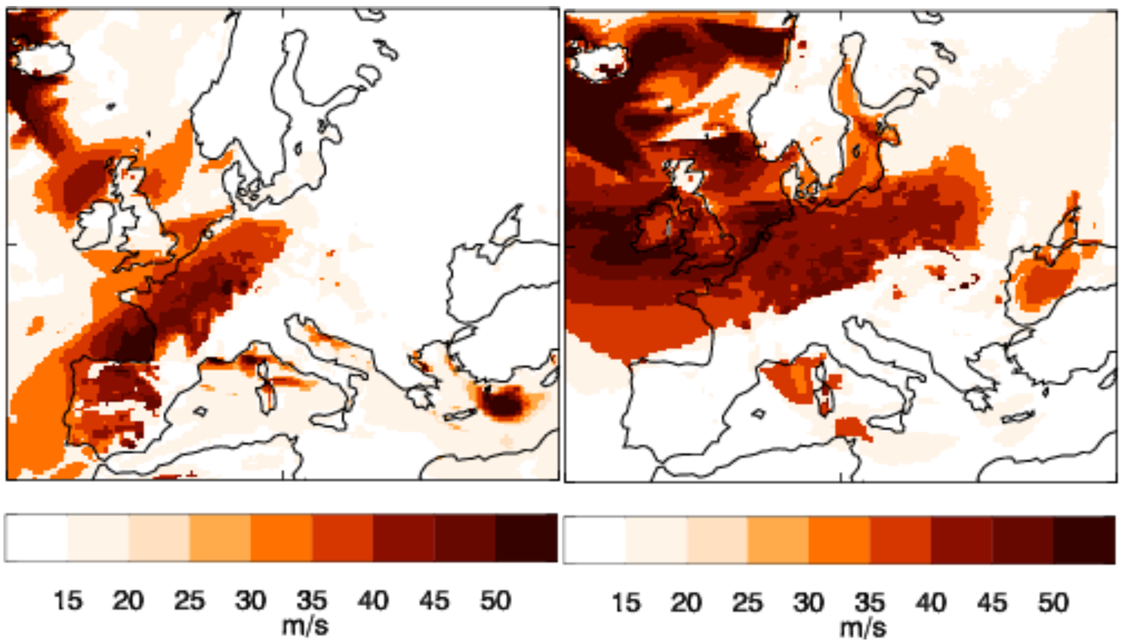


Figure 7. This shows the windstorm footprints of Xynthia (Feb 2010) on the left and Kyrill (Jan 2007) on the right. Although each storm had a slightly different storm track, one can see how the storms did not lose energy over land and were able to maintain strength deep into the European continent. Xynthia traveled over 1700 miles into Europe, Kyrill covered over 1800 miles.

Historical Record

Climate Indices Chosen:

AAO- Antarctic Oscillation

AO- Arctic Oscillation

AMM- Atlantic Meridianal Mode

AMO- Atlantic Multi-Decadal Oscillation

MEI- Multivariate ENSO Index

MJO- Madden Julian Oscillation

NAO- North Atlantic Oscillation

ONI- Oceanic Nino Index

PDO- Pacific Decadal Oscillation

SOI- Southern Oscillation Index

QBO- Quasi-Biennial Oscillation

Climate Variables Chosen:

850mb Zonal Wind Anomaly

300mb Zonal Wind Anomaly

Precipitable Water Anomaly

Surface Pressure Anomaly

Storms Chosen:

1953 N Sea Flood- Jan 1953

Capella (Jan 1976 Gale) - Jan 1976

Great Storm of '87- Oct 1997

Daria (Burns' Day Storm) - Jan 1990

Vivian- Feb 1990

Wiebke-Feb 1990

Lothar- Dec 1990

Anatol-Dec 1999

Martin- Dec 1999

Kyrill- Jan 2007

Klaus- Jan 2009

Xynthia- Feb 2010

St. Jude- Oct 2013

An inherent necessity of any Chief Risk Officer or Chief Catastrophe Officer is the ability to minimize risk, maximize opportunity and maintain business continuity. Understanding loss history and large-scale climate indices plays an important role in the analysis and calculation of business opportunities.

Accuweather Study

In April 2014, **Dan Kottlowski of Accuweather completed a study** on our behalf **on the genesis, development, intensity, track and clustering of European ETCs using various climate indices and signals**. The study is intended to show how readers might use climate indices and other signals to anticipate active European ETC seasons.

The study focused on **13 high-impact storms between 1953 and 2013.** Various climate indices (those used most often by Accuweather to assess future weather trends) were evaluated for each storm. **Long term and short term trends** were identified. While some of the indices showed little or no predictive skill, others did.

Table 1. Seven climate indices are listed that foretell active ETC seasons and events. Storms are listed by insured loss, indexed to USD 2012. Insured loss data for the 1953 flood is unavailable; an estimate was provided by the UK Met Office in a 60 year retrospective study. The 1953 storm would have likely topped Daria in a modern climactic and economic scenario. 'X' means no data available, 'POS' means positive phase, 'NEG' means negative phase, 'NEU' means a Neutral ENSO, 'LA' means La Nina, 'EL means El Nino, 'MOD' means moderate MJO, 'WK' means weak MJO, 'STG' means strong MJO.!

Storm	Insured Loss (US bn)	QBO	NAO	AO	AAO	ENSO	AMO	MJO
1953	2.0+*	X	NEG	NEG	X	NEU	POS	X
Daria	8.2	NEG	POS	POS	NEG	NEU	NEG	6/MOD
Lothar	8	POS	POS	POS	POS	LA	POS	7/WK
Kyrill	6.7	POS	NEG	POS	NEG	EL	POS	7/WK
Great Storm	6.3	NEG	POS	NEG	NEG	EL	POS	6/STG
Vivian	5.6	NEG	POS	POS	POS	NEU	NEG	3/MOD
Klaus	3.5	POS	NEG	POS	POS	LA	POS	7/WK
Martin	3.3	POS	POS	POS	POS	LA	POS	7/WK
Xynthia	2.9	POS	NEG	NEG	NEG	EL	POS	7/WK
Anatol	2.2	POS	POS	POS	POS	LA	POS	7/WK
St Jude	1.6	POS	NEG	POS	NEG	NEU	POS	8/WK
Wiebke	1.4	NEG	POS	POS	POS	NEU	NEG	4/STG
Capella	1.3	X	NEG	POS	X	LA	NEG	8/WK

For storms with a west-southwest to east-northeast track, at least two of the QBO, NAO and AO indices are positive. Storms with a south-to-north track have at least two of the three QBO, NAO and AO indices negative. A negative AAO correlates closely with the south-to-north track.

An important observation from the study is **the importance of NAO in the intensification of storm development**. When **NAO changes sign before a storm develops**, usually from negative to positive, there is **potential for stronger European ETC creation**. This finding suggests an increase of the jet stream's power, which supports the storm intensification theory.

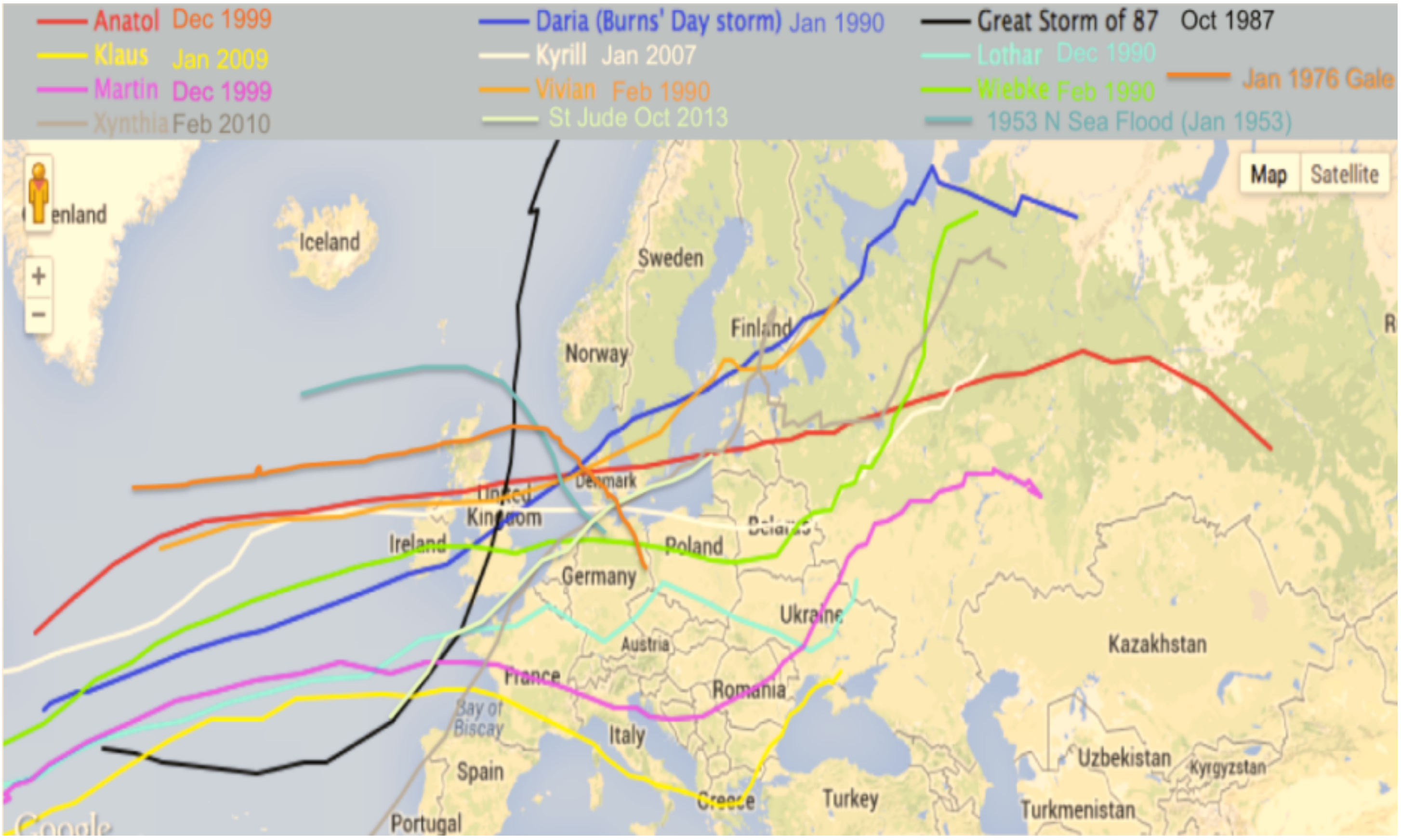


Figure 8. The various storm tracks of those listed in Table 1. The normal path of most storms is from the west-southwest to the east-northeast. The remaining storms without the aforementioned path take unusual routes through the North Atlantic and Europe.

Data suggests that fast moving storms with a general west-to-east orientation track with a strong west-to-east jet stream. A strong, horizontal polar jet stream positioned across North America and the North Atlantic is found with a positive NAO and AO, and favors a strong mid-latitude jet stream, fueling development of strong ETCs. **This pattern encourages the development of storm clusters**.

What is QBO?

The quasi-biennial oscillation (QBO) is a slow moving pattern (average cycle period is 28.5 months) of atmospheric waves. These waves start in the tropical troposphere and travel higher before being dissipated in the stratosphere, and cause successive waves of easterly and westerly wind anomalies.

The phases of QBO alter the strength of the Atlantic jet stream: westerly (negative) phases weaken the Atlantic jet stream, while easterly (positive) phases strengthen the jet stream and tend to cause stormier European winters.

The positive phase of QBO enhances this jet pattern and aids in the development of ETC clustering with west-southwest to east-northeast tracks.

The more severe ETCs track through or near the English Channel, with a directional path towards the German Bight.

Storms with southerly paths bring high impacts to South France and Spain, while more northerly storms impact the UK. **Areas east of the UK, including France, the Netherlands, Belgium, Luxembourg and Germany are heavily impacted by both south-to-north and west-southwest to east-northeast storms**.

However, **there does not seem to be an efficient long-term predictor for the strength and path of storms**. This is not very surprising, as highly-funded research in forecasting tropical storm intensification shows only modest improvements. Predicting the path and strength of non-tropical storms is even more difficult.

With potential impacts from the UK into Scandinavia, storms with west-southwest to east-northeast orientations can track far into Europe. While no long-term climate signal can predict paths, a **negative NAO and negative AO strongly suggests a more southerly storm track**, **influencing ETCs to impact France and Spain**, with **possible tracks into Italy and Eastern Europe**. Nevertheless, these climate signs can also support storms that impact much larger areas if they track south-to-north, as with the case of the 1987 storm.

Reanalysis data from the NCEP/NCAR database gives evidence that a strong jet stream with anomalously strong winds correlates with the development of stronger and more frequent high impact storms.

Specifically, years with a higher-than-normal number of storms clustered together shows anomalously powerful wind flow at the 300mb level. The 1999-2000 and 2013-2014 European ETC seasons are particularly good examples, as shown in Figure 9.

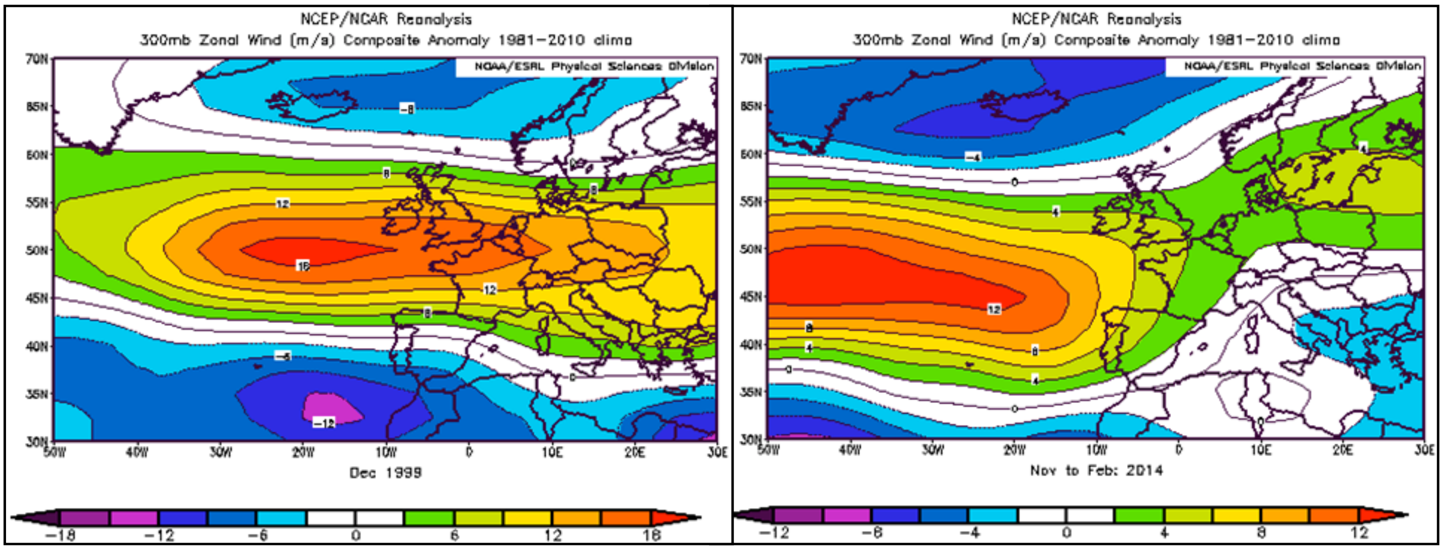


Figure 9. The NCEP/NCAR reanalysis of 300mb zonal wind in meters per second. On the left is the 1999-2000 season, on the right is the 2013-2014 season. For the 1999-2000 season, the anomalous wind band extends over 70 degrees longitude.

In both scenarios, **surface storms tend to form in the left front quadrant and the right rear quadrant** of the oval shaped wind anomaly. This means that **two separate storms can form at nearly the same time within this high level wind flow pattern and maintain parallel tracks into Europe**, creating a storm family or storm cluster.

A good example of these 'clustered ETCs' struck Europe over February 10th-14th of 2014. **Figure 1 (inside front page) shows how some patterns combined and intensified into storms.**

The cover image of this paper shows waves striking a lighthouse and a pier at Douro's river mouth in Porto, Portugal on Monday, February 10th, 2014. **This particular cluster put the entire coast of Portugal on the highest scale of alert as storm Stephanie rolled in.**

The 300mb high level winds can be predicted with a certain level of skill in current climate model software. **The ECMWF climate model that has output to nine months could help diagnose and predict high-impact seasons**. Additionally, **QBO**, which enhances west-to-east storm tracks, **can be predicted several months in advance**.

Predictions Under A Changing Climate

The 2013-2014 European winter storm season had some of the most severe sequences of storms since 1990. Given that some of this may be due to climate change and resultant altered weather patterns, studying the climate change impact on European ETCs becomes a high priority.

Schwierz et al. conducted a study that used three different climate scenarios for Europe to create an insurance loss model. State-of-the-art global models were utilized to provide estimates of the uncertainties.

Over the past 30 years, insured natural catastrophe losses have increased significantly. While factors that contribute to the rise include socioeconomic development along coastlines, the frequency of weather-related catastrophes has increased at a corresponding rate**. Schwierz et al.'s study takes the demographic shifts into mind when analyzing the impacts of climate change on European ETCs**.

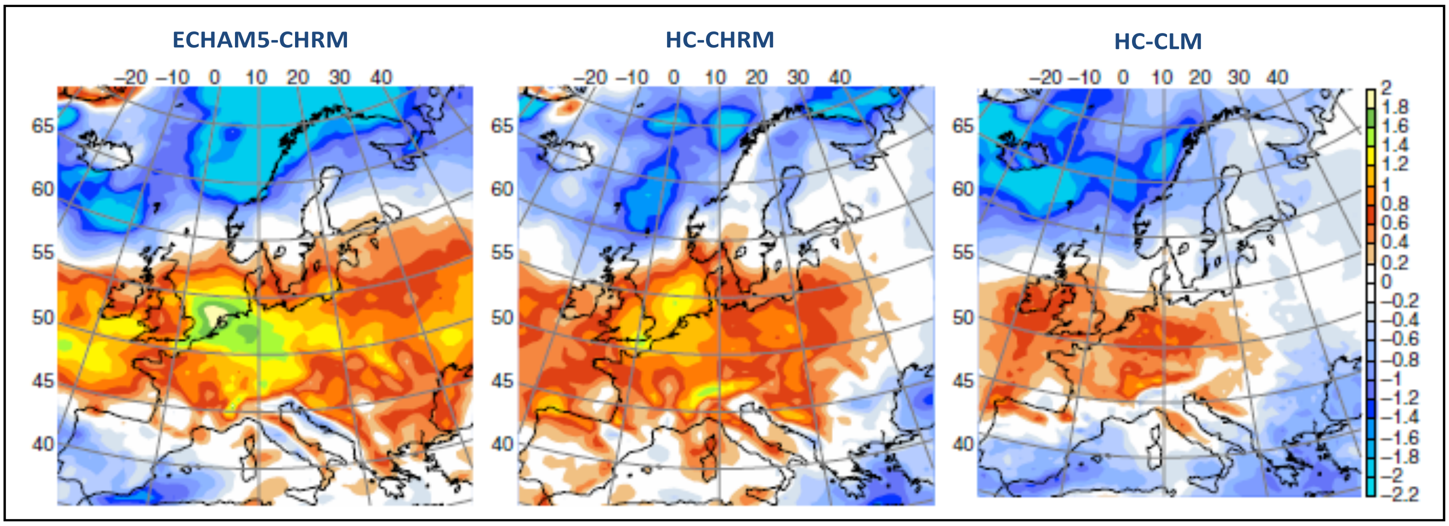


Figure 10. Expected climate change impact on ETC gust fields. Shown is the difference between historical CTL scenario (Oct 1961-Mar 1990) and the futuristic A2 scenario (Oct 2071-Mar 2100) set forth by the IPCC. Each box represents a different comparison of mean gust fields, given the three global climate model simulations (from left to right, ECHAM5-CHRM, HC-CHRM, HC-CLM).

The most striking climate impact is **an increase in wind gusts over a broad band that stretches from the eastern North Atlantic, over Great Britain and into Northern and Central Europe**. **The ECHAM5-CHRM climate model extends the wind field all the way to Eastern Europe**. This area of increased wind is circumscribed by two parallel bands of reduced gusts from Spain to the Eastern Mediterranean Sea (in the South) and the Northern Atlantic to Scandinavia (in the North).

The figure from Schwierz et al's study shows that regional gust models have minor deviations over oceans, but considerable differences over land. Wind gust projections differ by country and region, depending on climate model.

Frequency of events are expected to increase over Southern Scandinavia, Northern Great Britain, the North Sea and the English Channel, Benelux, Germany (particularly over Northern Germany), extending towards Poland and the Baltic States, with an additional increase over the Alps, Southern Italy and the Adriatic Sea.

Events are expected to increase average annual loss over the 10-year (23%), 30-year (50%) and 100-year (104%) timeframe. The expected loss for rare high-impact events is disproportionately large, where **Germany (114%) and Denmark (116%) see the greatest increase in insured loss in the 100-year model**.

Loss potentials for Great Britain and Germany increase by 37% and 21%, respectively, **indicating a much broader loss distribution with potential for more tail events.**

Schwierz et al. generated a probabilistic event sets for different countries, using Swiss Re's insurance loss model as event set inputs.

The resulting climate change impact for wintertime windstorms is calculated and analyzed by country.

Analysis shows average expected loss increases in all countries except Ireland.

Largest increases are in Denmark and Germany, which are both situated within the band of strongest gust increases over the North Sea.

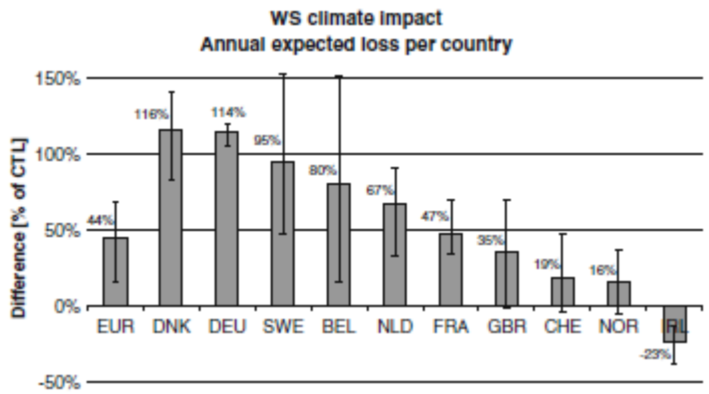


Figure 11. Climate change impact on annual expected loss, for selected regional markets given Swiss Re's insurance loss model. Error bars encompass results of the three model chains considered. (CTL=Control).

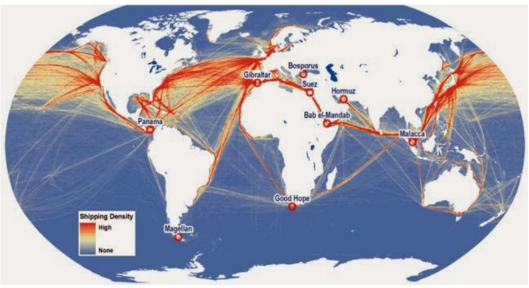
In the A2 scenario simulation, the **maximum wind increase is of 6-8% from the English Channel to the German Bight**. The general **areas of increased gusts extend that corridor, from Western to Central Europe**.

A2 simulations also show an increase in the overall number of ETC events, assuming climate change and global warming scenarios.

We can expect an increase of intensity and frequency of wintertime ETCs. This will correspond to **more windstorms tracking along the corridor from Great Britain to Germany via the Netherlands**

In other words, the **regions with the highest total gross premiums written can expect more detrimental activity from European ETCs**.

Insurance Case Study: Parametric Rolling and Post-Panamax Containerships



Global trade routes emphasize the passage across the North Atlantic, even during the winter months when ETCs are more likely to form, intensify and cluster.

The *Ital Florida* is example of one of the containerships that have staggered into port after being whipped by the 'watery wilderness' of Herman Melville's mythos.

Since the 1950's, containerships have grown in size with the expansion of global trade. **14,000 containerships pass through the Panama Canal every year,** carrying grain, oil and manufactured goods.

The expansion of the Panama Canal has resulted in massive dredging projects and the installation of larger load systems at ports around the world as they prepare for the arrival of post-Panamax and New Panamax ships.

How does this relate to European ETCs**? A significant portion of global trade crosses the North Atlantic Ocean**. If containerships take that route between November and March, they run the risk of experiencing high winds and waves during the winter windstorm season.

In 1998, *APL China* lost a number of containers overboard when it was struck by Typhoon Babs, demonstrating that **post-Panamax ships are vulnerable to a phenomenon known as 'parametric rolling'**. This occurs when waves above a certain threshold or critical height come exactly twice as fast as a ship's roll period.

Parametric rolling can occur in stern-quartering or bow-quartering seas. Cargo on post-Panamax ships is particularly vulnerable to be lost in these seas, because of the U-shape, flared bow and wide beam of the oversized, post-Panamax hull.

In *APL China* litigation, the expert witnesses proved that in certain sea conditions, **post-Panamax ships are especially prone to parametric rolling**, or, the unstable phenomenon whereby **large roll angles are coupled with significant pitch motions**.

Parametric rolling introduces extreme stresses on containerships and their securing systems, and it differs dynamically from synchronous rolling. **Stormy conditions can cause steerage to be completely lost**.

Of particular interest is that normal, **40ft waves of a certain wave-period can cause a post-Panamax containership to heel more than 40 degrees**. It isn't necessary for freak waves, or monsterwellen, to cause steel lashings to lose their hold on large loads.

Litigation for the *APL China* ended in 2003; the **proof of parametric rolling helped limit APL's liability** and allowed for a smaller settlement. Since then, **parametric rolling has helped explain what happened on the *Maersk Carolina*, *P&O Nedlloyed Genoa* and *CMA CGM Otello* and many other maritime mysteries**.

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Implications for Insurers

As sophisticated insurance markets continue to thrive in Western Europe and insurance penetration expands in Central and Eastern Europe, **mid-latitude weather patterns remain unpredictable**.

While countless projects attempt to accurately predict tropical storm intensification, only modest improvements are made; **anticipating non-tropical storm path and strength is even more difficult**. Clashing weather systems often lead to **extreme weather that can only be forecasted up to two weeks in advance**.

Thus, every year between October and April, Europe braces itself against what could be a powerful winter storm season**. It is not uncommon for ETCs to lash the continent with winds over 100mph, sending trees, scaffolding and buildings to their demise**.

Given the destruction caused by European ETCs, it is important to **inform and prepare our industry of the financial and social impact of these weather patterns.**

It is clear that NAO, AO, MJO, QBO and the 300mb high-level wind anomalies show distinct effects on extratropical storm path, intensity, clustering and frequency. A combination of each climate index phase and signal corresponds to a greater or lesser percentage of ETC landfall along certain sections of the European coastline, with the ability to continue into the continent.

Assuming climate change scenarios, society should be equipped for the worst case scenarios. Climate change will not act as a 'Doomsday Device' i.e. *Dr. Strangelove*, but altered climate interactions are indubitably changing global weather patterns.

Our research shows how much work is being done by governments and private institutions to develop more comprehensive regional climate models that incorporate and weigh all the pertinent climate indices, climate signals and risk exposures.

As research continues, so consumers and insurers will be more informed, adjusting their insurance and reinsurance buying habits to accommodate new scientific findings. Based on the available data, it would be wise to anticipate more intense and more frequent European ETCs.

Glossary

Arctic Oscillation- An index of the dominant sea-level pressure variations between the North Pole and 45^0N.

Azores High- A large subtropical semi-permanent center of high pressure centered over the Azores. Also known as the Bermuda High.

Cold-core- A cyclone associated with a cold pool of air residing at the storm's center high in the troposphere.

Convective- A storm characterized by the presence of lighting and thunder.

Disturbance- An unstable creates a variation from normal wind conditions.

Eddy feedback- The feedback system keeps the jet stream from shifting.

Extratropical Cyclone- Middle latitude cyclones that have distinct fronts and horizontal gradients in temperature and dew point.

Icelandic Low- Semi-permanent low pressure system centered between Iceland and southern Greenland.

Jet Stream- Fast flowing, narrow air currents found in the atmosphere. The shape and location of the jet stream influence local weather patterns.

Madden-Julian Oscillation-Major part of intraseasonal (30-90 days) variability in the tropical atmosphere. Travels east from Indian Ocean.

North Atlantic Oscillation- Climactic phenomenon that measures the atmospheric difference between Icelandic low and Azores high.

Occluded Front- Formed during cyclogenesis, when a cold front overtakes a warm front. They usually form around mature low pressure areas.

Parametric Rolling- The phenomenon where large roll angles are coupled with significant pitch motions. These can be prompted by normal size waves.

Polar Vortex- The semi-permanent and large-scale cyclone located near the planet's geographic North Pole.

Sea Level Pressure- Atmospheric pressure at sea level.

Sinusoidal- A curve that shows a repetitive oscillation, named after the sine function.

Tropical Cyclone- Tropical latitude cyclone fueled by high sea surface temperatures and vertical temperature gradients.

Warm-core-A cyclone whose central core has a higher potential energy than the general circulation around it.

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